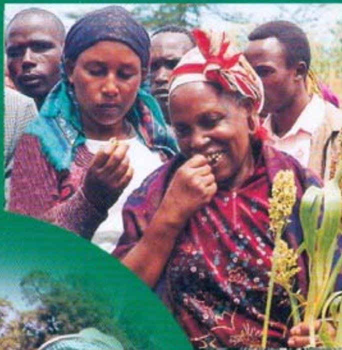
Targeting Agricultural Research for Development in the Semi-Arid Tropics of Sub-Saharan Africa



International Crops Research Institute for the Semi-Arid Tropics

Citation. Freeman, HA, Rohrbach, DD and Ackello-Ogutu, C. (eds.) 2002. Targeting agricultural research for development in the semi-arid tropics of sub-Saharan Africa. Proceedings of a workshop, 1-3 July 2002, Nairobi, Kenya. PO Box 39063, Nairobi Kenya: International Crops Research Institute for the Semi-Arid Tropics. 372 pp. ISBN 92-9066-455-X. Order code CPE 145.

Abstract

This publication contains the papers, discussions and recommendations at an international workshop, Targeting agricultural research for development in the semi-arid tropics of sub-*Saharan Africa.* The meeting was attended by over 50 R&D specialists from national and international research institutes, regional organizations, universities, NGOs, donor agencies and the private sector.

There have been significant changes in policy, market conditions and household livelihood strategies in sub-Saharan Africa, particularly in the past decade. This meeting sought to examine the effects of these changes on smallholder farmers' investment strategies; identify factors influencing technology choice; assess trends and prospects relating to agricultural technology; and examine institutional arrangements to support research.

The presentations and discussions highlighted the key biophysical, socio-economic, and institutional factors influencing technology adoption. Recommendations were made on specific ways to improve technology adoption and impact in semi-arid areas, including new approaches to be considered by international research institutes such as ICRISAT.

Résumé

Cette publication offre les exposés, les débats et les recommandations du colloque international '*Diriger la recherche agricole sur le développement des zones tropicales semi-arides d'Afrique sub-saharienne*'. Cet atelier a été animé par plus de 50 spécialistes en recherche et développement provenants d'instituts de recherche nationaux et internationaux, d'organisations régionales, d'universités, d'ONG, des organismes bailleurs de fonds et du secteur privé.

Il y a eu des changements significatifs dans les directives politiques, dans les conditions des marchés et dans les stratégies de moyens de subsistances des foyers en Afrique sub-saharienne, particulièrement durant la dernière décennie. Cet atelier a tenté d'examiner les effets de ces changements sur les stratégies d'investissement des petits propriétaires fermiers, d'identifier les facteurs influençant les choix technologiques, d'évaluer les tendances et perspectives liées à la technologie agricole, et d'examiner des aménagements institutionnels pour soutenir la recherche.

Les exposés et débats ont mis en lumière les facteurs biophysiques, socio-économiques, et institutionnels clés influençant l'adoption des technologies. Des recommandations ont été faites afin d'améliorer l'adoption ainsi que l'impact des technologies en zones semi-arides, incluant de nouvelles approches que les instituts internationaux de recherche tel que l'ICRISAT ont à considérer.

Targeting Agricultural Research for Development in the Semi-Arid Tropics of Sub-Saharan Africa

Proceedings of a workshop
held at
International Center for Research in Agroforestry
Nairobi, Kenya
1-3 July 2002

Editors

H Ade Freeman, David D Rohrbach,
and Chris Ackello-Ogutu

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
PO Box 39063, Nairobi, Kenya

2002

Contents

Preface

William D Dar[1]

The semi-arid tropical environment - ICRISAT's mandate region - is constantly changing. We have seen sweeping changes in agricultural and trade policy, and livelihood strategies, particularly in the past decade. ICRISAT periodically reviews these changes, with guidance from our partners, adjusting priorities as needed to better focus on our goal of poverty alleviation. This workshop is part of a continuing effort to formalize this review process. With the involvement of partners and stakeholders from NARS, sister CGIAR Centers and others, we seek to revisit our research agenda, identify key issues, and correspondingly revise or readjust our research priorities.

ICRISAT's vision is to initiate a Grey to Green Revolution, targeted at regions and farmers who have been bypassed by the Green Revolution of the 1960s and 1970s. Our work is targeted at marginal environments, particularly the semi-arid regions of sub-Saharan Africa. The guiding motto behind our work is Science with a Human Face - not research simply for its own sake, but research for development, which can deliver significant benefits to the poor.

The Institute works through partners in different countries, and from different sectors - national research and extension systems, universities, the private sector, NGOs and farmer organizations, policy makers, advanced research institutes, and others. I note that a very wide range of partners and stakeholder groups is represented at this meeting. We seek your inputs into the process of redefining our research priorities for sub-Saharan Africa.

Welcome to ICRISAT Nairobi. I hope you will have a pleasant and productive meeting, and I am confident that the outputs of these discussions will provide us with useful guidelines that will help the Institute and its partners sharpen our research focus in order to achieve even greater impact on farmers' fields.

---

1. Director General, ICRISAT, Patancheru, India.

Welcome Address

Said N Silim[1]

Ladies and gentlemen

Welcome to Nairobi. Some of you may be wondering whether we really are in the semi-arid tropics. Nairobi has an abundance of greenery, thanks to two rainfall seasons a year; but the arid, drought-prone areas begin just east of the airport. Almost 80% of Kenya is classified as drylands.

I see scientists and development experts from all over Africa assembled here - which is appropriate, because we aim to tackle a formidable problem: how to stimulate agricultural development in the semi-arid tropics (SAT) of Africa.

Huge investments have been made in agricultural research in the region, with the aim of creating wealth and improving food security. However, the impact has been minimal. The people in the rural SAT of Africa have become poorer rather than richer; many are unable to produce enough food even to meet household requirements. Rapid population growth has resulted in land fragmentation and intensification of cultivation. Since the rural poor do not have the resources to procure inputs, the natural resource base has become increasingly degraded, and productivity has declined further. Rural poverty is generating large-scale migration into urban areas, creating an equally serious problem of urban poverty caused by lack of employment opportunities.

Researchers have asked one question for many years: Why has the rate of technology adoption been so low? I have often asked myself the same question. Perhaps you can help find the answer.

Change in the agricultural, social, and policy environment, particularly over the past decade, has added another layer of complexity to the long-standing problem of slow development and increasing poverty. For example, technologies for intensification of agriculture, once considered promising, may be less relevant in the context of labor shortages created by the HIV/AIDS pandemic. We must now also ask: Are our R&D priorities consistent with the investment strategies of rural households in Africa?

---

1. ICRISAT, Nairobi, Kenya.

We come from different institutions, each with its own mandate and research agenda, but we share a common interest in Africa's development, in particular in the drought-prone environments of the SAT. Between us, we have considerable experience in R&D targeted at these areas, and a good sense of the constraints to agricultural development. We must pool this experience and knowledge to identify strategies that will address the real needs of the poor who live in the African SAT; and rearrange our research priorities accordingly. I expect that by the end of our deliberations we will:

- Articulate a shared vision of the type of society we wish to have in the SAT
- Identify strategic problems or challenges that need to be addressed
- Develop a clearly prioritized agenda for development that will improve the welfare of the people while ensuring that the natural resource base is improved.

I wish you success in your deliberations. I hope that when we look back at this meeting a few years from now, we can say with pride that the Nairobi meeting did make a difference to the well-being of the poor in the semi-arid tropics of Africa.

Thank you.

Introduction

The agricultural economies of Africa have witnessed a number of significant changes during the past 10 to 20 years. The extent and broad-ranging implications of these changes justify a reassessment of research and development (R&D) priorities in agriculture.

A major justification for the conference "Targeting Agricultural Research for Development in the Semi-Arid Tropics of Sub-Saharan Africa" is that the aggregate impacts of agricultural research in semi-arid regions of Africa are difficult to see. During the past two decades, agricultural production has lagged behind population growth in drier regions of the continent. Only limited improvements have been achieved in the productivity of crops and livestock. Food insecurity remains widespread. Most small-scale farmers still fail to produce enough food to meet household requirements. At least one-quarter of all households is chronically under-nourished and continues to subsist on less than US$1 per day.

Low rates of technology adoption raise questions about whether R&D priorities are consistent with the investment strategies of rural households. These investment decisions are being influenced, in part, by changing market conditions. Input and product markets have been largely liberalized in much of Africa. The combination of free trade and globalization has increased the relative importance of tradable agricultural commodities relative to non-tradables. Farmers now face broader investment choices in cash crop or livestock enterprises. A small section of farmers operating in drought-prone regions are successfully commercializing their operations. Some are taking advantage of more liberal labor markets to pursue employment opportunities off the farm. But the majority of farmers remain mired in poverty reinforced by low asset inventories and poor access to markets. These inequalities are being reinforced by the growing incidence of HIV/AIDS.

Farmers vary considerably in capabilities and investment objectives, and correspondingly need a wider choice of technology options. Yet the capacity of publicly funded research systems - national, regional, and international research institutions - to respond to these challenges appears to be declining. While the numbers of scientific staff in national research systems have been increasing, operational budget per staff member has been falling. Low public sector salaries have encouraged the migration of many highly qualified scientists out of national research institutes. Questions have been raised about the future sustainability of regional research organizations and their commodity networks while funding for international agriculture research has stagnated. Increasing investments by the private sector can only offset a part of these losses. Thus new institutional arrangements may be necessary to make agricultural research more efficient.

The workshop was organized around six sessions representing six thematic areas of concern to research and development in the semi-arid tropics. The thematic areas were in turn organized into topical presentations of both research and position papers on related issues that are relevant to SAT R&D. The sessions consisted of paper presentations, panel discussions, and open discussions on the presentations.

This publication documents the full proceedings of the workshop - the paper presentations, discussions and recommendations by the conference participants.

Objectives of the workshop

David D Rohrbach

ICRISAT has convened this meeting in order to examine why past progress has been so limited, and to work with key partners to reset collaborative priorities for technology development. The reconsideration of priorities is particularly important in the context of declining budgets for agricultural research. The limited extent of our past impacts may have contributed to this decline. However, institutions like ICRISAT also need to move beyond the development of new varieties, and resource management technologies, to play a larger role in promoting their application.

Though the meeting has been organized by ICRISAT, with financial support from the United States Agency for International Development, USAID, we expect the deliberations to be relevant for a wide range of institutions involved in agricultural development on Africa's drier regions. Stronger partnerships are needed linking national and international institutes. The achievement of impact also requires better links between public and private research and development organizations. This includes private industry. We expect the priorities set during this conference to be relevant to each of these partners.

The meeting will:

- Consider how investment strategies of smallholder farmers are influenced by their changing livelihood options.
- Lay out factors characterizing the environment of technology choice.
- Assess trends and prospects relating to agricultural technology.
- Examine the evolution of institutional arrangements for agricultural research in Africa.

The conference schedule allows substantial time for discussion of the papers and associated research findings. The meeting will close with a summary discussion and review of the conference recommendations. We

1. ICRISAT, Bulawayo, Zimbabwe.

expect these recommendations will be circulated to a wider range of partners including the sub-regional organizations responsible for coordinating agricultural research in Africa. Ultimately, this meeting should generate an on-going discussion about research priorities and impacts. The welfare of Africa's small-scale farmers depends on this sort of initiative.

Rural Household Decision Making and Technology Change

Technological change occurs, ultimately, at the household level. Papers in this session explore the relationships between livelihood strategies and decisions to invest in improved technologies. Case studies are presented from Zimbabwe, Burkina Faso and Kenya. There were significant location-specific differences, for example in the relative shares (and trends) of agricultural income in total income; and in the factors driving diversification. But the broad lesson is that smallholder farmers seek to diversify their sources of income, using both farm and non-farm income to ensure food and livelihood security. Agricultural research must identify and develop technologies based on this understanding of livelihood strategies.

Drought, rural household decision making and technological change in southern Zimbabwe

David D Rohrbach and Jane Alumira[1]

Thirteen million people currently require emergency food aid due to drought in southern Africa (FAO 2002). In Zimbabwe alone, a joint mission of the United Nations Food and Agriculture Organization (FAO) and the World Food Program (WFP) has estimated that six million people are vulnerable to starvation. These include the majority of small-scale farmers. The country's aggregate cereal supply shortfall is estimated at 1.9 million tons, almost 75% of the national grain requirement. The cost of importing this grain is likely to exceed US$ 285 million. Additional resources are sought for the distribution of seed and fertilizer to support the re-establishment of production during the 2002/03 season.

Zimbabwe's food deficit was worsened by the reduction of grain stocks caused by poor rains during the 2000/01 cropping season. Grain production by large-scale commercial farmers also declined as a result of the government's land reform program. But the main cause of Zimbabwe's grain production shortages is this past season's drought.

While the aggregate level of Zimbabwe's grain shortage is unusually severe this year, the incidence of drought is not. Poor rains cause significant declines in southern Africa's regional grain harvests approximately one out of every four years (Bepura, 1999). In Zimbabwe, drought has caused major crop losses during 4 of the last 10 years, and 8 of the last 20. The 1991/92 drought was said to be the worst in a century.

The countries in southern Africa have struggled to find a longer-term solution to such persistent drought. In 1983, the SADC Council of Ministers invited ICRISAT to establish a regional program to improve production levels of two drought tolerant cereal grains - sorghum and pearl millet. Farmers growing crops in semi-arid areas were viewed the most vulnerable to the risks of drought. The new Sorghum and Millet Improvement Program (SMIP) was tasked to work with scientists in national agricultural research institutes to develop varieties and associated management practices necessary to increase grain productivity in these regions. Particular emphasis was placed on developing earlier maturing varieties capable of escaping drought.

1. ICRISAT, Bulawayo, Zimbabwe.

After almost 20 years of effort, more than 45 new varieties of sorghum and pearl millet have been released. The main advantage of these varieties is their earlier maturity compared with traditional sorghum and pearl millet cultivars. This increases the probability of a harvest when rains end early. Farmer recognition of this advantage has stimulated widespread adoption of the new varieties. These are now sown on over 20% of southern Africa's sorghum and pearl millet area. In Zimbabwe, ICRISAT surveys reveal that 30% of national sorghum area, and almost 50% of the pearl millet area, are planted to the new varieties.

But the problem of food shortages caused by drought remains. While the new varieties of sorghum and pearl millet improve the likelihood of a harvest, larger and more consistent gains in productivity can only be obtained from the associated adoption of improved crop management practices. Better water and nutrient management are required to raise average grain yields in both drought years and seasons of favorable rainfall. Yet most small-scale farmers remain either reluctant or unable to make these investments. As a result, improvements in household and national food security remain limited.

The following analysis examines this conundrum. Farm survey data from southern Zimbabwe are used to explore the diversity of farm responses to drought. The analysis highlights two factors explaining the common failure to adopt improved crop management practices in semi-arid environments. It also highlights the need for more creative responses to drought.

First, the extreme poverty of many households simply limits their capacity to invest in new crop management technologies. Many farmers lack draft animals necessary to plough and plant on time. The lack of animals also limits manure supplies. Most of these families lack cash for fertilizer necessary to achieve deeper root and stronger plant growth. Labor constraints limit the level and timeliness of weeding. Such resource constraints cannot be resolved with a simple change of variety or the occasional delivery of free seed and fertilizer in a relief program.

But not all rural households farming in semi-arid regions are extremely poor. Many have resources to buy food when domestic production falls short. A portion of these resources could be invested in improving crop management to increase the probability of a harvest in the event of drought. However, most of these farmers choose not to make such investments. This is because the returns to the allocation of limited farm labor and capital to alternative farm and non-farm enterprises are generally perceived higher than the returns to grain production (Reardon 1997; Barrett et al. 2001). These households are more likely to pursue an off-farm job than plant an extra field. Drought relief is then sought through food purchases.

Improved drought responsiveness in southern Africa requires recognition of the variability of livelihood and coping strategies pursued by rural households. Efforts to improve food production capabilities need to be complemented with enhanced opportunities for non- and off-farm employment. Improvements in the capacity to purchase grain may be more valuable to many households than efforts to build markets for the extraction of surplus product. Severe drought will still create the need for food relief. But this needs to be well targeted to avoid the disruption of rural markets.

Three issues merit further investigation. First, empirical research is needed to assess the severity of poverty traps and the prospects for escape. The variability of the rural economy, even in poorer semi-arid areas, suggests the prospects may be more favorable than is commonly recognized (Barrett and Carter 2001; Barrett et al. 2002). Correspondingly, additional research needs to consider the evolution of resource ownership and particularly of livelihood strategies. How do communities change following the introduction of a road, a new cash crop or an opportunity for labor migration? Finally, more efforts need to be directed toward assessing if farm and non-farm economies can complement each other. Better-endowed households are well known to provide a partial safety net of seed and grain to poorer community members. Remittances support construction work, petty trade and the hiring of more labor. The advantages of these growth linkages merit better exploitation.

Zimbabwe's semi-arid areas

Three-quarters of Zimbabwe's smallholder farming areas are semi-arid with annual rainfall averaging less than 750 mm and a high probability of drought (Figure 1). Five droughts have occurred over the past 11 years. These include the 1991/92 drought identified as the worst in 100 years. Widespread drought also occurred in the 1994/95, 1998/99, 2000/01 and 2001/02 seasons.

ICRISAT recently conducted a number of farm surveys in the southern half of the country. In 1998/99, a two-phase farm management survey sampled farm households in the Gwanda and Tsholotsho districts. In 2001, ICRISAT completed a re-survey of farm households in the Semukwe Communal Area of Matobo District. These families had previously been

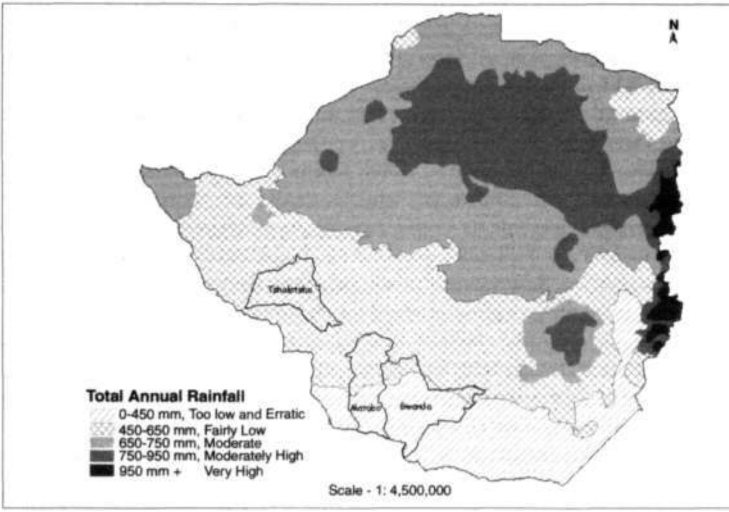


Figure 1. Zimbabwe: distribution of rainfall and recent survey areas.

interviewed in a detailed farm management survey in 1988 and 1989. The new survey provides the opportunity to examine changes in household farming practices and livelihood strategies over a 12-year period. During the interim period, farm surveys have been conducted in the neighboring communities of Hwange, Lupane, Dandanda, Kezi, Nata, Shurugwi, Mtetengwe, Buhera, Matibi 2 and Mutambara.

This analysis primarily highlights data from the 1998/99 survey. This encompassed a random sample of 120 farm households drawn from six villages in Tsholotsho Communal Area, and a similar sized sample from six villages in southern Gwanda. The Tsholotsho villages are situated approximately 120 km west of the provincial capital city of Bulawayo. Most of these villages have good access to a tarred road leading into the city. Rainfall in this region averages around 500 to 600 mm annually. Soils are generally granitic sands with patches of Vertisols in lower lying areas. The Gwanda sample lies on an all-weather dirt road approximately 150 km southeast of Bulawayo, and 50 km from the town of Gwanda. Rainfall here averages around 400 to 450 mm annually, and soils are similarly sandy. The rural population densities in both regions are relatively low averaging around 15-25 people per square kilometer.

Annual rainfall in southern Zimbabwe is unimodal, generally extending from late October to early April. However, the timing of this rainfall is highly variable. In many years, these rains either start late or end early. Farmers commonly encounter a 15 to 25 day mid-season dry spell between January and February. In the latest 2001/02 season, these regions experienced consistent rains from late October to mid-December, but most of the southern half of the country experienced no rainfall after mid-January. Since the majority of fields were planted after mid-December, many farmers harvested little or nothing.

Though Zimbabwe as a whole experienced drought in 1998/99, rainfall in the Tsholotsho and Gwanda survey regions was only marginally below average. The rains started late, but then fell consistently across the season.

Production and food insecurity

Most farm households in southern Zimbabwe struggle each year to produce enough food to meet family requirements. Cereal production is prioritized, though legume and vegetable crops are also sown to obtain a varied diet (Table 1). Such diversification also reduces the risks of drought.

Table 1. Average area planted (hectares per household) to alternative field crops by farmers in Gwanda and Tsholotsho, 1998/99 cropping season.

	Gwanda (n = 120)		Tsholotsho (n = 120)	
	Area planted	Percent of households growing	Area planted	Percent of households growing
Maize	0.75 (0.79)	92.5	1.43(1.29)	98.3
White sorghum	1.40(1.43)	89.2	0.29 (0.47)	50.8
Pearl millet	0.31 (0.71)	37.5	0.67(1.13)	49.2
Red sorghum	0.11 (0.35)	18.3	0.07 (0.25)	12.5
Groundnut	0.20 (0.29)	77.5	0.13 (0.30)	58.3
Bambara nut	0.11 (0.13)	73.3	0.09 (0.15)	55.0
Cowpea	0.09 (0.14)	70.8	0.06 (0.11)	60.0
Other	0.01 (0.06)	4.2	0.05 (0.14)	7.5
All field crops	2.98 (2.09)	100	2.78 (2.02)	100

Standard deviation in parentheses.
Source: ICRISAT surveys 1999.

The allocation of land is similar in the two main survey areas of Gwanda and Tsholotsho. All farmers also grow either sorghum or pearl millet. These are essential food security crops offering a minimum grain harvest in the event of drought. Farmers increasingly complain about the predation of sorghum and pearl millet by birds. This problem seems to be growing as children go to school and family members migrate in search of off-farm employment. But the severity of bird predation is spatially varied.

Despite the low rainfall, virtually all households also grow maize. If rains are favorable, this crop will perform better than sorghum or millet. Perhaps more importantly, maize provides an essential source of calories early in the harvest season, as this can be harvested and eaten while still green. Maize is also less prone to bird damage.

All farmers also grow at least one legume crop. Most grow smaller fields of groundnut and bambara nut. But cowpea is also commonly grown, often in a low-density intercrop with maize. Various types of cucurbits provide additional food, even in the driest years. These similarly tend to be intercropped at low density with the cereal grain crops. Vegetables, particularly tomatoes and rape, are commonly grown in smaller garden plots.

The levels of production derived from these plots are highly variable. The average family needs a harvest of approximately one metric ton of cereal grain to meet its annual food requirements. Following the 1998/99 cropping season, production levels averaged about one metric ton in the two survey areas. However, 61% of farm households in Gwanda, and 67% in Tsholotsho, produced less than this. One-third of the farmers in each area produced less than 500 kg of grain.

A major reason for these low production levels is the low level of average grain yields. The 1998/99 season was not a particularly poor one. Nonetheless, maize yields averaged less than 600 kg ha^{1} in each survey area (Table 2). White sorghum performed marginally better than maize in Tsholotsho and less well in Gwanda. Pearl millet yields averaged less than 500 kg ha^{1}. But these yields were also extremely variable. A few farmers obtained yields of around 1 t ha^{1}, while the majority achieved less than 500 kg ha^{1}. In comparison, farmers in Zimbabwe's higher rainfall zones (eg. those receiving more than 750 mm) commonly achieve average maize yields of 1.3 to 1.5 t ha^{1}.

For comparative purposes, farmers were asked to characterize their level of production sufficiency during each of the previous five harvests. While production levels vary across years, most farmers commonly experience food

Table 2. Mean grain crop yields (kg ha^{1}) in Tsholotsho and Gwanda in 1999.

	Gwanda	Tsholotsho
Maize	595.7 (798.9) n=95	540.7 (687.0) n=105
White sorghum	464.3 (736.3) n=97	573.7 (880.9) n=56
Pearl millet	471.7 (719.7) n=41	434.6 (611.1) n=51

Standard deviation in parentheses.
Source: ICRISAT surveys, 1999.

deficits. One-quarter of the respondents in both Gwanda and Tsholotsho claimed they faced a grain production deficit every year. Seventy percent of these households claimed they experienced a grain production deficit, relative to family consumption requirements, at least three years out of the past five. None of the respondents consistently met their food needs. These numbers coincide with the results of earlier ICRISAT surveys in the southern half of the country (Rohrbach 1998).

Thus, the common perception of farmers as surplus producers is incorrect, at least for many residing in southern Zimbabwe. The majority of these households generally fail to meet their consumption requirements from their own production. They must purchase a portion of their grain supplies. By inference, the level of household food security depends as much on cash incomes, and the capacity to purchase food, as on production levels.

Diversified cash incomes and livelihood strategies

All farm households in Tsholotsho and Gwanda earn cash income from multiple sources (Table 3). The most common sources are livestock sales and remittances. Three-quarters of the farmers sampled earn cash income from these sources. In comparison, only 15-20% of e respondents earned cash from the sale of grain or legume crops.

The level of cash earnings from crop production is also small. These account for less than 1% of cash earnings for the average household in Gwanda, and less than 4% of average cash earnings in Tsholotsho.

While income sources are highly diversified, they are also substantially skewed. Fifty percent of the farm households in the sample earned less than Z$ 6000 (US$ 167) in cash income in 1998/99. One-third earned less than Z$ 3200 (US$ 89), the amount required to purchase 500 kg of maize grain on the local market. The majority of farm households appear to earn less than US$ 2

Table 3. Mean level of income (Z$) per household by source, 1998/99.

	Gwanda (n = 109)			Tsholotsho (n = 107)		
Farm						
Crops	80	(299)	(n = 15)	460	(1634)	(n = 21)
Livestock	5395	(12488)	(n = 78)	2645	(8668)	(n = 45)
Fruits and vegetables	338	(870)	(n = 29)	331	(2354)	(n=20)
Non-farm						
Crafts	861	(3673)	(n = 30)	1097	(6393)	(n = 24)
Caterpillars	165	(603)	(n = 17)	23	(96)	(n= 10)
Beer	29	(160)	(n=5)	160	(554)	(n = 22)
Construction	268	(899)	(n-15)	232	(972)	(n = 17)
Labor	675	(3391)	(n = 22)	2513	(10596)	(n = 24)
Off farm						
Salary	2870	(14274)	(n = 20)	2006	(10192)	(n =21)
Pension	1619	(7453)	(n = 6)	903	(3952)	(n = 8)
Remittances	518	(1134)	(n = 48)	1025	(2288)	(n = 55)
Total	12818 (US$356)			11395 (US$317)		

Numbers in parentheses are standard deviations.
Source: ICRISAT surveys 1999.

per day in cash and kind income. Not only are these farmers food-insecure, they are also severely impoverished.

The variation in income levels and sources highlights the need to look beyond average statistics in order to characterize livelihood conditions. Two factors appear obvious bases for the stratification of household incomes and wealth. These correspond with the pursuit of alternative livelihood strategies.

First, the importance of remittances is mirrored in the high proportion of female-headed households in the two farming regions. In Gwanda, 46% of households are female-headed. In Tsholotsho, women head 58% of farm households (Table 4). Most of these migrants work in South Africa. Travel between southern Zimbabwe and South Africa has increased following majority rule in 1994.

But not all of these households retain access to a husband's remittances. It is important to distinguish de facto female-headed households, wherein the husband contributes actively to farm household income and decision making, from de jure female-headed households led by single, widowed or divorced women. De facto female-headed households tend to be cash rich, while dejure female-headed households tend to be poor.

Table 4. Percentage distribution of male and female-headed households in Gwanda and Tsholotsho, 1999.

	Male or jointly headed	Female-headed (de facto)	Female-headed (de jure)
Gwanda(n = 120)	54.2	15.0	30.8
Tsholotsho(n = 120)	42.5	34.2	23.3

Source: ICRISAT surveys 1999.

In Gwanda, two-thirds of the female-headed households (or 31% of all farm households) are led by women alone. In Tsholotsho, 40% of female-headed households are led by single women. These de jure female-headed households account for 23% of all farm households in the survey regions.

A second important determinant of household wealth, and livelihood options is the ownership of cattle. Virtually all plowing in southern Zimbabwe is performed with cattle or donkeys. But cattle are preferred for their multiple value as sources of transport, meat and milk. Households with cattle are able to plant earlier or on a more timely basis relative to available rainfall. They have access to manure and they own a highly valued and tradable commodity.

Four livelihood groups can be identified on the basis of these proxy variables for income and wealth. Households may primarily pursue their income on the farm, or off the farm. The gender status of the head of household offers a proxy for this investment decision. De facto female-headed households are assumed to have a male head pursuing a primary income source elsewhere. The male-headed households (or jointly headed by husband and wife) and de jure female-headed households are assumed to pursue a primary income source on the farm. Many of these farm oriented households also have access to off-farm income earned by other family members. But this is not assumed to present a main livelihood source.

The second main stratification criterion is based on the ownership of what is probably the single most important farming asset, cattle. Households owning cattle are differentiated from those without cattle. While draught power and transportation may alternatively be obtained from donkeys, ownership of cattle is a preferred and more valuable alternative. Cattle are, correspondingly, a common representation of wealth. Farmers owning more cattle are more likely to also own more complementary farm assets.

This distribution of farm households according to this disaggregation of asset ownership and livelihood focus is presented in Table 5. Roughly, one-quarter of farm households in the two survey regions fall within each stratification class.

The Gwanda and Tsholotsho survey regions were originally chosen for their differences in rainfall. Tsholotsho was also believed to have better market access than Gwanda. However, the survey data reveal that the differences between households within the two survey regions are greater than the variation across the two regions. Recent research by Jayne et al. (2001) indicates this is a common occurrence even across diverse agroecological zones. Each village will have its wealthier households and poorer households. The variation of assets and incomes creates a variable set of livelihood opportunities. But it also creates a complicated set of interdependencies within the village economy. The analysis below correspondingly combines the data for Gwanda and Tsholotsho.

Table 5. Percentage distribution of key population groups in Gwanda and Tsholotsho, 1999.

	Male headed cattle owners	Male headed without cattle	Female headed *(de facto)*	Female headed *(de jure)*
Gwanda (n = 120)	34.2	20.0	15.0	30.8
Tsholotsho (n = 120)	25.8	16.7	34.2	23.3

Source: ICRISAT surveys 1999.

Stratification and farm capital

The stratification of farm households by gender and cattle ownership highlights the existence of two obvious income classes (Table 6). Male-headed households with cattle and de facto female-headed households with a significant flow of off-farm earnings earn three to four times as much cash, than households without cattle and without significant off-farm income. The distribution of ownership or access to physical and social capital (Table 7) corresponds with this allocation of financial capital.

Male-headed households with cattle earn the largest share of their cash income from livestock production. They also earn more from the sale of field crops than the other household classes, though the aggregate level of earnings from crop sales is low. These tend to be older farmers with more agricultural experience. Some have previously worked off the farm and now earn pensions. Some still earn salaries from rural, non-farm jobs. But since they live

Table 6. Mean level of Income (Z$) by source and farming assets per household, 1998/99.

	Male-headed cattle owners n = 67	Male-headed without cattle n = 42	Female-headed *(de facto)* n = 50	Female-headed *(de jure)* n= 51
Farm				
Crops	547 (1778)	120 (421)	258 (1187)	42(116.0)
Livestock	8377(15068)	1432 (4864)	3444 (5222)	993 (2227)
Fruits and vegetables	139 (542)	212 (808)	659 (3426)	372 (714)
Non-Farm				
Crafts	1340 (4916)	453 (2777)	586 (1948)	1323 (8397)
Caterpillars	48 (169)	166 (770)	18 (80)	171 (497)
Beer	151 (584)	28 (131)	60 (162)	109 (458)
Construction	166 (846)	779 (1592)	71 (272)	100 (504)
Labor	75 (327)	472 (903)	5190(15253)'	988 (3843)
Off-Farm				
Salary	2558 (7955)	1300 (5238)	6176 (15191)	133 (845)
Pension	3416 (9910)	386 (2500)	300 (2121)	94 (470)
Remittances	528 (1345)	156 (264)	1580 (3018)	806 (1190)
Total Z$	17345(31445)	5967 (8255)	18342 (23776)	5131 (9071)
Total US$ conversion	482	153	510	143

***Appears to include some salary/remittance income.**
Numbers in parentheses are standard deviations.
Source: ICRISAT surveys 1999.

on the farm, they are more likely to seriously pursue a set of agricultural investments. Due to their wealth and age profile, these households tend to have the largest quantities of farming assets including ploughs, wheelbarrows and ox-carts. They are also more likely to see an extension agent than farmers in the other three livelihood classes.

The second wealthiest grouping encompasses de facto, female-headed households with access to substantial incomes from both salary and remittances. (The labor earnings of some of these households also appear to include off-farm income.) These are among the youngest households in the sample, in terms of both the age of the household head, and farming experience. In part because they are younger, they are relatively more educated than their neighbors. This probably encourages the ambition to seek better and steadier incomes off the farm.

Table 7. Mean farming experience and farming assets per household, 1998/99.

	Male-headed cattle owners (n-72)	Male-headed without cattle (n = 59)	Female-headed (de facto) (n=44)	Female-headed (de jure) (n=65)
Years farming	20.7(16.6)	15.7(14.4)	10.8 (8.7)	19.5(16.7)
Number of livestock				
Cattle	12.4(11.9)	0.0 (0.0)	3.4 (7.0)	3.6 (8.4)
Donkeys	4.4 (3.6)	1.7 (2.6)	1.8 (2.7)	2.1 (3.1)
Goats	23.1 (25.3)	8.0 (9.8)	9.6(11.4)	14.7(30.1)
Sheep	3.3 (6.9)	0.4 (1.5)	1.1 (3.1)	0.7 (2.0)
Chickens	11.8 (8.3)	7.3 (6.4)	8.2 (6.0)	8.0 (7.0)
Number of implements				
Plough	1.4 (0.8)	0.6 (0.6)	0.9 (1.1)	0.7 (0.6)
Wheelbarrow	0.9 (0.5)	0.3 (0.5)	0.6 (0.5)	0.6 (0.6)
Ox-cart	0.9 (0.6)	0.2 (0.4)	0.5 (0.6)	0.3 (0.5)
Truck/car	0.1 (0.3)	0.0 (0.0)	0.1 (0.4)	0.0 (0.0)
Years schooling of head	5.4 (3.0)	4.9 (3.1)	6.7 (3.2)	4.3 (3.5)
No. of extension visits				
Crops advice	1.0 (2.4)	0.4 (1.3)	0.4 (0.8)	0.6 (1.8)
Livestock advice	1.1 (2.5)	0.3 (0.8)	0.2 (0.6)	0.3 (1.6)

Numbers in parentheses ace standard deviations.
Source: ICRISAT surveys 1999.

Key questions arise about the investment orientation of these households. Will they invest in crop and livestock production, or will they eventually aim to migrate entirely off the farm. While most of these households maintain a basic configuration of farm assets (e.g. plow, a few cattle, wheelbarrow), they appear to be investing the larger share of their cash earning in non-agricultural assets and activities.

The third livelihood class encompasses male-headed households without cattle. These appear to be substantially poorer than those with animals. The cash earnings of these households are extremely limited. Though earnings from livestock sales are more important than from the sale of crops, these households are more likely to turn to the local non-farm economy to earn supplementary income from crafts, construction, the collection and sale of caterpillars and labor sales.

The extreme poverty of these households is also apparent in ownership patterns for livestock and farming assets. On average, these farmers own fewer donkeys, goats, chicken and sheep than the households in any other livelihood class. They also own fewer farming implements. However, the justification for this poverty is not readily apparent. They tend to be younger and less educated than many of their neighbors. But a more detailed investigation would be necessary to assess whether this is a transitory or permanent livelihood position or poverty trap.

Available evidence suggests that *de jure* female-headed farm households are also extremely poor. These tend to be headed by an older woman whose husband has died or abandoned the family. In some cases a minimum set of farming assets appear to have been built up before the husband departed. In others, these assets appear to have been built through hard farm work and savings. These earnings are supplemented, in many cases, by the remittances obtained from a son or daughter working away. However, the high cost of living in urban areas is reducing the availability of this income.

These farmers are more likely than many of their neighbors to pursue income from crafts, caterpillars and labor sales. Goats and chickens provide particularly important sources of income security.

Cropping strategies

Despite rainfall constraints, most households in Tsholotsho and Gwanda still attempt to produce enough grain to meet family consumption requirements. But cropping investments are too limited to produce a surplus. Among poorer households (the male-headed households with no cattle, and *de jure* female-headed households) crop management is simply constrained by the low level of farm assets. Wealthier households, in contrast, have adopted an explicit decision to pursue an extensive production strategy. Crop production is pursued for subsistence purposes, while additional labor and cash are invested in livestock and non- or off-farm employment. In either case, the prospects for improving crop yields are limited.

The farm stratification classes that have been farming the longest tend to have more land available than the younger households. But the more significant differences in farm investment patterns are apparent in the proportion of land being planted.

The male-headed households with cattle plant the largest area to both grains and legumes (Table 8). *De jure* female-headed households own a similar arable area, but only plant one-half as much land. This is partly the result of a draught power constraint, and partly because of a labor constraint. Most of these female-headed households have only one or two cattle. These tend to be too weak to plough a significant area at the start of the production season.

The active rental market for plowing services is evident in the fact that male-headed households without cattle are able to plant as much land as female-headed households or more. Similarly, de facto female-headed households with significant cash incomes can readily hire draught assistance, and thus plant more land than de jure female-headed households. When services are hired, however, planting is less likely to be performed on time relative to the rains. Crops are sown later in the planting season, and often later after any particular rainfall.

Despite the differences in area planted, and the timeliness of planting, there appears to be no significant difference in the choice of crops across these farm classes. All farmers allocate 85% to 90% of their cropped area to cereal grains.

We did not assess the quality of land cropped by the various households. But it is commonly suggested that older households have access to better land - measured in terms of soil type, proximity of fields to the homestead and proximity to a road. Younger households tend to be located in outlying areas of a village. Some farmers negotiate the allocation of different types of fields, for example those with heavier and lighter soils, in order to diversify their cropping and farming risks. But others place primary priority on the accessibility of their lands or proximity to a road.

Table 8. Distribution of area (ha) planted and left fallow across four livelihood groups in Gwanda and Tsholotsho, 1999.

	Male-headed cattle owners (n=72)	Male-headed without cattle (n = 44)	Female-headed (de *facto)* (n = 59)	Female-headed (*de jure)* (n = 65)
Total arable area	5.84	4.72	4.71	5.88
Cropped				
Grains	3.61 (1.9)	2.32 (1.7)	2.14 (1.5)	1.80 (1.5)
Legumes	0.50 (0.6)	0.29 (0.4)	0.25 (0.3)	0.27 (0.3)
Fallow	1.73 (3.4)	2.11 (7.3)	2.32 (5.1)	3.81 (10.2)

Numbers in parentheses are standard deviations.
Source: ICRISAT surveys 1999.

Fanners throughout Zimbabwe have been relatively quick to adopt modern seed varieties. These are viewed as relatively low cost means to raise yields. The adoption of hybrid maize was broadly promoted in the years around independence in 1980. More than 95% of Zimbabwe's maize area was planted to hybrids by 1995 (Rohrbach 1989). Even farmers in drought prone regions sought to take advantage of the productivity gains derived from early maturing hybrids. But in recent years, adoption rates for hybrid maize have begun to lag. The cost of hybrid seed has been rising relative to the value of the grain product. This cost is also probably rising relative to farm household incomes. The survey data correspondingly reveal that households with larger cash resources are more likely to be planting hybrid maize seed (Table 9). Households with cash constraints are more likely to be planting open pollinated varieties or, commonly, seed drawn from a previous hybrid maize crop. Male-headed households are also more likely to plant improved varieties of sorghum, though this gender distinction is not apparent in the case of pearl millet.

The main contribution of the new varieties of all cereal grains is their early maturity. This increases the probability of a harvest, particularly for a late-planted crop.

The new varieties of maize, sorghum and pearl millet are also more responsive to improved crop management. However, the combination of capital constraints and apparently uncompetitive investment returns has severely limited investments in both chemical fertilizer and manure.

Approximately 20% of the farmers in Gwanda and 50% of the farmers in Tsholotsho have experience using chemical fertilizer. In almost every case this has been derived from the free receipt of this input in past drought relief programs.

Table 9. Percentage proportion of households planting improved varieties of alternative grain crops across four livelihood groups in Gwanda and Tsholotsho, 1999.

	Male-headed cattle owners (n-72)	Male-headed without cattle (n-44)	Female-headed (de facto) (n . 59)	Female-headed (de jure) (n = 65)
Hybrid maize	94.4	79.5	93.2	76.9
Improved sorghum	45.8	36.4	30.5	26.2
Pearl millet	33.3	29.5	32.2	29.2

Source: ICRISAT surveys 1999.

Virtually none of these farmers consistently apply chemical fertilizer. In 1998/99, less than 3% of the sample farmers used basal chemical fertilizer and less than 4% used any top dress fertilizer (Table 10). More significantly, only one farmer bought chemical fertilizer. All other users received this input free, either from local development programs or from a relative living off the farm. This fertilizer was more likely to be allocated to vegetable plots than to field crops.

The extensive character of the production system is similarly apparent in the limited use of animal manure. Though virtually all farm households own animals, less than 25% use animal manure on their field crops. Farmers with more animals are a little more likely to use manure, but the availability of this input hardly assures its application. More than 60% of cattle owners make no use of the manure available from these animals. The use of available goat manure is only marginally more common.

Farmers cite various justifications for failing to use this nominally free input. Some claim they are unsure of the value of manure and are afraid it may burn their crops. Some claim they do not have an ox-cart to transport the manure. Others argue they do not have the labor to dig out the manure and spread this on their fields. Yet most of these excuses stand in sharp contrast to the common use of manure in higher rainfall parts of the country (Mugwira and Murwira 1997). Ultimately, these justifications suggest the perception that the returns to manure use are too low to justify the allocation of limited capital and labor to its application.

Such crop management strategies appear logical in such a risky agricultural environment. But they contradict the advice of extension workers. Local extension recommendations call for the application of at least 100 kg of nitrogen to each hectare of maize grown in semi-arid regions. This recommendation is essentially irrelevant to the 95% of farmers who fail to

Table 10. Percentage proportion of households using chemical fertilizer or manure on their field crops across four livelihood groups in Gwanda and Tsholotsho, 1999.

	Male-headed cattle owners (n = 72)	Male-headed without cattle (n-44)	Female-headed (*de facto*) (n = 59)	Female-headed (*de jure*) (n = 65)
Basal fertilizer	5.6	0.0	3.4	1.5
Top dress fertilizer	4.2	2.3	5.2	4.6
Manure	30.6	6.8	17.2	18.5

Source: ICRISAT surveys 1999.

apply chemical fertilizer inputs. Those few who do apply chemical fertilizer are using less than one-quarter of the recommended levels. Extension workers have responded by advising farmers simply to apply what chemical fertilizer they can. But the value of this advice is obviously limited.

Extension workers similarly advise these farmers to use 15 to 30 metric ton of manure to each hectare of grain crops. Yet fewer than 10% of these households have enough animals to obtain this much manure, much less apply it. Among the approximately 15% of farmers applying manure to maize, average application rates are less than two metric ton per hectare. In effect, the official recommendation for manure is similarly irrelevant.

ICRISAT has been working with partners in the national research and extension service to encourage farmers to experiment with smaller doses of chemical fertilizer and manure. These offer substantially higher returns per unit of investment, compared with official recommendations. They also promise lower risks. Yet even these returns may not be high enough to justify the reallocation of scarce capital toward crop production.

A main difference between wealthier and poorer households appears in the allocation of labor to crop production. *De jure* female-headed households, in particular, allocate more labor per unit of area planted to field crops (Table 11). The farmers with the most family labor available, the male-headed households owning cattle, apply the smallest amount of labor per unit of area planted. While virtually all households weed their maize crop once, the two groups of poorer households are more likely to apply a second weeding.

Table 11. Mean labor allocation to crop production across four livelihood groups in Gwanda and Tsholotsho, 1999.

	Male-headed cattle owners (n-72)	Male-headed without cattle (n = 44)	Female-headed *(de facto)* (n = 59)	Female-headed *(de jure)* (n = 65)
Full time farm labor (person years)	4.1	3.1	2.9	3.7
Labor per ha (person years)	1.0	1.2	1.2	1.8
Weeding of maize plots twice (% of households)	30.6	47.7	39.7	50.8

Source: ICRISAT surveys 1999

Overall, we see a picture of an extensive production system wherein food security is sought from expanding the cropped area, and possibly the choice of a new, early maturing variety, rather than the intensification of crop management. Only poorer households planting a smaller crop area seem to manage their plots a little more intensively. But the advantages of an additional weeding are offset by late planting caused by draught power constraints.

The impact of these investment decisions is evident in the low level of average grain yields. Few farmers achieve cereal grain yields over one metric ton per hectare. Most achieve substantially less (Table 12). The male-headed households seem to do better with maize, while the female-headed households achieve higher average yields with sorghum or pearl millet. But these differences are not statistically significant across the household classes. Yield variability is high.

Table 12. Distribution of grain yields (kg ha^{-1}) across four livelihood groups in Gwanda and Tsholotsho, 1999.

	Male-headed cattle owners (n-72)	Male-headed without cattle (n = 44)	Female-headed (de *facto)* (n = 59)	Female-headed *(de jure)* (n=65)
Maize	626.3 (731.1)	748.6(1016.4)	500.4 (633.5)	408.7 (549.4)
White sorghum	412.3 (507.9)	351.6 (371.2)	610.6 (894.6)	668.2(1092.8)
Pearl millet	466.5 (581.0)	477.7 (857.1)	750.0(1902.4)	519.5 (977.2)

Numbers in parentheses are standard deviations.
Source: ICRISAT surveys 1999.

In effect, poorer households most in need of the additional grain harvest are also least able to invest in inputs necessary for improved crop management. Wealthier households appear to have chosen not to make these investments. In either case, subsistence food production levels are deficient. Food security can only be assured with grain purchases.

Crop enterprise investments and the market

In recent years, ICRISAT has sought to encourage more investment in drought tolerant crops like sorghum and pearl millet by promoting the development of market demand for these crops. ICRISAT has encouraged traders and grain processors to purchase grain in areas like Tsholotsho and Gwanda to help improve returns to investments in the production of these crops. This includes experimentation with grain contracting.

However, the combination of low yields and the high probability of drought undermine efforts to develop this product market. Grain surpluses are limited and variable. They may be available following a season or two of favorable rainfall, and then disappear. Marketing costs are high because of low population densities and the low density of marketable product. Local grain shortages bid up local prices to uncompetitive levels. One miller advertised a willingness to purchase 500 metric tones of white sorghum grain, and received less than 20 metric tons. A seed company has offered a premium price contract for 150 to 300 metric tons of pearl millet and cowpea seed for the past three seasons. Yet the maximum delivery level was only 50 metric tons. Due to drought, this past season, the company was lucky to obtain 15 metric tons of seed. Last year a local brewer contracted several hundred farmers to produce red sorghum on contract. Due to the drought, he may receive less than one metric ton; this is less than the quantity of seed originally distributed.

Farmers have expressed enthusiasm to participate in production contracts. They commonly express a desire to produce for the commercial market. But the agroecology does not appear to support this. Ultimately, it is cheaper for many grain processing companies to import grains from higher rainfall zones in the north of the country, than to contract for production in these semi-arid zones.

Such problems of low and variable productivity have led to the gradual abandonment of crop production in neighboring Botswana. It is cheaper for food and feed industries in this country to import grain from South Africa or Zimbabwe than to buy it from local farmers. These trends have been reinforced by the rapid growth of Botswana's economy. The wage rates off the farm are now far higher than the returns to labor in smallholder crop production.

The competitiveness of sorghum and pearl millet is particularly difficult given the dominance of maize in Zimbabwe and the neighboring southern Africa economies. Markets and processing systems are well developed for maize. Many industrial processors are reluctant to buy sorghum or pearl millet, even if this is competitively priced.

The commercial advantages of alternative dry land crops such as sunflower, sesame, cotton and paprika may be more favorable. But substantial investments are still required to develop these production systems and market linkages. Few companies are interested in making these investments.

When asked about their investment priorities, small-scale farmers throughout southern Zimbabwe almost universally cite their interest in purchasing more livestock. Despite occasional losses associated with drought, animals, and cattle in particular, are still widely viewed as a more profitable investment than crop production. An early analysis by ICRISAT (Takavarasha 1993) indicates farmers are probably correct in this judgment.

The sample farmers in Gwanda and Tsholotsho were asked how they would invest Z$ 5000, an amount approximately equal to the annual cash income of the two poorer stratification groupings. The similarity of investment strategies across each of the four farm classes suggests a common view of livelihood opportunities. As in past ICRISAT surveys, farmers in every class placed primary priority on investments in livestock (Table 13). The two poorer groupings proposed to allocate almost one-half of their investment capital in animals. Farmers in each of the four groupings also proposed to invest one-quarter of the suggested sum in consumption expenditure - for groceries, clothes and improved housing. Less than 10% of the available capital was proposed for the purchase of crop inputs.

Table 13. How the household would invest Z$ 5000 (approximately US$ 140) across four population groups in Gwanda and Tsholotsho, 1999.

	Male-headed cattle owners (n-72)	Male-headed without cattle (n = 44)	Female-headed (de facto) (n = 59)	Female-headed (de jure) (n = 65)
Farm production				
Livestock	1537 (1953)	2428 (1931)	1964 (2059)	2396 (2008)
Crop inputs	445 (1131)	224 (724)	354 (866)	461 (1073)
Tools	633 (1328)	493 (1005)	518 (994)	340 (628)
Consumption				
Food and groceries	672 (1205)	469 (1129)	367 (841)	423 (720)
Clothing	193 (476)	319 (977)	92 (453)	248 (651)
Home improvement	486 (1388)	387 (1050)	867 (1736)	544 (1332)
Non-farm investments				
Education	625 (1134)	379 (996)	332 (823)	247 (767)
Projects	228 (994)	140 (573)	280 (1006)	151 (744)

Numbers in parentheses are standard deviations.
Source: ICRISAT surveys 1999.

The relatively higher investment in home improvement proposed by de facto female-headed households coincides with a pattern of actual investment evident in this population. Salary or remittance income supports consumption expenditure among non-migrant family members. It also supports the development of the rural homestead. Many migrants still expect to retire to a rural home.

Most households recognize the importance of investments in education. But many have also been disappointed to learn that schooling does not necessarily lead to a job. This is particularly the case in many outlying districts unable to attract qualified teachers.

Implications for technology development

Differences in the investment patterns and asset levels across the four farm classes highlight the existence of diverse livelihood options and strategies. They also suggest varying prospects for future technological change.

De facto female-headed households are relatively cash rich and can better afford to invest in purchased inputs like chemical fertilizer. They can also hire labor, and invest in labor saving equipment like planters and cultivators. But the incentive to make these investments appears limited. The question remains, will these farmers invest in expanding their production. Or does the farm simply provide an insurance policy against the loss of an off-farm job. A longitudinal analysis of how off-farm jobs affect farming investments may help resolve this conundrum.

Male-headed households with cattle are planting the largest crop areas. But these cropping investments remain extensive in character. To offset the risks of drought, these farmers plant more fields over an extended period, rather than concentrating their resources on a few plots. This strategy makes sense, given the extreme variability of seasonal rainfall and high risks of a mid-season drought. These are the households best positioned to respond to commercial market opportunities. But questions remain, is there an adequate payoff to intensification.

Male-headed households without cattle remain at the margins of subsistence. These appear caught in a poverty trap. Intensification of their cropping enterprises is difficult without the establishment of a livestock base. Marginal gains may be achieved with better targeting of manure from goats and small doses of chemical fertilizer but, as these farmers themselves note, higher returns are expected from strengthening livestock inventories and management.

The prospects for *de jure* female-headed households are just as uncertain. A few of these households have livestock herds and stocks of farm implements built up by a previous husband. But most are starved of capital, and can barely plow enough land to meet their subsistence needs in a favorable rainfall year. They do not have the cash for chemical fertilizer, and manure stocks are severely limited. These farmers are the most likely to sell their labor to obtain food or seed from neighboring farmers at the beginning of the cropping season. This too implies the existence of a poverty trap.

The prospects for technological change in the cropping system are not particularly favorable. However, a main shortcoming of this assessment is the static perspective. Farming systems are evolving in southern Zimbabwe. A number of exogenous factors could still have a significant impact on investment patterns and livelihood prospects.

Labor migration expanded from areas like Gwanda and Tsholotsho following majority rule in South Africa. The impacts of this migration on rural communities in Zimbabwe are still poorly understood.

Rural communities in southern Zimbabwe have been heavily affected by the HIV/AIDS epidemic. This has caused the loss of remittance incomes and farm labor. Medical and funeral expenses account for a growing share of household expenditures. For many rural households, this epidemic may deepen the poverty trap.

But markets are also evolving, for both crops and livestock products. The introduction of new trade opportunities can quickly shift relative investment returns. ICRISAT has initiated a longitudinal analysis of how rural communities are evolving as a result of changing market and non-market conditions. But this research remains at an early stage.

Food security and poverty alleviation

In semi-arid agroecologies, such as southern Zimbabwe, food security is commonly sought through the pursuit of both farm and non-farm enterprises. The production of a subsistence grain supply is prioritized to offset the high costs of food purchases. But the allocation of scarce labor and capital to non-farm and off-farm enterprises offers a means to obtain larger and more consistent gains in cash income. These options increase in importance in environments with a high probability of drought.

Technical scope undoubtedly remains for improving food production in drought prone areas like southern Zimbabwe. Recent experimental evidence suggests that cereal grain yields can be significantly increased through relatively small changes in crop management (Twomlow and Ncube 2001). But most such changes still require an investment of resources unavailable to poorer households. And the better endowed farmers still need to be convinced that the returns to allocating family labor and capital to achieve gains in crop productivity outweigh the returns from alternative investment opportunities. They also need to be convinced to accept the variability in productivity gains associated with the probability of drought.

At a minimum, efforts to improve the food security of rural households need to account for the fact that the needs and capabilities of these farmers are diverse. While some households appear locked in a poverty trap, many remain fully capable of purchasing grain and seed. The better endowed households are well known to provide seed and grain to their poorer neighbors. In effect, the diversity of farm circumstances aids these communities.

In extreme drought conditions, food and seed shortfalls undoubtedly exist at the community level. The majority of households may well need external assistance. Nonetheless, food aid still needs to be better targeted toward more vulnerable households. Production relief needs to be allocated so as to facilitate an escape from poverty.

In the short term, some of the largest gains in household food security may be obtained from strengthening rural grain markets. In 2002, starvation may occur in Zimbabwe, not because of low production levels, but because of the lack of cereal grains on the market. The combination of exchange controls, import controls and domestic trade controls have severely restricted the availability of grain in the rural market. Relief supplies are unreliable. Between July 2001 and July 2002, rural grain prices increased at least fivefold. While the Zimbabwe circumstance is extreme, the problems of uncertain grain supplies and rising prices are not unusual. Not only do these reduce food security in the immediate aftermath of drought, they also encourage farmers to retain investments in subsistence food production that are relatively unproductive. This reduces national incomes and food security in the longer run.

In the medium term, the food security of rural households may most be improved by promoting greater diversification of income sources. Rather than assuming that farmers simply target self-sufficiency in grain production, technical assistance should encourage complementary investments in livestock, vegetable production, non-farm enterprises, and labor migration. Priority should be placed on the development of a diverse array of markets, while promoting growth linkages beneficial to poorer as well as better endowed farmers. Once grain markets are well developed, it may even be useful to encourage reduced production of cereal grains, if larger and more consistent incomes can be derived from alternative sources.

References

Barrett, CB, and Carter, MR. 2001. Can't get ahead for falling behind: new directions for development policy to escape poverty and relief traps. Choices 16 (4).

Barrett, CB, Reardon, T, and Webb, P. 2001. Non-farm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications, Food Policy 26(4): 315 - 331.

Barrett, CB, Blume, LE, McPeak, JG, Minten, B, Murithi, F, Okumu, BN, Pell, A, Place, F, Randrianarisoa, JC, and Rasambainarivo, J. 2002. Poverty traps and resource degradation. Basis Brief No 5. January 2002. Madison, Wisconsin: Department of Agricultural and Applied Economics, University of Wisconsin.

Bepura, C. 1999. Drought management: a SADC perspective. Paper presented at the International Conference on Integrated Drought Management. 20-22 September 1999. CSIR Conference Center, Pretoria, South Africa.

FAO. 2002. Food supply situation and crop prospects in Sub-Saharan Africa. No 2. August 2002. Rome: FAO Global Information and Early Warning System.

Jayne, TS, Yamano, T, Weber, M, Tshirley, D, Benfica, R, Neven, D, Chapoto, A, and Zulu, B. 2001. Smallholder income and land distribution in Africa: implications for poverty reduction strategies. MSU International Development Paper No 24. East Lansing, Michigan: Michigan State University.

Mugwira, LM and Murwira, HK. 1997. Use of cattle manure to improve soil fertility in Zimbabwe: past and current research, and future research needs. CIMMYT Maize Program and Natural Resources Group. Network Research Results Working Paper 2. Mexico: CIMMYT.

Reardon, T. 1997. Using evidence of household income diversification to inform study of the rural non - farm labor market in Africa. World Development, 25(5): 735-747.

Rohrbach, David D. 1989. The economics of smallholder maize production in Zimbabwe: implications for food security. International Development Paper no. 11. East Lansing, Michigan: Department of Agricultural Economics, Michigan State University.

Rohrbach, David D. 1998. Modeling soil fertility management options: an experience from Zimbabwe. Pages 164 -177 in Agricultural resource management for sustainable cropping in semi-arid Kenya. CARMASAK Proceedings No. 1. (G.E. Okwach and M.M. Siambi, eds.). Machakos, Kenya: Kenya Agricultural Research Institute.

Takavarasha, Dumisani. 1993. The adoption of crop residues as an alternative cattle feed in semi-arid Zimbabwe. Pages 60-72 in Cereal grain policy analysis in the national agricultural research systems of eastern and southern Africa. W. Mwangi, D. Rohrbach, and P. Heisey (Eds.) Addis Ababa: CIMMYT and SADC / ICRISAT SMIP.

Twomlow, SJ and Ncube, B. 2001. Improving soil management options for women farmers in Malawi and Zimbabwe: proceedings of a Collaborators Workshop on the DFID - supported project 'Will Women Farmers Invest in Improving their Soil Fertility Management? Experimentation in a risky environment. 13 -15 September 2000, ICRISAT Bulawayo, Zimbabwe. PO Box 776, Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics.

Changes in rural household livelihood strategies and outcomes in Burkina Faso

Jupiter Ndjeunga[1] and Kimseyinga Savadogo[2]

This report describes and examines changes in rural livelihood assets, activities and incomes in the Sahelian, Guinean and Sudanian zones of Burkina Faso during the last 20 years. A rapid resurvey in 2002 of rural households from an ICRISAT sample in 1985 showed that household assets have increased significantly.

- Per capita livestock ownership has increased twofold (from 0.9 in 1985 to 1.6 in 2001); household cart ownership has increased threefold (from 0.38 to 0.9).
- More than 70% of households owned at least one piece of animal traction equipment as opposed to 40% in 1985.
- Farmers are using more inorganic fertilizers with high intensity in more favorable rainfall areas. In all zones, the application of fertilizers is low in subsistence crops compared to cash crops.
- Households have diversified in and out of the agricultural sector. Many farmers in the Sudanian zone of Burkina Faso have largely diversified into cash crops such as cotton.
- In 2001, non-farm sources represented about 27% of the average household income in the Sahel, 20% in the Sudanian and 11% in the Guinean zones.

Key words: crop, livestock, non-farm income and region.

Introduction

The purpose of this paper is to characterize and provide a broad assessment of rural livelihood changes that have occurred in the semi-arid tropics of West Africa during the last 20 years. It examines the strategies used by rural households to smooth consumption patterns in the face of climatic, price and income risks. With a resurvey of the six ICRISAT villages (previously surveyed in 1985) in 2001, using household-level primary data in the Sahel, Sudanian and Guinean zones of Burkina Faso, we attempt to characterize household assets, activities and income.

1. ICRISAT, Bamako, Mali.
2. University of Ouagadougou, Burkina Faso.

During the last 20 years, donors and governments in West and Central Africa have largely invested in agricultural research and technology dissemination. Yet many of these technologies have had a limited impact on rural livelihoods. The agricultural transformation never occurred. In effect, during this period agricultural research priorities may have changed. Due to the changing climatic, physical, socio-economic, institutional and policy environments households may have shifted their investment priorities and formulated new mechanism for coping with risk.

There is therefore a need to assess household income strategies to better target research and priorities, and to formulate policies that will improve rural livelihoods. Income strategies of rural households in these zones are mainly dependent upon the generation of purchasing power in non-cropping occupations (both employment- and asset-based). To a large extent, these occupations are not oriented toward processing crop outputs or supplying inputs to cropping in the region. In part, these strategies are a means of insulating food consumption from broad swings in the local cereal sector. This is in turn linked to the substantial reliance of households on purchased food to ensure consumption security, a fact that belies the conventional image of subsistence farmers. Almost all households rely to a certain extent on purchases, but those with the poorest cropping outcomes, provided they have non-cropping-based cash resources, purchase the most in proportional terms (Reardon and Matlon 1987).

Moreover, households spread income risk not only across occupations, but also across locations. This reduces crop-based co-variation in regional incomes. Overall where climatic variability is highly pronounced, farmers develop multi-sectoral strategies to protect food consumption levels in the face of adverse weather.

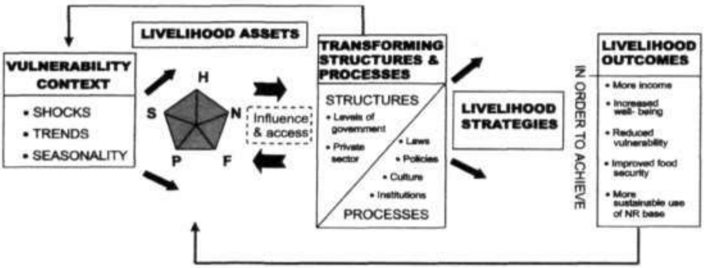
This report describes broad changes in livelihood outcomes and strategies and draws insights that could serve to formulate future research and development priorities and policies.

A theoretical framework

The theoretical framework used for characterizing livelihood is the sustainable rural livelihoods (SRL) framework (Figure 1). The framework brings together relevant concepts to allow poverty to be understood more holistically (Farrington et al. 1999). It draws on the improved understanding of poverty but also on other streams of analysis in economic theory, development theory, anthropology and sociology, relating to households, gender, governance and farming systems.

The framework encourages users to think about existing livelihood patterns as a basis for planning research and development activities. This entails analysis of various tools to better understand:

- The context in which (different groups of) people live, including the effects upon them of external trends (economic, technological, population growth etc.), shocks (whether natural or manmade) and seasonality.



H represents **human capital:** the skills, knowledge, ability to labor and good health important to the ability to pursue different livelihood strategies;

P represents **physical capital:** the basic infrastructure (transport, shelter, water, energy and communications) and the production equipment and means, which enable people to pursue livelihoods;

S represents **social capital:** the social resources (networks, membership of groups, relationships of trust, access to wider institutions of society) upon which people draw in pursuit of livelihoods;

F represents **financial capital:** the financial resources which are available to people (whether savings, supplies of credit or regular remittances or pensions) and which provide them with different livelihood options;

N represents **natural capital:** the natural resource stocks from which resource flows useful for livelihoods are derived (e.g. land, water, wildlife, biodiversity, environmental resources)

Figure 1. DFID's Sustainable Livelihoods Framework.

- People's access to different types of assets (physical, human, financial, natural and social) and their ability to put these to productive use.
- The institutions, policies and organizations, which shape their livelihoods.
- The different strategies that they adopt in pursuit of their goals.

The value of a framework such as this is that it encourages users to take a broad and systematic view of the factors that cause poverty - whether these are shocks and adverse trends, poorly functioning institutions and policies or a basic lack of assets - and to investigate the relations between them. It does not take a "sectoral" view of poverty, but tries to recognize the contributions made by different interconnected assets, processes and structures that people draw on to devise livelihood strategies in order to achieve an anticipated livelihood outcome. This does not imply that development activity itself should always be multi-sectoral. The need is to conceive of problems and solutions in a holistic way, but then to select target and manageable approaches for implementation.

Data and sample characteristics

Survey approach

From 1981 to 1985, an ICRISAT baseline study was carried out with the primary objective to analyze the farming systems in the West African Semi-Arid Tropics in order to identify the constraints to agricultural production. The characteristics of the three study regions and six villages are presented in Table 1.

The three study regions differ significantly in rainfall average and soil type. The Djibo region is a low rainfall area with an average of 465 mm annually during the last 40 years. Soils are sandy and the major food crops are pearl millet, fonio and cowpea, with white sorghum. The villages of Oure and Silgueye were selected in this region. The Yako region is representative of large portions of the relatively densely populated Mossi Plateau in the Sudan Savanna agro-climatic zone. Rainfall is low and soils are shallow with low natural fertility. Cropping systems in this zone are dominated by white sorghum, millet and red sorghum, with yams, cotton and groundnut serving as cash crops of relatively minor importance in terms of cultivated area. The villages of Ouonon and Kolbila were selected from this region. The Boromo

Table 1. Characteristics of regions and villages in ICRISAT baseline studies in 1985 and in 2002.										
	Long-term annual rainfall (mm)			Population density (person per sq km)		Access to main roads		Population (inhabitants)	
Region	1985	2000	Village	1985	1999	1985	2002	1985	2000
Djibo	480	465	Woure	41	39	Good	Good	755	712
(Sahel)	(34%)	(35%)	Silgueye	41	59	Poor	Poor	636	911
Yako	724	714	Kolbila	67	63	Good	Good	1321	1235
(Sudan)	(25%)	(26%)	Ouonon	40	39	Poor	Good	1224	1179
Boromo	952	955	Koho	85	130	Good	Good	1145	1754
(Guinea)	(21%)	(21%)	Sayero	25	32	Poor	Good	931	1209

Coefficient of variation (CV) in parentheses.
Source: ICRISAT baseline survey 1981- 85 and 2002.

region in the Northern Guinea Savanna has relatively good agricultural potential with high annual rainfall with comparatively high population pressure. Major food crops are white and red sorghum, maize and, to a lesser extent, millet. Cotton is the most important cash crop. The region is inhabited primarily by Dagari and Bwa ethnic groups but has also experienced important immigration from more densely populated areas on the Mossi Plateau. Soils are of intermediate depth and fertility. The villages of Koho and Sayero were selected from this region.

During 18-31 May 2002 a repeat survey was carried out in the same regions and using the same households sampled with the primary objective to assess changes that may have occurred during the previous two decades. From the 1985 ICRISAT sample, it was found that heads of about 67 households were still existing, 48 of these had passed away, and a number of households were split with some members living in the village and others out of the village or country. All households with the former head still alive, or their heirs and the split households whose heads still lived in the village were interviewed. Thus a total 240 households were interviewed of which 115 were originally interviewed in 1985 (Table 2). This report analyzes data from these 115 households. In addition, in each village a focus group interview was carried out.

Questions focused on the same survey instruments used in 1985. Major differences in the two sets of data lie in the frequency of interviews, which could affect the reliability of data at hand. While the 2002 repeated survey data is based on a single yearly recall, the 1985 data was collected with multiple frequencies reflecting the accuracy of information gathered. For such

Table 2. Distribution of households by region in 2002.

	From Matlon 1988 (1985 sample)				
			Split households		
Region	Household head still alive	Household heirs	In the village	Out of the village	Total
Djibo (Sahel)	19	11	25	25	80
Yako (Sudanian)	23	13	20	24	80
Boromo (Guinean)	25	24	13	18	80
TOTAL	67	48	58	67	240

Source: ICRISAT baseline survey 1985 and 2002.

data as expenditures and consumption, stocks and flows, an annual frequency based on single recall may not be accurate.

Rainfall during the 1985 cropping season was about the same as that in 2001. Thus, the data well reflect farmer behavior under almost the same type of stress conditions.

Sample characteristics

In 2001, the data reveals that the average age of the household head is about 55 years compared to 51 years in 1985 suggesting that decision makers are on average probably well experienced. There is no significant difference in age between regions (Table 3). Average household sizes are lower than those of 1985. There are significant differences between regions. While household sizes have significantly decreased in the Guinean region of Boromo, from 19 to 12, they have increased in other regions such as the Sahel and Sudanian zones. This is largely explained by the migration of the young to neighboring towns or countries such as Ouagadougou or Bobo-Dioulasso in Burkina Faso and Cote d'Ivoire, or Mali.

Like household size, the total work force has also significantly decreased in the Guinean zone for the same reasons stated above. In general, the per capita land cultivated has increased significantly by more than twofold in the Sudanian and Guinean zones, whereas land cultivated has remained relatively stagnant in the Sahel. This is largely because of the increase in the use of animal traction especially in the Sudanian and Guinean zones relieving the labor constraints and allowing households to increase their cultivated area.

Table 3. Household characteristics in the Sahelian, Sudanian and Guinean zones in 1985 and 2002.

	Region							
	Djibo (Sahel)		Yako (Sudanian)		Boromo (Guinean)		Group	
Variable	1985	2001	1985	2001	1985	2001	1985	2001
Sample size	30		36		49		115	
Age of household head	48	54.97	53	57.19	52	54.04	51	55.27
	(12)	(15)	(15)	(14.78)	(13)	(16.67)	(14)	(15.59)
Household size	9.43	11.10	12.44	14.89	19.10	12.31	14.50	12.80
	(4.75)	(6.25)	(9.12)	(6.65)	(16.07)	(9.08)	(12.54)	(7.78)
Total work force	5.08	6.54	6.53	5.92	10.14	5.95	7.69	6.10
	(2.68)	(3.88)	(4.99)	(3.22)	(8.24)	(5.21)	(6.55)	(4.30)
Number of dependents	5.35	4.56	5.91	8.97	8.96	6.35	6.80	6.70
	(2.37)	(2.68)	(4.27)	(5.17)	(7.95)	(4.69)	(6.12)	(4.71)
Dependency ratio	0.45	0.42	0.48	0.60	0.46	0.53	0.46	0.52
	(0.13)	(0.08)	(0.07)	(0.16)	(0.07)	(0.17)	(0.09)	(0.16)
Per capita land cultivated (ha)	1.37	1.01	0.76	1.69	0.81	1.98	0.94	1.64
	(0.80)	(0.47)	(0.31)	(1.47)	(0.35)	(1.52)	(0.56)	(1.36)
Per capita livestock owned	1.28	1.96	0.39	0.50	0.99	2.12	0.88	1.57
	(2.33)	(2.83)	(1.38)	(1.70)	(1.95)	(4.83)	(1.92)	(3.64)
Ownership of cart	0.20	0.37	0.25	0.86	0.59	1.27	0.38	0.90
	(0.41)	(0.56)	(0.44)	(1.82)	(0.50)	(3.09)	(0.49)	(2.29)

The number of households in each stratum is given in sample size. The per capita land cultivated (excluding fallow), deflated by household adult equivalent (AE). Ownership of cart is a discrete (0,1) variable.

Source: ICRISAT data 1985 and 2002.

Assets ownership has increased significantly in the three regions. Livestock holdings have increased significantly during the last 20 years. This is especially important in Guinean zone where the per capita livestock owned is estimated at 2, an increase from 0.81 in 1985. Similarly cart ownership has increased. While all households owned at least 1 cart in the Guinean zone, about 37% of households owned a cart in the Sahel.

Village institutional make-up

There have been some institutional and organizational changes since 1983. In three out of the six villages, a primary school has been built. In each village, one or two farmers have been trained in primary health necessities; and one or two drinking water pumps have been built by non-governmental organizations. Furthermore, farmers have felt the need to form associations to cope against food insecurity, to help smooth their consumption (e.g. savings and loan associations) or invest in some community projects (e.g. grinding machine). Farmers have also been organized into groups (groups being used as collateral) to facilitate their access to credit supplied by the rural bank of Burkina Faso (CNCA) or the cotton company (SOFITEX).

Surprisingly, there have been few improvements in market infrastructure. During the last 15 years, no markets have been created in the villages. Farmers or households still sell/buy their produce/inputs in neighboring markets (Table 4).

Results

During the last 20 years, a number of changes have occurred with regard to household ownership of assets. Many more households own agricultural

Table 4. Map of institutions/resources by village.

	Village											
	Silgueye		Oure		Kolbila		Ouonon		Koho		Sayero	
Institutions	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Primary school	0	0	0	1	0	0	0	1	1	1	0	1
PSP (health)	0	1	0	1	0	2	0	2	0	1	0	1
Markets	0	0	0	0	0	1	0	0	1	1	1	1
SLA for men	0	1	0	0	0	0	0	1	0	0	0	1
Men's organization	0	1	0	1	1	2	0	3	1	3	1	3
Women's organization	0	1	0	0	0	1	0	2	0	1	0	1
Church/mosque	0	1	0	1	0	1	0	1	0	0	0	1
Cereal banks	0	0	0	1	0	1	0	0	0	0	0	0
Grinding wells	0	0	0	0	0	1	0	2	0	2	0	0
Drinking water pump	0	2	0	2	0	2	0	0	0	2	0	1
Traditional wells	0	0	0	2	0	0	0	0	0	1	0	1

SLA: Saving and loan association. PSP: Poste de Sante Primaire. Before: Before the year 1985. After: After the year 1985.
Source: ICRtSAT data 1985 and 2002.

equipment, draft animal and more livestock although farmers continue to diversify in and out of agriculture, engaging in non-farm activities to level of income risk. Pearl millet, sorghum, maize, fonio, groundnut and cowpea remain the most important staples in these regions; more recently the introduction of cotton has shifted farmers' priorities in the Guinean zone. While cropping systems are slowly evolving through specialization into mono-cropping due to the increased use of animal traction especially in the Guinean and Sudanian zones, this has not changed much in the Sahel.

Many more farmers use inorganic fertilizers and animal traction. However, the use of improved varieties is rather limited. Less than 1% of households use improved sorghum and pearl millet varieties.

Use of inputs

Uptake of improved pearl millet and sorghum varieties

Uptake of improved pearl millet and sorghum varieties is low and less than 1%. This is consistent with other studies (Ndjeunga et al. 2001). Over 90% of households draw their seed from their own stocks. If stocks are insufficient, farmers will approach relatives, friends or neighbors to get seed. Market transactions are limited as most transactions are made in the form of barter or exchange of varieties. Reasons for participating in the seed markets are insufficient seed stocks or the urge for experimentation. The major constraint to adoption of improved varieties remains the low access to or lack of seed. Other minor reasons are the poor access to information on improved varieties and bird attacks especially for early maturing varieties.

Uptake of inorganic and organic fertilizers

Uptake of improved fertilizers has increased in all regions. Survey results indicate that overall the percentage of households using inorganic fertilizers increased from 49% in 1985 to 63% in 2002 (Table 5). There are significant differences across regions. Surveys results indicate that while no farmer was using inorganic fertilizer in 1985, slightly more than 50% are using fertilizers in the Sahel. Similar results are found in the Sudanian zone. The uptake of fertilizers in the Guinean zone of Boromo is very high.

The percentage of farmers using inorganic fertilizers only has decreased. Farmers perceived both fertilizers to be complementary. In the Sahel, more

Table 5. Cross-tabulation of uptake organic and/or inorganic fertilizers by region in 1985 and 2001.

	Region							
	Djibo (Sahel)		Yako (Sudanian)		Boromo (Guinean)		Total	
	1985	2001	1985	2001	1985	2001	1985	2001
Sample size	30		36		49		115	
No fertilizers (%)	367	6.3	5.6	6.3	6.1	13.8	13.9	8.8
Organic only (%)	63.3	42.5	66.7	31.3	0	10.0	37.4	27.9
Mineral only (%)	0	6.3	0	2.5	16.3	27.5	7.0	12.1
Both (%)	0	45.0	27.8	60.0	77.6	48.8	41.7	51.3

Source: ICRISAT data 1985 and 2002.

than 45% of households surveyed use both types of fertilizers compared with none in 1985. Similar results are found in the Guinean zone of Yako. In contrast, in the Guinean zone of Boromo the proportion of farmers using both types of fertilizers has decreased and more farmers use mineral fertilizers only. In effect, these farmers are cotton producers, are given fertilizers on credit and may have limited access to organic sources to apply to large cultivated areas.

In general, the intensity of organic fertilizers use has decreased from 821 kg ha^{1} to 660 kg ha^{1} (Table 6). This may be due to the increasingly limited supply of organic fertilizers required to apply to larger cultivated areas. However, in some regions this has increased. In the Sahel, the intensity has increased from 227 kg ha^{1} to 816 kg ha^{1} and in the Sudanian zone from 326 kg ha^{1} to 701 kg ha^{1}. In contrast, in the Guinean zone, the use of organic fertilizers significantly decreased from 1550 kg ha^{1} to 460 kg ha^{1}.

Table 6. Inorganic and organic fertilizer use - intensities by region in 1985 and 2001.

		Region							
		Djibo (Sahel)		Yako (Sudanian)		Boromo (Guinean)		Total	
Fertilizer type		1985	2001	1985	2001	1985	2001	1985	2001
Organic	Mean	227	816	326	701	1550	459	821	659
	SD	508	920	363	667	1927	762	1438	801
Inorganic	Mean	0.0	2.69	4.63	23.87	35.5	41.84	16.58	22.80
	SD	0.0	7.89	9.98	32.64	20.26	45.33	21.79	36.18

Source: ICRISAT data 1985 and 2002.

In all regions, the intensity of inorganic fertilizer use has increased. On average in all regions, the intensity has increased from 17 kg ha^{1} to 23 kg ha^{1}. The intensity differs by region. In the Sahel the average fertilizer use is estimated to have increased from none to about 3 kg ha^{1}. In the Sudanian zone, this has increased from about 5 kg ha^{1} to 24 kg ha^{1} and in the Guinean zone from 36 kg ha^{1} to 42 kg ha^{1}.

Households apply more inorganic fertilizers on cash crops than subsistence crops. For example, in 1985 households applied less than 1 kg ha^{1} of fertilizers on pearl millet, about 1 kg on sorghum, about 55 kg ha^{1} on maize and 137 kg ha^{1} on cotton (Table 7). Similar trends are observed in 2001. The intensity of fertilizer use increases with the commercial value of the crop.

Although fertilizer use has increased, its application is still below recommended rates from public research and extension institutions.

Table 7. Intensity of organic and inorganic fertilizer use - by crop in 1985 and 2001.

	Inorganic fertilizers		Organic fertilizers	
Principal crop	1985	2001	1985	2001
Pearl millet	0.86	8.02	201.57	619.21
Local white sorghum	6.58	15.68	598.14	391.99
Local red sorghum	1.288	28.69	419.54	808.48
Improved sorghum	2.19	28.57	222.58	0.00
Maize	54.89	26.43	10232	1638.76
Rice	7.93	51.64	0	85.51
Groundnut	2.40	1.33	112.85	153.08
Cowpea	13.74	9.90	0	445.26
Sesame	0	15.38	0	92.31
Red pepper	0	10.04	0	133.93
Sweet potatoes	0	13.03	0	582
Okra	11	19.18	1244	957.34
Eggplant	0	0	998	0
Cotton	137	85	1870	448
Tobacco	0	0	0	500
Onions	0	234	0	503
Tomatoes	0	330	0	382

Source: ICRISAT data 1985 and 2002.

Ownership of draft animal and agricultural equipment

Ownership of draft animals and agricultural equipment has significantly increased. In 1985 about 50% of households did not own a draft animal. This has decreased to 33% in 2001 (Table 8).

During the last 15 years, the proportion of farmers owning only one piece of animal traction equipment has decreased (Table 9). Increasing uptake and ownership of traction equipment can be attributed to access to alternative sources of non-farm income. In effect, non-farm income greatly affects the adoption of expensive animal traction equipment (Savadogo et al. 1994).

Table 8. Ownership of draft animals (%) by region in 1985 and 2001.

	Region							
	Djibo (Sahel)		Yako (Sudanian)		Boromo (Guinean)		Total	
Draft animal	1985	2001	1985	2001	1985	2001	1985	2001
Do not own	73	69	58	13	31	13	50	33
Oxen	17	18	12	19	22	73	34	36
Donkeys	7	9	28	54	50	14	12	25
Horses	0	4	11	14	0	0	3	6

Source: ICRISAT data 1985 and 2002.

Table 9. Ownership of agricultural equipment (%) by region in 1985 and 2001.

	Region							
	Djibo (Sahel)		Yako (Sudanian)		Boromo (Guinean)		Total	
Agricultural equipment	1985	2001	1985	2001	1985	2001	1985	2001
Hand tools	77	57	56	17	43	22	56	30
Plow	23	47	6	73	56	86	30	67
Weeder	23	3	36	20	36	0	30	1
Ridger	0	3	3	0	22	47	10	20
Seeder	0	0	0	100	0	2	0	2
Phytosanitary equipment	0	0	0	0	0	24	0	10

Source: ICRISAT data 1985 and 2002.

Income sources

Households diversify over a range of farm and non-farm activities. They include agricultural activities including crop production and employment in the agricultural sector. During the last 20 years, cotton has become an important cash crop to which farmers, especially in the Guinean zone, diversify. Other farm activities include livestock rearing. Non-farm activities include commerce, art or craft-based activities, construction, services like selling prepared food products, vehicle repairs and transportation, non-agricultural wages, gathering wood and income from transfers to places outside the region.

The relative roles of cropping and agricultural wages, livestock husbandry, off-farm employment (within-zone versus outside-zone or migrant), and transfers in 1985 and 2001 and across regions are highlighted in Table 10.

Crop production and agricultural wage income

Crop and livestock remain the principal sources of income for households accounting for more than 82% of rural income in 2001 compared with 76% in 1985. Non-farm sources account for about 20%. However, in 1985 about 25% of rural income came from non-farm sources. This is consistent with findings by Reardon et al (1992). In the 1990s the introduction of a cash crop such as cotton supported by a well-developed product market has induced farmers to diversify agricultural practices towards cotton production. While cotton represented, on average, 3% of total agricultural income in 1985, this has increased about 20% in 2001. Income sources differ significantly by region.

For the Guinean zone, i.e. Boromo, in 1985, 12 853 FCFA/AE (adult equivalent) came from the agricultural sector (excluding livestock but including farm wage income), or 29% of income (Table 10). In the Sahel, i.e. Djibo, agriculture accounts for 23% of income. In 2001, the absolute importance of these sources has significantly changed. In the Guinean zone households generate 37 358 FCFA/AE of total income but only 17 401 FCFA/AE in the Sahelian zone (Table 10). This is largely explained by the expansion of cotton production in the Guinean zone. Cotton accounts for 46% of total agricultural income. This is consistent with findings in similar environments in the CMDT zone of southern Mali where cotton represents 44% of agricultural income (Abdulai and Crole Ress 2002).

Table 10. Household income sources (levels) in the sample by region in 1985 and 2001 (In Francs CFA per adult equivalent per annum. All levels rounded to nearest 10).

	Region							
	Djibo (Sahel)		Yako (Sudanian)		Boromo (Guinean)		Total	
Income source	1985	2001	1985	2001	1985	2001	1985	2001
Agriculture								
Crop production	12405	17401	17343	31620	12853	37358	14142	28793
Agri wage	n.a.	5675	n.a.	951	n.a.	287	0	2305
Cotton	0	0	0	0	990	17359	422	5789
Livestock								
Livestock	28997	17723	14130	11078	19385	32710	20248	20503
Local non-farm								
Commerce	572	5597	3056	1056	2117	2984	2084	3212
Artisanal	5183	1894	1848	83.	9784	1020	6004	999
Construction	3674	196	15	200	39	866	963	132
Services	2906	1743	1296	1167	701.57	1066	1463	1325
Non-agric wage	n.a.	1126	n.a.	394	n.a.	1275	n.a.	932
Gathering	n.a.	194	n.a.	4	n.a.	51	n.a	83
Non-local non-farm								
Transfers	n.a.	4030	n.a.	8034	n.a.	1231	n.a.	4432
Per capita income	53739	55582	37383	54695	44564	78465	44710	62914

Crop production: The value at producer prices of all crop production harvested after the 1985 rainy season, less the value of inputs used during that season.

Agricultural wages: Wages received during the 1985 cropping season, working on other households' plots in the immediate region (i.e. not migratory work).

Livestock husbandry: Net sales plus home consumption of livestock.

Non-agricultural income earned locally (in the zone): This is non-migratory work income earned in occupations other than cropping and livestock husbandry. Income here is net: gross income minus expenses. The activities include: construction, non-livestock commerce, artisanal (e.g. making mats, baskets, weaving); gathering (wood gathering for sale), services (prepared food products, transport and vehicle repair).

Non-agricultural income earned outside the zone (either within the country or in foreign countries): remittances sent to the household by its own members working abroad, or brought back by the latter after migratory work. The work could have been in the agricultural sector outside of their zone. "Non-agricultural" thus refers to lack of relation with the zone's agricultural sector.

Transfers: transfers from persons not from the household, outside the region (family members living permanently in Cote d' (voire or Ouagadougou or Mali).

Source: ICRISAT data 1985 and 2002.

The agricultural labor market is very limited in both zones. The Sahel is more limited than the Sudanian zone because seasonality is more pronounced and cultivation practices differ (e.g. there is no clearing and very little pre-season cultivation). Average aggregate income per AE was approximately 17% greater in the Sahel than in the Guinean zone in 1985. This significantly changed to 29% greater in the Guinean than in the Sahel zone in 2001. The major difference between strata incomes is due to differences in non-cropping, non-transfer income (livestock income and earnings from local and non-local non-farm occupations). In 1985 77% of incomes in the Sahel came from non-cropping, non-transfer income compared with 71% in the Guinean zone. This relative share has dropped significantly in both zones in 2001 to 58% in the Sahel and 51% in the Guinean zone.

Livestock husbandry

Livestock are a store of wealth that serve as an important insurance mechanism in that they can be sold in poor crop production years to provide purchasing power for grain consumption. For reasons already described, livestock incomes are about two times greater in the Sahel than in the Sudanian zone - 28 997 FCFA/AE vs. 19 385 FCFA/AE. However, this trend has shifted. Livestock incomes are about two times more in the Guinean than the Sahelian zone - 32 710 FCFA/AE versus 17 723 FCFA/AE. This change supports the evidence that revenue from agriculture and especially derived from cotton is invested livestock as the main store of wealth.

Local non-farm income

In the Sudanian zone in 1985, a substantial portion of non-farm employment was closely interlinked with the local cereal economy, on both the input and output sides, as well as with local effective demand. Local non-farm income was derived almost entirely from artisanal manufacture of mats, baskets and tools, and services (primarily sorghum beer-making) (Table 10). These activities are relatively dependent, on either the input or output side depending on the activity, on the local agricultural economy. The total income from these occupations was 28% of income; in 2001 this share had decreased to about 9%.

In the Sahel in 1985, 12 335 FCFA/AE or 23% of income was earned locally in non-farm occupations. This is composed primarily of commerce in cola nuts (not grown in zone) and artisanal manufacture of non-food consumption goods. The balance is composed of relatively small amounts of construction earnings (the bulk of this sort of activity is carried out as part of migration activities included under non-local income) and services (very little of which includes food preparation).

While the majority of local non-farm income in the Sudanian zone sample is sorghum beer-brewing (which is closely related to the local cereal economy), the majority of the same type of income in the Sahel sample is in commerce, unrelated to local crop supply, and artisanal manufactures. The effective demand for artisanal manufacture is rooted in overall income, which is mostly derived from sources unrelated or only indirectly linked to the local cereal economy.

Non-local off-farm income and transfer

In 2001 households in the Sahel earned 4030 FCFA/AE or 7% of income in either cropping or non-cropping-related activities performed during the period spent as migrant. However, in the Sudanian zone 7262 FCFA/AE or 2% of income is derived primarily from this type of employment. These occupations include both non-agricultural (mining, well-digging etc.) and agricultural (plantation labor etc.) activities. Agricultural activities took place almost exclusively in coastal countries much less affected by the drought than those under study here.

Drivers of diversification

The simultaneous quantile regressions modeling the determinants of income diversification as measured by the crop share of total income are presented in Table 11. The reported specifications highlight coefficients derived for the 0.25. 0.50 and 0.75 quantile regressions.

For households in the lowest 25% of crop share to total income, there is evidence that income diversification is positively associated to per capita income indicating that as income rises there is greater diversification away from crops towards alternative income generating activities (Column 1, Table 11). There is also suggested evidence that households located in the Guinean zone tend to be more diversified than households located in the Sahelian zone. This is largely due to better access to input and products markets, better road accessibility and access to a high value crop, cotton, all of

Table 11. Determinants of crop shares of income (quantile regression at 0.25,0.50 and 0.75).

	Quantile		
Variable	Q25	Q50	Q75
Family size	-1.106(0.616)*	-0.895 (0.577)	-0.881 (0.605)
Age of household head	0.138(0.138)	0.163(0.176)	0.124(0.171)
Total work force	0.337(1.210)	-0.706(1.447)	-0.255(1.263)
Per capita area cultivated	3.691 (2.153)*	0.753 (2.227)	1.441 (2.141)
Region	9.278 (2.360)**	13.997(4.449)***	12.110 (3.089)***
Perceived value of owned equipment	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Per capita income	0.000 (0.000)*	0.000 (0.000)	0.000 (0.000)
Total value of livestock	-0.000 (0.000)	-0.000 (0.000)*	-.001 (0.000)**
Constant	13.509(11.412)	30.380(16.023)*	50.145(10.999)***

test [q25]region = (q75]region [F(1,231)=0.53] (Not different) Number of obs =240
test [q25]cequip= [q75)cequip [F(1,231)=1.48] (Not different) 25 Pseudo R^2=0.1074
test [q25]perinc= [q75]perinc [Prob>F=0.1724] (Not different) 50 Pseudo R^2=0.1167
test [q25]eleva1= [q75]eleva1 [F(1,231)=2.54] (Different) 75 Pseudo R^2=0.1546
*** significant at 1%.
** significant at 5%.
* significant at 10%.

which allow for higher productivity agriculture and a variety of employment options (this is consistent with findings by Block and Webb 2002).

Furthermore, per capita cultivated area exerts positive association with income diversification. The result is consistent with findings reported by Reardon et al. (1992) for the Sudanian zone of Burkina Faso suggesting greater land holdings means greater diversification. This finding actually lends support to the notion that land increases household investment in non-cropping activities by providing, directly or indirectly, the capital needs to invest (Ellis 2000).

The coefficient for family size is negative and statistically significant. However, the coefficient on the total work force and age of household head are positively associated with crop diversification but insignificant. In effect, relatively more established households with high labor force but low family size derive a large share of income outside cropping (Barrett and Reardon 2000). The level of livestock ownership is negatively associated with income diversification.

For households in the upper 75% of crop share to total income, the same pattern is found except that most of the coefficients are not significant but have the expected sign (Column 3, Table 11). There is strong evidence that region is associated with diversification and livestock holdings are negatively associated with diversification.

Conclusions and implications

The results of this study are based on a limited sample of 115 households in the Sahelian, Sudanian and Guinean zones. Thus, we cannot claim that the findings can be generalized. Nevertheless, they are highlighted as potential hypotheses that could be pursued to guide future research. With that caveat in mind, a number of research, development and policy implications are discussed below, based on the above results.

Uptake of improved technologies (e.g. inorganic fertilizers) has significantly increased. Diversification into cash crops could induce households to invest in fertilizers or other improved technologies. During the last 20 years, and despite investment in information dissemination, households are applying fertilizers below the recommended rates.

In policy formulation rural households are often uniquely treated as crop producers, or at most as crop and livestock producers. The consequence of looking at them this way is that the policymaker or technology designer believes that the rural household is comparing net earning levels and variability of various options only within the farm sector. Examples would be whether or not to invest money in a draft animal, or to grow cotton as opposed to grain.

In contrast with this uni-sectoral view of the rural household, the typical household in our sample earned about one-half of total earnings from cropping or livestock activities with the rest being derived from off-farm businesses, migration remittances and transfers. The appropriate inference is that when the household is deciding on where to invest its money or use its labor time, it evaluates earning potential across the various crop, livestock and non-farm sectors. Our results confirm this on an income basis (as opposed to a labor-use basis).

Furthermore, given extreme inter-annual variability in cropping outcomes, opportunity costs may be relatively higher in those sectors that are relatively less affected by that variability (although this is not quantified in this paper). Consequently we find that households disperse their time and money investments over a wide range of sectors and locations. The level and stability of earning appears to be perceived as greater in the non-cropping activities.

These findings are equally relevant to agricultural research and extension strategies. Given that rural households are not constrained to invest their funds and time in cropping, and appear sensitive to inter-sectoral relative net returns, it may be difficult to persuade rural households to intensify their cropping through greater labor, capital or variable input use, since these same resources provide an important risk aversion function elsewhere. This is consistent with a finding elsewhere for Burkina Faso that farmers who chose not to adopt animal traction were in fact much more heavily engaged in commerce than those who did (Barrett et al. 1982).

In a related argument, it can be shown that labor saving technical change in agriculture does not translate necessarily into a reduction of labor demand or opportunity for sale of labor in the overall rural economy. That is, an increase in farm income coming from a productivity increase could translate into an increase in demand for the output of off-farm activities. Derived labor demand from off-farm activities could absorb the labor that had been freed from agricultural tasks. Conversely, if cropping becomes much more profitable because of labor productivity increasing technology, then households may choose to allocate more labor to cropping and less to non-farm activities. However, if the increase in productivity were insufficient or too variable to lead to a shift in household income strategy toward cropping, then households would probably choose to use the labor freed from cropping tasks in off-farm income generating activities. This would, of course, depend on the households' demand for leisure function.

Sample households are highly involved in market activity to generate both income and food. Conventionally in policy discussions, rural households in Africa - especially in the semi-arid zones - are viewed as subsistence producers; at most they may have some surplus grain which is sold to urban areas. The consequence of this view is that demand-side price and marketing policies are considered to have an insignificant effect on rural households. In contrast with this view, we have found that from one-half to three-quarters of household income comes from interaction with the non-agricultural market. While cereal sales are a very small part of income in bad years such as the one surveyed, cereal purchases are an important part of the diet (see Reardon and Matlon 1987). In fact, the degree of vulnerability to cropping outcomes is inversely related to dependency on the market from both the income and expenditure side.

References

Abdulai, A, Crole Rees A. 2002. Determinants of income diversification amongst rural households in southern Mali. Food Policy. Forthcoming.

Barrett, C, Reardon, T, and Webb R 2002. Non-farm income diversification and household livelihood strategies in rural africa: concepts, dynamics, and policy implications. Food Policy. Forthcoming.

Block, S and Webb P. 2002. The dynamics of livelihood diversification in post-famine Ethiopia. Food Policy. Forthcoming.

Ellis, F. 2000. The determinants of rural livelihood diversification in developing countries. Journal of Agricultural Economics. 51(2):289-302.

Fafchamps, M, Udry, C and Czukas K. 1998. Drought and savings in West Africa: Are Livestock a buffer Stock? Journal of Development Economics. 55(2):273-305.

Jaeger, W and Matlon PJ. 1990. Utilization, profitability and the adoption of animal draft power in West Africa. Amer. J. Agric. Econ. 72 (l) : 35-48.

Matlon, PJ. 1988. The lCRISAT Burkina Faso farm level studies: survey methods and data files. Economics group, VLS and Miscellaneous series, ICRISAT, Hyderabad-India.

Ndjeunga, J, Kara Amara, Sogodogo D and Zarafy H. 2001. Local village seed systems in West Africa: lessons learned. ICRISAT. Unpublished paper.

Reardon, T and Matlon PJ and Delgado C. 1988. Coping with household level food insecurity in drought affected areas of Burkina Faso. World Development. 16 (9):1965-1975.

Reardon, T, 1997. Using evidence of household diversification to inform study of the rural non-farm labour market in Africa. World Development. 25(5):735-748.

Reardon, T, Delgado, CL, and Matlon PJ. 1992. Determinants and effects of income diversification amongst farm households in Burkina Faso. Journal of Development Studies. 28(l):264-296.

Savadogo, K, Reardon, T and Pietola K. 1994. Farm productivity in Burkina Faso: effects of animal traction and non farm income. Amer. J. Agr. Econ. 76:608-612.

Woldehanna, T and Oskam A. 2002. Income diversification and entry barriers: evidence from the Tigray region of northern Ethiopia. Food Policy. Forthcoming.

Dynamics of household livelihood strategies: Implications for agricultural research

H Ade Freeman[1] and Frank Ellis[2]

Introduction

Rural households in low-income countries are pursuing diverse livelihood strategies deriving income from a wide range of farm, off farm, and non-farm sources (Reardon 1997; Ellis 1998; Bryceson 2000; Ellis 2000; Barrett et al. (b) 2001). There is also evidence that the share of non-farm income is increasing in the income portfolio of rural households (Bryceson 2000). However, despite increasing income diversification, agriculture remains an important income source for a large proportion of rural households (Ellis 1998 ; Bryceson 2000; IFAD 2001; Orr and Orr 2002). Moreover, most off-farm diversification in Africa is linked to agriculture through forward and backward production linkages (FAO 1998).

Improved technology and better access to markets have been identified as crucial in fostering broad-based growth, enhancing sustainable management of natural resources, and poverty reduction in rural areas (de Janvry and Sadoulet 2000; IFAD 2001; Csaki 2001; Tripp 2001). Yet, there is scarce empirical evidence on the implications of household livelihood strategies for the design and development of agricultural technologies and rural institutions that benefit the poor.

This paper utilizes micro-level data on household assets, activities and incomes to examine household livelihood strategies and draw implications for the design and development of future technologies that recognize the diversity of household livelihood strategies and can stimulate the growth of the rural non-farm sector.

The case study

The fieldwork combined participatory research methods and a quantitative household survey to examine the livelihood patterns and strategies of rural

1. ICRISAT, Nairobi, Kenya.
2. ODG, University of East Anglia, Norwich, UK.

individuals and households. The participatory research involved a wealth ranking exercise and focus group discussions formed around particular activities or issues. In other instances, specific understanding of strategies and constraints were obtained through discussions with individuals and households. The sample survey took place at the same time that qualitative, Participatory Rural Appraisal (PRA) work was being conducted in the village. Households were stratified based on the wealth ranking exercise that categorized households into poor, middle, and well off. A random sample was drawn from household lists in each income-wealth group. This resulted in a final sample of 35 households in each village, 10 households each from the well-off and middle categories, and 15 households from the poor category. The five villages studied thus provided a total sample of 175 households.

The fieldwork for this research was conducted in Suba District in Nyanza Province. The district was carved out of Homa Bay District in 1995, and is located in the southwestern part of Nyanza along Lake Victoria. It borders Kisumu and Siaya districts to the north, Homa Bay District to the southeast, Migori District to the south, the Republic of Tanzania to the southwest and the Republic of Uganda to the west. Average annual rainfall ranges from 700 to 1200 mm with 60% reliability. There are two rainy seasons: the long rains occur from March to May while the short rains occur between August and December. Average temperatures range from 17.10°C to 34.8°C.

The villages selected for the study in Suba District are listed in Table 1. These villages were purposively selected bearing in mind poverty-relative wealth considerations given the overall research focus on poverty and food insecurity. Villages differed in the degree of reliance on different natural resources, market access, infrastructure and service support.

Survey results

Income and asset endowments of the sample households by income quartile are shown in Table 2. Even though livelihoods and income are not synonymous, income data provides a direct and measurable outcome of livelihood circumstances and strategies (Ellis 2000). There are substantial differences in household incomes with average per capita income in the richest households 20 times higher than that for the poorest households.[3] Poorer households also had smaller endowments of productive assets. The

3. This is partly of course an artefact of the stratification procedure adopted, and does not represent the degree of inequality in the underlying village populations.

Table 1. Characteristics of sample villages.

Division	Location	Sub-location	Village	Soils	Production systems	Market access
Lambwe	Lambwe West	God-Jope	Nyapuodi	• Poor soils due to erosion (due to occasional heavy downpours, overstocking and strong winds during dry season) and prevalence of weeds especially *kayongo*	• Major crops are maize, sorghum, beans, vegetables (kale, onions and tomatoes), cassava, green grams, groundnuts, cotton and fruits (paw paw, pineapples and bananas introduced in 2001 and 2000) • Livestock production (cattle, goats, sheep, poultry and donkeys) • Typical farm size is 4 ha	Good year-round vehicle access
Central	Kaksingri East	Sumba West	Makende	• Low soil fertility • Heavy erosion due to cutting down of trees, overgrazing and overstocking	• Major crops are maize, sorghum, cassava, beans, groundnuts, sunflower and millet • Livestock (zebu type cattle, goats, sheep and poultry) • Typical farm size is 1.2 ha	Poor year-round vehicle access
Mbita	Gembe West	Mbita Township	Gingo	• Increased wind erosion and reduced soil fertility • Striga weed is on the increase	• Fishing • Major crops are sorghum, millet, maize intercrop with beans and marginal horticulture (onions, tomatoes and kale) • Livestock (cattle, goats and poultry) • Average land holding is 4 ha	Dry season vehicle access only
Mbita	Gembe West	Mbita Township	Nyachebe	• Soils are poor with weeds increasing infestation of weeds especially Striga.	• Fishing • Major crops are sorghum, maize, beans, sweet potatoes and vegetables • Livestock (cattle, goats and poultry) • Average land holding is 8 ha	Good year-round vehicle access

Continued

Table 1. *Continued*

Division	Location	Sub-location	Village	Soils	Production systems	Market access
Central	Kaksingri West	Rangwa West	Roo	• Soils are relatively fertile	• Fishing • Major crops are sorghum, maize, cassava, sweet potatoes, bean and groundnuts • Livestock (cattle, goats, donkeys and poultry) • Average land holding for older heads of households is 3-5 ha while that of the younger head of households is about 1 ha	Beach in poor year-round vehicle access

Table 2. Household characteristics by per capita quartiles.[1]

	I	II	III	IV
Income per capita (KSh)	3966	11187	21269	74373
Age of household head	51.1	48.1	46.8	43.8
Years of education of household head	6.0	6.5	6.6	7.8
Average years of education of all resident	12.7	14.7	15.8	16.5
Household size	4.1	4.1	3.9	3.6
Ratio of workers to family size	0.4	0.4	0.4	0.5
Total land owned (ha)	1.9	2.2	2.3	2.5
Land owed per capita (ha)	0.6	0.7	0.6	0.8
Livestock (CEU)[2]	4.2	4.3	6.3	6.9
Tools[3]	7.8	7.1	14.1	9.0
Households with: Concrete or brick house (%)	2	10	11	16
Piped water (%)	0	2	0	0
Bicycle (%)	36	46	44	55

1. I is the first income quartile comprising households with the lowest income while IV the fourth income quartile comprise households with the highest income.
2. CEU is cattle equivalent units: Goats = 0.12; Sheep = 0.10; Chickens = 0.02.
3. Tools is a value based index based on productive assets owned by households.

heads of poorer households had the least education and household members had the least average years of education. Poor households had larger families, owned smaller farms, had fewer livestock and productive tools and were least likely to own a bicycle.

Household income shares by source and income quartiles

Sample households were involved in a range of activities that generated income. The portfolio of household income shares by source is shown in Table 3.

Table 3. Per capita shares of different sources and income quartile.

	I	II	III	IV	Total
Crop	42	20	9	4	8
Livestock	19	22	13	4	8
Fishing	6	16	15	30	25
Rent	0	2	0	0	0
Other natural resources	13	18	14	7	10
Non-farm	11	20	42	53	46
Remittances	4	1	2	1	1
In-kind	5	1	5	1	2

Even though 63% of resident household members reported farming as their main occupation, crop and livestock income only accounted for 16% of total household income. Poorer households obtained a greater share of household income from cropping and livestock activities. These households also derived substantial amounts of income from off-farm activities involving exploitation of common property resources such as collecting firewood, making ropes and charcoal. Low entry barriers and corresponding low returns to household assets characterize these activities. In contrast the richest households derived over half of their income from non-farm sources. Remittance income and transfers were less important in overall income portfolios across all income groups. The data on household income portfolios show that the share of non-farm income in total income monotonically increased with wealth. This corroborates evidence on the positive correlation between the share of non-farm income and total incomes that has been reported in other African countries (Reardon 1997; Barrett et al. 2001a).

Household income from cropping included the value of subsistence consumption. Although the value of subsistence consumption is highest among poorer households, food is a major wage good for all households irrespective of their wealth.

Households build their livelihoods from decision-making processes involving the use of assets that individuals (or the household) own or have access to. This process characterizes a household livelihood strategy (Soussan et al. undated). Following Ellis (2000) we developed typologies of household livelihood strategies using observable choice of activity and income data. A household is characterized as primarily pursuing a livelihood strategy if it obtains two-thirds or more of its income from an activity or combination of activities. As Ellis (2000) notes the income threshold selected can make a big difference to the pattern of household livelihood strategies.

The characterization of livelihood strategies resulted in four distinct household livelihood strategies. First, agricultural based livelihoods comprised households that earned their income primarily from cropping, livestock, and fishing activities; a second livelihood strategy comprised households that earned their income from engaging primarily in non-farm activities. The data suggested two mixed livelihood strategies in which households combined agricultural activities and non-farm activities. Given that the returns to different non-farm activities varied substantially we distinguished low return non-farm activities from high return non-farm activities based on information obtained from the focus group discussions. Communities perceived activities such as collecting firewood, rope making and basket weaving as low return activities that poorer members of the community engaged in. In contrast high return non-farm activities, such as obtaining salaried employment with the public or private sector, involved specialized skill or education. We therefore distinguished two mixed livelihood strategies one defined as mixed livelihoods including diversification into low return non-farm activities and the other mixed livelihoods including diversification into high return non-farm activities.

The distribution of sample households according to the typologies described above is reported in Table 4. The table shows that households pursued distinct wealth-differentiated livelihood strategies. These result from differences in the level of entry barriers involved in pursuing each strategy (Barrett et al. 2001b).

Table 4. Livelihood strategies by income quartiles (%).

	I	II	III	IV	Total
Principally agriculture	52	34	14	36	34
Principally non-farm	5	16	40	43	26
Mixed strategy with low return non-farm	23	41	28	14	26
Mixed strategy with high return non-farm	21	9	19	7	14

The poorest households pursued agricultural livelihood strategies and low return mixed strategies that required limited specialized skills and involved little capital assets. Households with few ex ante asset endowments are compelled to diversify into these strategies because they have relatively low entry barriers. In contrast wealthier households diversified into non-farm strategies that provided higher returns. Entry into these activities, however, required higher levels of skill, capital assets or both. Table 5 shows the relationship between household livelihood strategies and ex ante asset endowments, and provides additional insights into the importance of asset endowments in the choice of a household pursuing a particular livelihood strategy.

Table 5. Distribution of assets by livelihood strategies.

	Principally agriculture	Principally non-farm	Mixed strategyl[1]	Mixed strategy2[2]	Total
Age of household head	49.7	46.8	44.3	49.2	47.5
Total adult equivalent unit	3.6	4.1	3.9	4.4	3.9
Education of household head	6.1	8.2	5.9	7.0	6.7
Education of resident members[3]	12.9	17.4	15.3	14.6	14.9
Total land owned (ha)	2.1	2.1	2.3	2.5	2.2
Total cattle equivalent units	4.2	6.8	4.5	8.1	5.5
Tools	7.1	12.9	7.9	12.1	9.5
Households with:					
Concrete or brick house (%)	6	11	7	21	10
Stand pipe (%)	0	2	0	0	1
Bicycle (%)	32	51	50	58	45

1. Mixed strategy with low return non-farm activities.
2. Mixed strategy with high return non-farm activities.
3. Average number of years of education of resident household members.

Our findings provide additional evidence that diversification into non-farm activities is related to greater upward income mobility. Given the importance of non-farm incomes and its importance in offering rural households a route out of poverty we further investigated non-farm income sources. The relationship between agriculture and the non-farm economy at the household level is shown in Table 6.

Table 6. Farm non-farm linkages by per capita income quartiles.

	I	II	III	IV	Total
Upstream	33	30	8	26	23
Downstream	50	40	58	53	51
No linkage	17	30	33	21	26

About 75% of non-farm activities are directly linked to agriculture either as backward or forward production linkages. Forward production linkages involving diversification into agro-processing, trading and transportation services are particularly important while backward linkages in the form of supply of farm inputs and services are less important. This latter finding reflected, in part, the weak derived demand for farm inputs and services in an agricultural system that predominantly used traditional production technologies.

We further examined the determinants of household livelihood strategies with probit regressions. The regression equations estimate the probability of a household pursuing a livelihood strategy as a function of its asset endowments and a community variable measuring market access. This provided additional insights into how household asset endowments influenced their choice of livelihood strategy. Given that several of the independent variables are choice variables the regression results only provide evidence about the correlation between livelihood strategies and household assets without implying causality. Even so, the probit regression results were instructive.

The results from the probit regressions link the probability of households pursuing three distinct livelihood strategies - agricultural strategy, mixed strategy including diversification into low return off-farm activities and non-farm strategy - as a function of household asset endowments and market access. The dependent variable takes a value of one for a household pursuing the i^{th} livelihood strategy and zero otherwise.

The results are reported in Tables 8, 9 and 10 for agricultural, mixed and non-farm livelihood strategies, respectively. Households with a higher proportion of workers were more likely to pursue an agricultural livelihood strategy. These households were also less likely to be members of credit or savings groups, or they received remittance income that could be used for financing farm investments. Households pursuing agricultural livelihood strategies were also less likely to own a bicycle, an important transportation asset in this area. The level of education of the household head did not have a significant influence on the choice of pursuing an agricultural livelihood strategy. A likely explanation is that farming activities in this area are based on traditional technologies that require limited skills. A surprising finding is that the coefficient on the land variable, though positive, did not significantly influence the choice of pursuing an agricultural livelihood strategy. A probable explanation is that in this area where farm sizes tended to be higher than average, it may be access to good quality land rather than large farm sizes that determine the successful pursuit of an agricultural strategy. This finding is consistent with the perception of the communities that low soil fertility and high rates of soil erosion reduced the quality of land resources, severely limiting the potential for agricultural production. Households pursuing livelihoods that primarily comprised agricultural and low return off-farm activities were more likely to be those with younger heads and without family members that belonged to credit or savings groups. Non-farm livelihood strategies were more likely in households where the head had a relatively high level of education; family members belonged to credit and savings groups, and the household received remittance income that could finance non-farm activities. These households had a higher level of initial wealth as indicated by the tools index. Together these results imply that human capital variables, and other capital assets, imposed important barriers to entry into non-farm activities that provided higher returns to household resources. This is consistent with findings in other parts of Africa that show barriers to entry into high return non-farm activities (Dercon and Krishnan 1996; Barrett et al. 2001). Poorer households lacking education, specialized skills or capital assets are compelled to diversify into low return livelihood strategies in agriculture and low return activities off farm.

Table 7. Description of regression equation variables.

Variable	Type	Description
AGE	Continuous	Age of household head
AGE^2	Continuous	The square of the age of the household
GENDER	Binary	Gender of household head: 1 = male headed, 0 = otherwise
EDUCATION	Continuous	Number of years household head has spent in school
LAND OWNED	Continuous	Total area owned (acres)
HOUSEHOLD SIZE	Continuous	Total number of resident household members in adult equivalent units
DEPENDENCY	Continuous	Ratio of workers to family size
LIVESTOCK	Continuous	Size of livestock herd in cattle equivalent units
CREDIT	Binary	1 = member belong to a credit scheme, 0 = otherwise
REMITTANCE	Binary	1 = receive income from remittances, 0 = otherwise
TOOL INDEX	Continuous	Tools index
BICYCLE	Continuous	Number of bicycles
MARKET ACCESS	Binary	1 = good market access, 0 = otherwise

Table 8. Probit result for agricultural livelihood strategy.

Variable	Coefficient	Probability
Constant	0.385	0.739
AGE	-0.049	0.293
AGE^2	0.001	0.169
GENDER	0.405	0.165
EDUCATION	-0.005	0.895
LAND OWNED	0.012	0.614
HOUSEHOLD SIZE	-0.047	0.515
DEPENDENCY	0.696**	0.094
LIVESTOCK	0.001	0.943
CREDIT	-0.680**	0.080
REMITTANCE	-0.931*	0.020
TOOLS INDEX	-0.012	0.354
BICYCLE	-0.396**	0.066
MARKET ACCESS	-0.075	0.733
Chi-squared	28.924	
Significance	0.007	

* Significant at 5% level.
**Significant at 10% level.

Table 9. Problt result for mixed livelihood strategy including low return off-farm.

Variable	Coefficient	Probability
Constant	-0.884	0.507
AGE	0.056	0.339
AGE^2	-0.001	0.148
GENDER	0.199	0.524
EDUCATION	-0.114*	0.006
LAND OWNED	0.015	0.526
HOUSEHOLD SIZE	0.074	0.342
DEPENDENCY	0.080	0.858
LIVESTOCK	-0.010	0.654
CREDIT	-0.806*	0.049
REMITTANCE	0.048	0.905
TOOLS INDEX	-0.016	0.271
BICYCLE	0.305	0.178
MARKET ACCESS	0.020	0.932
Chi-squared	23.588	
Significance	0.035	

* Significant at 5% level.
** Significant at 10% level.

Table 10. Probit result for non-farm livelihood strategy.

Variable	Coefficient	Probability
Constant	-1.208	0.319
AGE	0.009	0.856
AGE^2	0.000	0.981
GENDER	-0.343	0.293
EDUCATION	0.098*	0.010
LAND OWNED	-0.034	0.218
HOUSEHOLD SIZE	-0.052	0.490
DEPENDENCY	-0.759	0.118
LIVESTOCK	-0.002	0.892
CREDIT	0.875*	0.006
REMITTANCE	0.574	0.104
TOOLS INDEX	0.020**	0.063
BICYCLE	0.005	0.983
MARKET ACCESS	-0.021	0.930
Chi-squared	31.606	
Significance	0.003	

*Significant at 5% level.
**Significant at 10% level.

HIV/AIDS and the health situation of rural households

HIV/AIDS is a major development and social problem that severely affects the livelihoods and food security of a large number of households in the sample villages. We did not obtain data on the incidence of the disease at the household level but the communities overwhelmingly agreed that the incidence and extent of the disease has increased over the past 10 years. **HIV/ AIDS** had reduced the availability of labor for farm work and fishing, diverted household expenditure from food, clothing, school fees and productive investments into medical care, forced the sale of household assets including land and livestock, and reduced income generating activities. The disease has created large numbers of orphans who are either being supported by grandparents, who are poor themselves, and often too old to work, or left to fend for themselves. The quality of human capital assets have also declined as teachers succumb to the disease and children are withdrawn from school to care for the sick or because parents are unable to pay school fees. These communities expressed the view that these factors have increased poverty and vulnerability in many households.

Local taxation regimes and their impact on livelihood strategies

We also examined local taxation regimes in the focus group interviews, given that taxes influence relative prices and the incentives to pursue commercial activities. Households in Suba District pay a wide range of legal and illegal taxes on all commodities involving monetary transactions. Fisherfolk require a number of licenses from the fisheries and health departments and pay levies to the county council on fish sales. Farmers pay taxes on crop sales, and on movement of commodities outside the district, while a livestock trader needs a license to start trading and taxes are imposed on livestock sales and movement. Chiefs and local administration authorities also compel households to contribute to harambees (local fund-raising activities). Moreover, tax collection systems are not transparent opening them to all sorts of abuse. Indeed the perception of the communities is that they are over-burdened by local taxes and other ill-defined payments to the authorities. The communities were unanimous that these payments discouraged commercial farming, fishing or livestock activities and limited their ability to undertake productive investments. Ellis and Bahiigwa (2001) reported similar findings on local taxation in rural Uganda.

Conclusions and implications for agricultural research

The analysis of rural household livelihood strategies presented in this paper is consistent with empirical evidence from other parts of Africa that most rural households obtain their livelihoods from a diverse portfolio of income sources (Reardon 1997; Ellis 1998; Bryceson 2000; Ellis 2000; Barrett et al. 2001). The projection is that rural households will continue pursuing multi-locational and multi-occupational livelihood strategies (Ashley and Maxwell 2001). The main implication following from this is that the assumption that all rural households are primarily farming households may not be valid and can lead to the wrong specification of technology needs. Technological change is critical in the transition from subsistence production to monetised farm and non-farm sectors. The challenge for agricultural research is to identify and develop the types of technologies that will help poor rural households work their way out of poverty. Such technologies need to recognize the linkages between agriculture and the rural non-farm sector, be compatible with household investment strategies, raise labor productivity in food production, improve the productivity of household assets and stimulate growth of the non-farm economy. Institutional innovation and enabling rural institutions are equally important in expanding growth opportunities for rural households.

The rising share of non-farm income in household income portfolios reported in this paper does not diminish the role agriculture can play in rural poverty reduction or the importance of agricultural policy and research (Reardon et al. 1998; Kydd 2002). As Kydd (2002) argues the challenge is to find ways to make agricultural research more successful. The study shows that non-farm activities are closely linked to agriculture particularly through commerce, crop processing and distribution. Reardon et al. (1998) argue that this corresponds to the first stage of the rural non-farm sector transformation. In this stage a dynamic agriculture is necessary for development of the non-farm sector and vice versa. Gordon and Craig (2001) argue that many countries in sub-Saharan Africa are in the first stages of rural non-farm sector transformation.

The observed patterns of income diversification imply that rural households allocate their scarce resources in farming as well as between farm and non-farm enterprises according to relative returns to resource use and subjective assessment of the riskiness of alternative investments. Many rural households are part-time farmers, part-time workers and micro-entrepreneurs (de Janvry and Sadoulet 2000). Rural households will continue evaluating relative returns and risk of alternative enterprises when making investment decisions. Agricultural research strategies need to consider this in priority setting and technology design. Many rural households may seek to free farm labor to pursue more productive activities off-farm. HIV / AIDS also reduces labor availability for farm work. These households are likely to prioritize labor saving technologies even in perceived labor-surplus areas. Other households with cash resources and access to information and markets may want to pursue intensified commercial agriculture with high labor demands. Such households may generate employment in agriculture and prioritize labor-using technologies. The simultaneous demand for labor saving and labor using technologies in rural areas underscores the need for agricultural research to emphasize the development of a wider range of technology options for households with differing technology needs.

The high share of the value of subsistence consumption in household income portfolios highlights the importance of food as a wage good in the study area. This finding is consistent with empirical evidence from other parts of Africa (Delgado et al. 1993; IFAD 2001; Upton 2001). Improved technologies that increase food production in these semi-open economies would reduce food prices. Given that food is a major wage good this is equivalent to an increase in per capita incomes of rural households (Schuh 2000). Most of these benefits would accrue to poorer rural households who tend to spend a larger share of income on food compared to better-off households. Increased labor productivity in food production would also free household labor to pursue higher return off-farm activities.

The finding that land and labor resources were not important factors conditioning the choice of agricultural livelihood strategies justifies the view that improvements in the quality of land and labor, key household assets, are necessary for lifting rural households out of poverty. Improving land productivity typically involves increased investment in natural resource management such as soil fertility and water management technologies. But rural households may not adopt improved natural resource management technologies if the returns to these investments accrue at a later date or are lower than returns to investments in alternative non-farm activities. Farmers producing a commercial crop are more likely to adopt improved soil and water management technologies. Thus, agricultural natural resource management research strategies need a paradigm shift away from a narrow agricultural production bias to a broad intersectoral perspective that emphasizes relative returns to household resources in alternative activities.

Tripp (2001) argues that future agricultural technologies will be knowledge intensive and inputs will increasingly be delivered by the private sector. It is therefore imperative to build the human capital of rural households if they are to benefit from new technologies and emerging opportunities for commercialization. Investment in human capital also facilitates the transition to non-farm employment. The projected increased role of the private sector in input supply calls for improving the technical knowledge of input suppliers so that they can effectively advise farmers on input use. All of this implies a changed role for extension systems most of which are facing severe budgetary limitations and barely function in many rural areas. Rather than focus on information dissemination to farmers, extension might use their limited resources to improve the technical capacity of private traders so that they can provide effective advisory services for farmers.

Even though the data did not allow us to test the strength of farm and non-farm linkages, the importance of backward and forward production linkages in non-farm activities suggest that future research should put greater emphasis on strengthening farm-non-farm linkages. The farm sector will eventually decline with economic development (Schuh 2000). Agricultural research should help rural households make that transition. Diversification into non-farm activities is associated with improved living standards. But the probit regressions suggested that there are significant entry barriers to non-farm activities. Agricultural research and policy interventions should aim at reducing entry barriers into remunerative non-farm activities. Emerging local government business licensing and taxation policies require careful monitoring in this regard.

Within the farm sector, technology change can facilitate diversification of cropping patterns through choice of variety, choice of crops, improved product quality. On-farm crop diversification can benefit both semi-commercial and commercial farmers. The challenge is to identify market niches that exploit these opportunities (Orr and Orr 2002). Future crop improvement programs may need to put more effort into incorporating preferred farmer and market traits into new varieties. Correspondingly, there has to be greater emphasis on improving farmer linkages into markets in ways that include market participation of smallholder farmers. This includes development of information and communication systems to improve the flow of information on products, markets and cropping options. Policy interventions should also facilitate the design and development of agro-processing suitable for small- and medium-scale rural entrepreneurs.

Institutional innovations that reduce transaction costs in marketing and distribution are equally important. Marketing arrangements that provide incentives for implementation of grades and standards in rural areas are necessary to facilitate access to high value urban, regional and international markets. Kydd (2002) observes that agricultural research needs to reflect the fact that technology and institutional development are co-evolutionary. An important implication of this is that institutional change that distorts or inhibits the participation by farmers in markets is likely at the same time to inhibit the uptake of technologies that can make strong contributions to future productivity and incomes in agriculture.

References

Ashley, C and Maxwell, S. 2001. Rethinking rural development. In Development Policy Review 19:(4). (Ashley, C and Maxwell, S. eds.) London: Overseas Development Institute.

Barrett, CB, Bezuneh, M and Aboud, A. 2001a. Income diversification, poverty traps and policy shocks in Cote d' lvoire and Kenya. Ithaca: Department of Applied Economics and Management, Cornell University.

Barrett, CB, Reardon, T and Webb, P. 2001b. Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications. Ithaca: Department of Applied Economics and Management, Cornell University.

Bryceson, D. 2000. Rural Africa at the crossroads: Livelihood practices and policies. In Natural Resource Perspectives, Number 52. London: Overseas Development Institute.

Csaki, C. (2001), Reaching the rural poor. In: Development Policy Review, Volume 19, Number 4 (Ashley, C and Maxwell, S. Eds.). Overseas Development Institute, London.

de Janvry, A and Sadoulet, E. 2000. *Rural poverty in Latin America, determinants and exit paths.* In: Food Policy : Volume 25, Number 4: Assessing the impact of agricultural research on poverty alleviation (Pachico, D, Hertford R and de Janvry, A. eds.). Elsevier Science. Ltd.

Delgado, C, Liedholm, C, Maynard M and Lundberg D. 1993. *What is the role of private-sector agriculture and farm linkages to the nonfarm economy?* In: Agricultural Transformation in Africa: A Round Table Discussion with Ackello-Ogutu, C, Carter, M, Cleaver, K, Delgado C, Gilbert, E, Kaestner III, BH, Liedholm, C, Maynard, M, Peters, P, Reardon, T, Sahn, D, Shaikh, A, Timmer P and Africa specialists of USAID and Winrock International. (Seckler, D, ed.). Winrock International Institute for Agricultural Development, Arlington, USA.

Dercon, S and Krishnan P. 1996. *Income portfolios in rural Ethiopia and Tanzania: choices and constraints.* The Journal of Development Studies. Vol. 32, No. 6, pp. 850-875. Frank Cass, London.

Ellis, F. 1998. *Household strategies and rural livelihood diversification.* The Journal of Development Studies. Vol. 35, No. 1, pp. 1-38. Frank Cass, London.

Ellis, F. 2000. *Rural livelihoods and diversity in developing countries.* Oxford University Press Inc., New York.

Ellis, F, and Bahiigwa, G. 2001. *Livelihoods and rural poverty reduction in Uganda.* LADDER Working Paper No. 5. University of East Anglia, Norwich.

Gordon, A and Craig, C. 2001. *Rural non-farm activities and poverty alleviation in sub-Saharan Africa.* Policy Series 14. Natural Resources Institute, University of Greenwich.

IFAD. 2001. *Rural poverty report 2001: The challenge of ending rural poverty.* Oxford University Press Inc., New York.

Kydd, J. 2002. *Agriculture and rural livelihoods: Is globalisation opening or blocking paths out of rural poverty?* Agricultural Research & Extension Network. Network paper No. 121.

Lipton, M. 2001. *Escaping poverty: The poor's productive resource needs: a keynote address.* A paper presented at 2020 Vision; Sustainable Food Security for all by 2020. September 4-6, 2001. Bonn, Germany.

Lopez, R and Valdes, A. 2000. *Fighting rural poverty in Latin America: New evidence and policy.* In: "Rural Poverty in Latin America" (Lopez, R and Valdes, A eds.). Macmillan Press Ltd, Great Britain and St. Martin's Press, LLC, USA.

Orr, A and Orr S. 2002. *Agriculture and micro enterprise in Malawi's rural South.* Agricultural Research & Extension Network, Network Paper No. 119.

Reardon, T. 1997. *Using evidence of household income diversification to inform study of the rural nonfarm labor market in Africa.* World Development. Vol. 25, No.5, pp. 735-747. Elsevier Science Ltd.

Reardon, T, Stamoulis, A, Balisacan, ME, Berdegue, J, and Banks B. 1998, Rural non-farm income in developing countries. In: The State of Food and Agriculture, Food and Agriculture Organization of the United Nations, Rome.

Reardon, T, Taylor, JE, Stamoulis, K, Lanjouw, P and Balisacan, A. 2000. Effects of nonfarm employment on rural income inequality in developing countries: an investment perspective. Journal of Agricultural Economics, 51(2).

Schuh, GE. 2000. The household: The neglected link in research and programs for poverty alleviation. Elsevier Science Ltd.

Soussan, J, Blaikie, P, Springate-Baginski, O and Chadwick M. Undated. Understanding livelihood processes and dynamics: livelihood-policy relationships in South Asia. Working Paper 7.

Tripp, R. 2001. Agricultural technology policies for rural development. In: Development Policy Review, Volume 19, Number 4 (Ashley, C and Maxwell, S. eds.) Overseas Development Institute, London.

Session 1: Discussion

Were Omamo[1]

Ndjeunga and Savadogo Paper

Discussions on the Ndjeunga and Savadogo paper threw up many points:

- The aim of this paper is to describe and evaluate changes in rural household strategies in Burkina Faso in 2001.
- The approach taken is to revisit households surveyed in the mid 1980s and re-administer a survey whose primary objective was to describe household demographic characteristics, farming systems and major non-farming activities.
- As in the original survey, the 2001 survey covered three agroecological zones distinguished by average annual rainfall and soil type. These differences in agroecological potential implied differences in crops produced.
- The analytical approach is holistic, motivated by the sustainable livelihoods framework.
- The findings are intriguing:
  - Based on several measures, the sampled households approval to be better off, or at best doing better, in 2001 than they were in 1985.
  - They have more physical assets as measured by farm equipment and draft power.
  - They have more sources of income both within and outside agriculture.
  - They are making more use of improved inputs, especially fertilizer.
  - As one would imagine, these effects are more pronounced in the area with highest agroecological potential.
  - Cotton has become an important cash crop, especially in the area with highest agroecological potential.
  - Horticultural crops are also increasingly important.
  - Off-farm income sources are found to be important, however it is not quite clear how important. On pages 9 and 10 we are told these sources account for 20% of household income. One page 12, that figure is 50%.
  - Regression analysis of drivers of diversification (and thus income-farming opportunities) highlight access to physical capital and agroecological potential as key determinants.
- Concerned about endogenity of some of the regressors but maybe the authors can elaborate.
- These results fit nicely into expectation, especially within a sustainable livelihoods context.

1. International Service for National Agricultural Research.

- The implications for research make sense - i.e. more way from uni-sectoral approach.
- The paper thus gives us an interesting and valuable update on the 1985 results for the region.
- However, how generalized are the findings? How reliable are they?
- One of the key tenets or principles of the sustainable livelihoods approach is that micro behavior of the kind described in the paper determines and reflects broader institutional arrangements (or governance structures) in rural areas. Further, these governance structures are themselves reflections and determinants of broader policy and institutional environments (as captured by political systems and the legal and regulatory frameworks that those systems permit).

The discussions also threw up these questions:

- To its credit, the paper does bring up institutional issues at the village level. But there is scope for more investigations. For instance, how precisely did these farmer associations arise, and why? How do they function? What are their welfare inputs? Why haven't markets developed in these areas?
- How are cotton production and marketing organized in a region in why there are no produce markets to this day? The same question holds for horticultural crops
- What explains the out-migration of the young from the region with the highest agro-ecological potential? Push or pull?
- How have changes in the broad policy and institutional environment affecting agriculture influenced local administrative and organization structures and how, if at all, have these influences affected the choices and livelihood strategies in the study region?
- Do we have any answers to this type of questions? Is there scope to address them as the study moves forward?

Discussions on the Freeman and Ellis paper

The highlights of the discussion on the Freeman and Ellis paper were:

- The aim of this paper is describe and evaluate household livelihood strategies in Suba District in Western Kenya.
- Again, the analytical approach is holistic, motivated by the sustainable livelihoods framework.
- Participatory research methods and quantitative household survey methods are combined in an innovative manner to yield what appears to be a uniquely rich data set.

- As with the Ndjeunga-Savadogo paper, access to buy physical, human and financial assets appears to be crucial to households' wealth status and their livelihood strategies within these categories.
- Again non-farming income sources are okay.
- Subsistence-orientation is deep-rooted.
- Freeman and Ellis take us a little further than do Ndjeunga and Savadogo by exploring what factors are associated with pursuit of livelihood strategies based primarily on non-farming activities.
- Human and financial capital appear to be okay - i.e. education and credit. Initial wealth is also okay.
- Among the most interesting and important finings are the different effects of given assets across alternative livelihood strategies
- For instance education matters must for strategies driven by non-farming activities.
- The same for credit.
- Again, it would be very interesting to know how this micro behavior determines and reflects broader institutional arrangements and how these are reflections and determinants of broader policy and institutional environments.
- What are the larger forums driving organization in this rural area?
- What is going on in Suba? Socially? Politically? Institutionally?
- HIV/AIDS and local taxation regimes are mentioned.
- These are steps in the right direction but how precisely do they matter?
- It is certainly true that examination of non-farm activities provides a window into rural and agricultural sector transformation.
- What do these activities, and the farming activities that they complement, tell us about rural governance structures and boarder policy and institutional environments?
- And based on that understanding, what does it all mean for agricultural research in the SAT - i.e. in content and process?

I don't pretend to have any answers to these questions. Maybe we can deliberate on them a bit. I know of Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and Eastern and Central Africa Program for Agricultural Policy Analysis (ECAPAPA) that we are struggling with them.

Discussion

Stephen Mbogoh[2]

It is clear from the case studies that farmers appreciate the complementarity between organic and inorganic fertilizers and that non-farm activities have strong linkages to agriculture. However, there are challenges facing R4D particularly in relation to the following aspects:

- How do we increase the incomes of households depending on agriculture?
- How can research help in building assets of different types of households - based on the important role of initial wealth in influencing livelihood strategies?
- There is need to promote research that is compatible with the different household livelihood strategies.
- How can agricultural R&D be used to stimulate the growth of non-farm activities without compromising on the mandate of research centers?
- How can issues of institutions and governance be incorporated in agricultural R&D, without going beyond the missions of the lARCs and NARS?

Participants' Response

- Mandate change for CGIAR or partnerships and comparative advantages of various institutions? Is ICRISAT's mandate really relevant? Should we think of changing it?
  - No need to change mandate, but utilize synergies in the various disciplines/partners. Building partnerships is the way forward, but pick the right partners.
  - The fact that institutions do not work well does not mean ICRISAT should get or change into issues of institutional governance!
  - It is better to look at the overall mission, not the mandate, to guide ICRISAT's and other CGIAR centers' engagement in SAT/SSA.
  - ICRISAT's problem is that it has been working with "Orphan Crops"! There is need to move beyond conventional work of breeding.
  - Think about agro-processing to increase market opportunities for farmers.
  - Need to look at specific cases of productivity, diversification, etc, instead of the whole.
  - Since food insecurity persists in SAT/SSA, we need not compromise focus on these crops in favor of horticulturals and livestock.
  - Social issues, like labor supply, HIV/AIDS, etc should be incorporated into economic research, since they affect adoption of technologies.

2. Department of Agricultural Economics, University of Nairobi.

- The very low adoption and impact of new varieties reported in the studies raises questions about their suitability to SAT farmers. Why are they not being adopted and why did ICRISAT invest so much in their development? What were the varieties developed for and what was the strategy in their development? How can we overcome the constraints to technology adoption and stimulate the demand for the technologies?

Responses from the panelists

- There has been substantial adoption of these technologies in southern Africa.
- Problems of adoption are more on the supply-side due to poor access to seed and complementary inputs and lack of information. It is imperative that we look at the different institutional settings and their effects on adoption rather than on the appropriateness of technologies.
- But, are there technologies on the shelves?
- Could we have misperceived the needs of the farmers in SAT? What should R4D focus on - need we put more emphasis on variety yield stability than high yields per se, since it appears farmers in SAT value yield stability more than high unstable yields?
- Is more involvement of stakeholders in planning and development a possible answer? How do we resolve the conflicts among the diverse interest groups to come up with acceptable strategy and technologies?
- What about the role of gender in SAT research and technology use?
- Commercialization of agriculture will entail increased use of non-farm inputs and increase participation in both factor and product markets. Will traditional coping strategies be appropriate for market-related risks? This is made more important in view of the seasonality in production and the fact that rural households are increasingly becoming net buyers of grains.
- The case of Zimbabwe paints a picture of available off-farm incomes but no grains to buy - could this be a result of market failure?
- The need for improving minimum levels of fertilizers and increased intensification:
  - But scope for intensification is small in SAT/SSA.
  - Livestock may offer higher incomes.
  - Need for laborsaving technologies.
  - Diversification, rather than optimization are necessary to meet the needs of different farmers.

The Environment Influencing Technology Choice

Technology adoption is influenced by factors both within and outside the agricultural economy. This session highlights agribusiness and market linkages, food security, gender and HIV/AIDS, and their implications for agricultural research. The global agrifood industry and the nature of markets are changing from supply-oriented to demand-oriented, with greater economic concentration in input supply, processing and retailing, and new market standards that emphasize product quality and differentiation (and by implication, create niche markets). Food security is primarily a poverty and income issue. R&D institutions can help increase farm productivity but household food insecurity can persist even when food production is sufficient at national level. Gender is an important element of household dynamics and social systems. Men and women have different priorities and objectives when they adopt a new technology, and researchers must take into account these differences, as well as the fact that women generally have less access to land, extension advice, inputs and credit. HIV/AIDS has had a devastating impact not only on health and life expectancy but also on poverty, household expenditure patterns and labor availability.

Agribusiness and market linkages

Lawrence Busch[1]

Introduction

It is particularly auspicious that ICRISAT has decided to hold this conference here today. I submit that as little as 10 years ago, the very idea of holding such a conference would have been considered largely unnecessary, perhaps even absurd. But times have changed. We are now faced with a new set of challenges - challenges that the agricultural research community has until now tended to ignore. In particular, the last decade has arguably seen more change in the global agri-food system than any previous decade in history. While global trade in food products has been around for at least 500 years (Bonanno et al. 1994), only within the last decade has it become possible to talk of a truly global agri-food system. There are several drivers of these events including the creation of the World Trade Organization (WTO), the declining cost of transport and communication, the urbanization of the planet and the rise of a global middle class. We examine each of these in turn.

1. The World Trade Organization. The last decade has witnessed the creation of the first organization for governance of world trade. The WTO, the outcome of half a century of GATT (General Agreement on Trade and Tariffs) negotiations, has transformed the ways in which nations deal with each other. In its most general provisions, the WTO sees the end of tariffs and quotas, and the gradual reduction of subsidies to production and export. This is not to suggest that the WTO has replaced a regulated global economy with the free market.[2] To the contrary, the WTO has shifted global governance from one set of institutions to another as yet ill-defined set. Furthermore, while the last few months have witnessed several events that suggest a hiatus in this process (e.g. the increase in US agricultural subsidies and the US tariffs on imported steel), it is unlikely that global trade will revert to its pre-WTO position.

---

1. Michigan State University, East Lansing, USA.
2. The very idea of a fully free market is absurd. Markets are institutions and like all institutions must have rules of governance (see Bromley 1997).

Of particular importance for agriculture and agricultural research are three WTO agreements, which have the effect of establishing a new form of global governance. [3]

The Sanitary and Phytosanitary (SPS) agreement is designed to ensure that nations do not use SPS issues as non-tariff trade barriers. Signatories to the agreement pledge that they will use either the standards promulgated by established international organizations (e.g. Codex Alimentarius) or will introduce scientific evidence to show that some, presumably higher, standards will be used (Jukes 2000). However, only a few nations have the wherewithal to promulgate their own standards. Those nations that do, such as the European Union (EU) and USA, often have higher standards than those promulgated by international bodies. Thus, in practice, developing nations desiring to export to Europe or USA must meet the not always compatible standards of these nations.

The Technical Barriers to Trade (TBT) agreement covers those aspects of food trade not explicitly mentioned in the SPS agreement. Technical barriers to trade include differential treatment of domestic and imported products, unnecessarily precise or arcane labeling or packaging requirements, undue delays at ports of entry, or special paperwork requirements. In many ways, TBT requirements are easier to grapple with than are SPS requirements.

The Trade Related Intellectual Property Rights (TRIPs) agreement was designed to harmonize intellectual property (e.g. patents, trademarks, copyrights, trade secrets) globally. Importantly, it was introduced as a result of pressure by large corporations in industrialized nations concerned about the unauthorized use of their intellectual property in developing nations. Ironically, western companies seeking to patent well-established traditional knowledge have also used this agreement, with more or less effectiveness (McMichael 2001). In one widely publicized case, the US patent granted for the clotting properties of turmeric was revoked after a formal protest was filed by the Indian Council for Scientific and Industrial Research. However, in most instances (1) developing nations have been hard pressed to mount the necessary legal campaign to challenge such patents, and (2) cannot afford the high costs of mounting their own intellectual property enforcement systems.

---

3. All three agreements are available in their entirety at http://www.wto.org/english/docs_e/legal_e/final e.htm

2. Transport and communications technologies. The last several decades have seen sweeping changes in the fields of transportation and communications. Those changes can be summarized as follows:

   a. Transport costs have declined as fuel costs have declined and means of transport have become more efficient. This is especially true of air transportation. Thus, a greater portion of agricultural production is now shipped by air than ever before. Combined with the poor roads and limited rail transport available in much of Africa, this has contributed to the partial disconnection of urban areas from their hinterlands in many developing nations. Hotels, restaurants and even a significant portion of urban food supplies in many developing nations are now provisioned via imports even when the surrounding countryside has the potential to fulfill many of those needs.

   b. Communication costs have also declined. Older, land-based telephone lines are being replaced or supplanted by microwave transmissions. In many nations, cell phone usage is greater than land line usage, due to the difficulties involved in setting up land lines. Furthermore, the combination of fax machines, electronic mail and the Internet offer retailers new and much cheaper ways to interact with their suppliers.

      Of particular significance is the rise of e-commerce in foodstuffs. Whereas in the past brokers played an important role in connecting thousands of producers with a smaller but still significant number of supermarkets, e-commerce is rapidly collapsing the broker role. Brokers do well in spot markets, where they provide the important service of linking buyers and sellers. But in the new world of e-commerce, buyers, sellers and transporters can identify each other, discuss quantities, qualities, timing and price, and ship goods directly. Several large e-commerce networks are now operating in the food industry and they are growing rapidly.[4] They offer potential new ways for smallholders and smallholder associations to link to domestic urban and even foreign buyers. This may seem like a dream, but with declining technology costs, such systems will soon be affordable in small towns and in a decade or less even in remote villages. Moreover, their use need not be restricted to e-commerce; delivery of market information, warnings of drought and flooding and probably a number

4. See, for example, https://www.agribuys.com, and http://www.foodtrader.com/

of as yet unknown uses will emerge. By joining this communications revolution, developing nations should be able to leapfrog older technologies.

Together, these shifts in transportation and communication technologies are forcing a reorganization of food supply chains on a scale not seen since the invention of the railway changed urban provisioning nearly 200 years ago.

3. Growth of urban areas. At the same time, urban growth is changing the relations people have with the land. This growth is driven by a combination of push and pull factors. Drought, flooding, civil strife and war, and a host of other catastrophes are pushing people away from rural areas. Nomadic populations, always the bane of urban governments, are being settled as land is enclosed and nomadic lifestyles become unsustainable. However, as always, cities offer the possibility of wealth and income - a potential rarely realized, but often hoped for. Thus, virtually all cities in developing nations are surrounded by *bidonvilles*, *favelas*, or slums where those displaced from rural areas eke out a living. In most developing nations, the food supply networks have yet to respond to this marked transformation of the landscape.[5]
4. Growth of global middle class. Urbanization has also been linked to the rise of a new middle class in many developing nations. While the size of the middle class varies from country to country, its members share several important features. First, they are often self-consciously modern. They tend to imitate middle class western values and buy (at least some) middle class western foods and food products. Second, they are likely to demand more meat, dairy, fruit and vegetable products than their poorer compatriots. The result is that the demand for these products continues to rise, offering new opportunities and new challenges for agricultural research.

The new global food regime

The rise of the WTO, the improvements in transportation and communication and their reduced costs, the rapid urbanization of developing nations, and the growth of a global middle class have not gone unnoticed in the private sector. Indeed, like the automobile industry in the 1970s, the food industry has begun to take on a global flavor. Each of the three branches of the food industry - retail, restaurants and catering - is now global in scope.

5. For example, the metropolitan area of Sao Paulo, with some 20 million inhabitants, is still provisioned largely by a wholesale spot market. However, this is beginning to change.

In most industrial nations, a handful of supermarket chains dominate the retail scene. In the USA the top four retailers command 40% of the market. Four chains in the United Kingdom control 70% of the market. In Australia three chains have 70% of the market. Wal-Mart has become the largest supermarket chain in Germany.

But as recently as 10 years ago, supermarkets were largely confined to industrial nations. In a decade, the tide has turned. Today, no longer severely hampered by tariffs and quotas, supermarket chains are aggressively moving into middle and even low-income nations to radically alter the provisioning of urban areas with food. In Chile four firms control 66% of the market. In Kenya, two chains each have more than 20 stores and are expanding rapidly. Even Zambia has a supermarket chain with 18 stores (Giovannucci et al. 2001).

Moreover, large multinational companies are expanding by rapidly purchasing profitable local and regional chains, either in whole or in part. Thus, Dutch-based Royal Ahold, with about 10000 stores globally, is 50% owner of Pais supermarkets in Guatemala. French firm Carrefour is also active worldwide with about 10000 stores. And, Wal-Mart's growth is now largely outside the USA.

The strategy used by these firms is essentially the same worldwide. It consists of factors like geography, store size and market segmentation. Geographically, a presence is first established in major cities. Then, stores are opened in secondary cities and small towns. Stores range from hypermarkets, to supermarkets, to neighborhood convenience stores, depending on the size of the market. Furthermore, the market is rapidly segmented. While the upper end of the market is the most profitable, it is relatively small. Thus, once established, supermarkets have an incentive to move down the economic ladder while increasing the volume of sales.

While the profit potential is high, competition remains fierce and profit margins are low. A small decline in revenues can mean the difference between profit and loss. Thus, the expansion of supermarkets into developing nations is a daunting task. Of particular concern is sourcing of fresh products. Large supermarket chains want fresh products on the shelves 12 months of the year. They want product quality to remain constant throughout the year. And they want to minimize price fluctuations.

Furthermore, the very size of the supermarket giants makes them vulnerable to activist groups (largely in the first world) of all kinds. Thus, in addition to concerns about quality, supermarkets are increasingly concerned about food safety, environment, animal welfare and even labor issues. As a result, retailers and retailer associations have begun to promulgate their own standards.

The new standards regime

Although seldom recognized as more than either obscure technical details or means to reducing transactions costs, standards are a central feature in contemporary life. Standards govern virtually every product manufactured, every contract signed, every service rendered. In the past standards were highly local and oftentimes personalized; today standards govern the production and consumption of just about everything. In so doing, standards discipline our very lives. For example, a standard for flour is also a standard for mills and for the persons who operate those mills. A standard for millet is a standard for farmers who produce millet. There is no way that small farmers can enter mainstream commercial markets unless they can meet such standards.

Whereas in the past standards were focused largely on creating uniformity, and thus on reducing transactions costs (Hill 1990), many if not most of today's standards are aimed at product differentiation.[6] Standards may be used to guarantee authenticity (e.g. Kenyan tea). They may be designed to fulfill certain widely agreed upon functions (e.g. food safety). They may be designed to facilitate coordination (e.g. boxes designed to fit on pallets, pallets designed to fit on trucks). They may ensure the reputation of the company producing the product in question.

In addition, standards are now used strategically by both governments and firms (Perry et al. 1997; Caswell et al. 1998; Hayward et al. 1998; Vries 1999). For example, China has embarked on a deliberate policy to upgrade its standards for fresh and processed food products as a means of enhancing its overall economic standing (Krislov 1997). Firms also use standards to differentiate their products from those of other companies. Thus, far from being mere technical requirements, standards are implicated in the moral economy of our contemporary world (Busch 2000).

In part induced by the formation of the WTO and its several agreements, the global standards regime is changing. Or, to put it differently, an

6. Bowker and Star (1999) note that standards are a subset of the problems inherent in all classification systems.

international standards regime is emerging - one which has hardly been noticed in most developing nations. Let us examine this new standards regime.

International standards. International standards have been around for some time, but until recently they have been largely voluntary. Whoever sat around the table when standards were formulated was able to participate in their development, but anyone was free to ignore the standards. This all changed with the creation of the WTO and its de facto enforcement of standards. In particular, standards promulgated by the Codex Alimentarius,[7] the International Plant Protection Convention[8] (IPPC) and the Office international des epizooties[9] (OIE) have become de facto mandatory. Together, these standards limit what can be traded internationally based on food safety, phytosanitary and animal health.

Industry standards. But despite the renewed interest in public international standards, it is the new private standards regimes that are likely to have the most profound effect on global food procurement and trade (Brunsson and Jacobsson 2000). Consider some of the private sector initiatives that complement and sometimes eclipse the public standards.

CIES, the global association of food retailers and processors, has established its own food safety standards.[10] These standards are designed to allow retailers to reduce costs incurred in meeting multiple international and national standards with respect to food safety by adhering to a single metastandard that combines requirements from all major food importing nations.

COLEACP, the Liaison Committee Europe Africa Caribbean, Pacific, is a private voluntary organization consisting of exporters and importers supported by the EU and charged with adherence to rules regarding maximum pesticide residue levels.[11] It is an interesting example of private enforcement of public standards. Exporters and importers are interested in joining with COLEACP because it leaves control in the hands of the private sector with only minimal government oversight. At the same time, governments like it because it relieves them of most of the costs of enforcement.

7. http://www.codexalimentarius.net
8. http://www.ippc.int/
9. http://www.oie.int
10. http://www.ciesnet.com/
11' http://www.coleacp.org

The Euro-Retailer Produce Working Group (EUREP) is an association of supermarket chains that have agreed to require minimum quality, safety, environment and labor standards in their purchases.[12] EUREP is important because it is in large part a proactive response to demands of consumers that go far beyond food quality.

The International Organization for Standardization (ISO) formulates standards for various tests used in measurement of food standards. These tests are all the more important as (some) food standards have become far more scientific than was the case in the past. Furthermore, ISO formulates managerial standards (ISO 9000) and environmental standards (ISO 14000).[13] Retailers frequently require adherence to these ISO standards as a mark of good agricultural or manufacturing practice among suppliers.

Finally, Social Accountability International has successfully developed its SA 8000 standards for human rights, including child labor, forced labor, health and safety, freedom of association, working hours and remuneration.[14] SA 8000 standards move what were once solely political issues into the economic arena.

A critical aspect of these proliferating private standards is the use of third party certification to ensure adherence to standards. Thus, literally thousands of third party certification firms have sprung up world wide, certifying everything from food quality to animal welfare to organic rules to non-use of hormones to cleanliness of packing facilities. Retailers prefer third party certification because it avoids directly policing suppliers and, at the same time, allows them to deflect criticism in the event of a failure in standards enforcement. However, third party certification can be quite expensive, involving, for example, flying a team of certifiers from Europe to Africa to inspect farms and pack sheds.

Of course, industry standards do not preempt the standards of individual firms. Those standards can and do include the types of packaging used, the degree of ripeness of fresh products, the time spent in transport and the form of private labels. For example, companies may specify the use of recyclable plastic crates for produce, even going so far as to specify the type and color of plastic to be used. Those wishing to sell to the rapidly growing global retail food industry must conform to these standards as well.

---

12. http://www.

13. http://www.iso.ch

14. http://www.

National standards. This is not to say that national standards are no longer relevant. Instead, national standards have tended to shift from direct inspection and monitoring (with varying degrees of effectiveness from nation to nation) to indirect surveillance. For example, whereas on-site inspection by government agents was once the norm, Hazard Analysis and Critical Control Points (HACCP), now commonly used in meat and seafood industries, requires continuous monitoring of production processes and maintenance of records for audit by government inspectors. In the USA, the Food and Drug Administration only inspects some 2% of all imported food products. But, especially in nations with weak food control authorities, it is the private sector that often is responsible for inspection.[15] In those instances, some attention may be paid to accrediting of certifying bodies. However, little is known about these procedures.

One exception to the shift to industry and private standards is the area of plant pests. As these usually do not affect humans, they are of relatively little concern to retailers. Governments remain the enforcers of these standards. US phytosanitary standards are of particular significance for African nations. Several years ago the USA opened its markets to a wide range of African agricultural products under the African Growth and Opportunity Act (AGOA). But most African nations have few products approved for importation by the Animal and Plant Health Inspection Service (APHIS). There is little or no evidence that APHIS deliberately seeks to bar admission of African agricultural products to the USA, but the costs and time involved in performing the necessary tests to add items to the list can be daunting for most African farmers, firms and nations. European Union plant quarantine requirements tend to be less restrictive as many of the pests common in Africa are common in Europe as well. But, here too, phytosanitary restrictions can sometimes be burdensome.

Meeting these new and emerging standards, both public and private, will not be easy. Moreover, by not being at the table when standards are formulated, developing nations risk being on the short end of the stick. The magnitude of the problem is made clear in a recent article that notes that revised EU rules on maximum levels of aflatoxin in foods will save approximately 1.4 deaths per billion while it will cost Africa US$ 670 million in lost exports (Tsunehiro et al. 2001).

---

15. Of course, such inspections are not random, Frequent offenders, particularly vulnerable products, and suspect nations can expect more careful and more frequent inspection.

This new world of supermarkets and global commerce offers both new opportunities and new threats to farmers, including those of the semi-arid tropics. Quite obviously, if farmers cannot meet the new standards, they will find themselves pushed out of the marketplace. But if they can, or more precisely, if they are helped to meet those standards, several new options open to them. Each of these markets offers new opportunities and new challenges for research. They include:

(1) Participation in the growing organic market (e.g. growing fruits or nuts without using chemicals). Organics are gaining market share rapidly in both the EU and the USA. Organic production can sometimes take advantage of the lack of chemical inputs into agriculture, and can use labor to replace chemicals. But success in organic markets requires both meeting organic standards and all the other requirements of the retailers.

(2) Selling through fair trade organizations (thereby taking advantage of the political commitments of at least some consumers). These organizations offer the significant advantage of higher prices paid by committed consumers. However, to date much of the sales have been to special fair trade stores (e.g. Max Havelaar), which carry only a limited range of non-perishable merchandise.

(3) Developing products for niche markets (e.g. including tropical fruits, nuts, and vegetables not widely consumed in industrialized nations). Such products can offer special opportunities to smallholders because they can often provide more labor for the crop than larger producers. However, just because smallholders can produce it, does not mean that there is a market for it.

(4) Participating in overseas ethnic markets (e.g. tapping the buying power of American, British, or French citizens of African origin). Ethnic markets can and do appeal to those who maintain a certain solidarity with their native land. As such, they can command higher prices for products that might not otherwise be exportable. Moreover, ethnic markets can be used as an entree into larger mainstream markets. However, here too, ethnic affiliation is not a substitute for quality.

Challenges for agricultural research

In sum, the global agri-food regime is changing at an astonishing pace. Food retailing, once quite specific to a given country, is now a global business.

Food standards, once the province of government, are more and more used by the private sector to gain market share. This poses a considerable challenge to national agricultural research systems (NARS) and to the international agricultural research centers (IARCs). I suggest that there are five challenges facing both NARS and IARCs, challenges which must be addressed along with both declining funding and an expanded mission (including, for example, environment, natural resource and sustainability issues):

1. Move from grain to higher value products. Today, even as some residents of the semi-arid tropics find it difficult to provide for their families, the world is awash in a sea of grain. In part due to the disgraceful and unending subsidies to the wealthy provided by the USA and the EU, farmers there continue to produce far more than the market demands. Moreover, recent advances in biotechnology and genetic engineering, although of relatively minor significance with respect to yields, are driving down costs of production by reducing expensive herbicide and insecticide applications (Ervin et al. 2000). At the same time, Argentina and Brazil are ramping up grain and oilseed production. In the case of Brazil, whole new areas of virgin land in the Matto Grosso are being opened to soybean production. Furthermore, we would do well to remember that the center of the global grain trade in 1900 was Hungary - where grain from the European breadbasket of the Ukraine, Poland and Russia was funneled to Western European markets (Buller 1919, Smith 1908). As these nations re-enter the global economy, there is little doubt that they too will contribute to a worldwide grain glut.

   At the same time, the successes of the Green Revolution, combined with the massive migration of people to urban areas, have transformed the landscape in developing nations. Today, there are very few true subsistence farmers. Even poor farmers in the semi-arid tropics engage in a wide range of activities to earn their livelihood. Subsistence farmers can and have benefited from increased yields of staple crops, such that they were able to increase their caloric intake. However, once self-provisioning is reached, surplus production must be sold in the marketplace. Given the worldwide surplus of grain and the concomitant low prices, farmers are unlikely to get much money for their surplus. Put differently, while increased yields can be enormously helpful to subsistence farmers who cannot meet caloric needs, it is impossible to produce one's way out of poverty. Poverty must be tackled by shifting from subsistence crops to crops that can be marketed. This brings me to the second challenge.

2. Meet urban demand in developing nations. As the world's population becomes more and more urban, meeting the food needs of these populations becomes more and more complex. Currently, major cities in developing nations are home to overflowing street markets. Often, urban consumers cannot find the traditional horticultural products at prices that they can afford or of a quality that is edible. With respect to cereals and oilseeds, they are often confronted with a choice between cheap, processed grain products imported from other parts of the world and unprocessed local grains of inferior quality. Moreover, imported food products often have extra prestige associated with them. They proclaim that the consumer is modern, is indeed a consumer. Given this, it is no surprise that they shift their diets toward those of the Western world. This brings me to the third challenge.

3. Add value through processing. Despite many years of agricultural research, post-harvest processing of SAT staple crops remains limited (Hulse 1995). One need only look at the vast range of wheat- and rice-based products to see the extraordinary difference. Sorghum-based breakfast products are to be found in a few nations. But in many more, even basic milling is often done by hand. Pearl millet poses even greater challenges due to its high oil content. Developing shelf-stable processed and semi-processed products remains a major research and marketing challenge. The same could be said of fruits and vegetables. Vast quantities of common fruits such as mangoes and citrus rot each year for lack of adequate post-harvest processing facilities. While some of this could be improved with existing technologies, there is considerable room for low-cost, effective, on- or near-farm preservation technologies. Moreover, such post-harvest processing has the potential to provide thousands of badly needed jobs. But there is no particular reason to set one's horizons solely on the domestic and local market.

4. Meet supermarket standards and specifications. Recent changes in the governance of world trade have opened a wide range of new opportunities for SAT farmers to market products to supermarkets. Global giants in the food retail business have emerged, including Royal Ahold, Wal-Mart, Carrefour and Tesco. These retailers have hundreds if not thousands of stores worldwide and desire to source products with specific qualities year-round. However, meeting their standards for quality, food safety and even environmental and labor conditions is no easy task. It will require significant research on both the production process as well as the organization of the entire supply chain.

5. Build alliances with producers in industrial nations. In the past, farmer groups were entirely national in scope. Today, however, that situation is changing rapidly. Farmers in industrial nations are forming strategic alliances with farmers in developing nations. Farmers in the northern hemisphere are allying themselves with farmers in the southern hemisphere. For example, a Michigan-based cooperative has members in Guatemala. Washington (US) apple producers have an alliance with Chilean producers. Producer-owned processing operations in industrialized countries are sourcing products in developing nations to create wholly new products (e.g. dried fruit and nut mixes with ingredients from around the world). Developing such alliances can be quite beneficial to farmers in the semi-arid tropics by providing access to markets previously deemed impenetrable. Finally, there is the greatest challenge of all.

6. Do all of this without squeezing (too many) farmers out of the market and without abandoning those farmers who still cannot produce enough to feed their families. There is little dispute that as farmers enter local and global markets for horticultural products, some will succeed while others will fail. The experience of every industrialized nation is nearly the same even if the precise causes are different: as industrialization and urbanization took place, employment in agriculture declined. The same will surely happen in developing nations. The challenge is to ensure that this happens slowly, such that there is ample time to develop other job opportunities - including those in input supply and food processing and marketing. If this happens too rapidly, it will cause major social and political upheavals.

References

Bonanno, A, Busch, L, Friedland, W H , Gouveia, L and Mingione, E (Eds.). 1994. From Columbus to ConAgra: The globalization of agriculture and food. Lawrence, KS: University of Kansas Press.

Bowker, Geoffrey C, and Star, SL. 1999. Sorting things out: Classification and its consequences. Cambridge, MA: MIT Press.

Bromley, Daniel W. 1997. Rethinking markets. American Journal of Agricultural Economics. 79:1383-1393.

Brunsson, Nils, and Bengt Jacobsson (Eds.). 2000. A world of standards. Oxford: Oxford University Press.

Buller, Reginald A H . 1919. Essays on wheat. New York: The Macmillan Company.

Busch, Lawrence. 2000. The Moral Economy of Grades and Standards. Journal of Rural Studies 16:273-283.

Caswell, Julie A, Bredahl, Maury E and Hooker, Neal H. 1998. How quality management metasystems are affecting the food industry. Review of Agricultural Economics 20:547-557.

Ervin, David E, Batie, Sandra S, Welsh, Rick, Carpentier, Chantal L, Fern, Jacqueline I, Richman, Nessa J and Schulz, Mary A. 2000. Transgenic crops: An environmental assessment. Washinton, DC: Henry A. Wallace Center for Agricultural and Environmental Policy at Winrock International.

Giovannucci, Daniele P, Sterns, Patricia Aust, Eustrom, Michael and Haantuba, Hyde. 2001. The impact of improved grades and standards for agricultural products in Zambia. East Lansing, MI: Michigan State University and United States Agency for International Development, PFID-F&V Report No. 3.

Hayward, David J, Le Heron, R, Perry, M and Cooper, I. 1998. Networking, technology, and governance: Lessons from New Zealand horticulture. Environment and Planning A 30:2025-2040.

Hill, Lowell D. 1990. Grain grades and standards: Historical issues shaping the future. Urbana, IL : University of Illinois Press.

Hulse, Joseph H. 1995. Science, agriculture, et Securite Alimentaire. Ottawa: Les Press Scientifiques du CNRC.

Jukes, David. 2000. The role of science in international food standards. Food Control 11:181-94.

Krislov, Samuel. 1997. How nations chose product standards and standards change nations. Pittsburgh: University of Pittsburgh Press.

McMichael, Philip. 2001. The impact of globalization, free trade and technology on food and nutrition in the new millennium. Proceedings of the Nutrition Society 60:215-220.

Perry, Martin, Le Heron, Richard, Hayward, David J and Cooper, Ian. 1997. Growing discipline through total quality management in a New Zealand horticultural region. Journal of Rural Studies 13:289-304.

Smith, Rollin E. 1908. Wheat fields and markets of the world. St. Louis: The Modern Miller Company.

Tsunehiro, Otsuki, Wilson, John S and Sewadeh, Mirvat. 2001. Saving two in a billion: quantifying the trade effect of European food safety standards on African imports. Food Policy 26:495-514.

Vries, Henk de. 1999. Standardization: A business approach to the role of national standardization organizations. Boston: Kluwer.

Food security challenges in sub-Saharan Africa: The role of research and development

Howard K Sigwele[1]

Food security in context

Assuming food security refers to physical and economic access to nutritious food to all people at all times for a healthy and productive life (World Food Summit 1996), agricultural research and development (R&D) and international institutions such as ICRISAT can play a significant role in achieving household and national food security.

On the physical / supply side, R & D can improve productivity through the development and adoption of appropriate technologies (varieties, hybrids, post-harvest processing etc). On the economic/demand side, increase in productivity at farm/household levels also implies increase in per capita incomes that could enable households to purchase/import food. Increased productivity could also generate additional employment opportunities through forward and backward linkages between farming and the rest of the economy following the adoption of technologies in both primary production and processing (Ehui and Delgado 1999).

Achieving national food self sufficiency through domestic production, holding physical stocks does not necessarily imply household food security as several households are net buyers of food and are very poor to produce enough food for themselves or unable to import sufficient quantities to meet daily requirements for a healthy and productive life. In fact in several countries that are food self-sufficient in basic products, hunger and malnutrition still persist due to mainly household and individual poverty (Sigwele 1993, World Food Summit 1996). In short, food availability/physical access does not translate into household food security primarily because of poverty and a limited resource base.

R & D can therefore play a major role in food security. Below is a list of thematic areas where such institutions can play a pivotal role in food security assuming stakeholders are actively involved in R & D policy development and implementation.

1. FANRPAN, Harare, Zimbabwe.

Poverty reduction and improvement in productivity

- At least 40% of poor people are based in rural areas. Female-headed households are some of the most income and food insecure. Urban food and income insecurity are also increasing rapidly.
- Agricultural productivity is very low and output enhancing technologies arenot adequately adopted.
- Low adoption of technologies due to limited resources, inappropriate sectoral and macro-economic policies (pricing, marketing, exchange and interest rates, taxation, input supply, inconsistency in policies and role of public versus private sector etc) (Krueger et al. 1988).
- Productivity has been almost stagnant for the last three decades (see Tables 1 and 2). Crop yields and yields of meat/milk per animal are still very low.
- Low productivity leads to high input cost per unit of output and therefore low per capita farm incomes. Schematically, the increase in yield/productivity leads to the improvement in per capita incomes which in turn lead to the society/ economy investing back in farming to raise productivity (Figure 1).

Sub-Saharan Africa has had almost stagnant yields and productivity in both the crop and livestock sub-sectors over the past two decades (Tables 1 and 2). For institutions like ICRISAT specializing in semi-arid tropical areas, it is important that biotechnologies in millet, sorghum, pulses etc. significantly increase farm yields and productivity to raise per capita household incomes.

Table 1. Trends in crop area, yield and output in sub-Saharan Africa, 1970-2000.

Crop	Harvested Area 2000 (m ha)	Yield 2000 (t/ha)	Production 2000 (m tons)	Average Annual Change 1970-2000 (%) Area	Yield	Production
Rice	7	1.6	11	2.4	0.6	2.9
Maize	26	1.5	38	1.5	1.2	2.7
Millet	20	0.7	14	1.4	0.4	1.8
Sorghum	21	0.8	18	1.2	0.5	1.6
Oil crops	24	0.3	6	0.9	0.7	1.6
Roots and tubers	18	8.4	154	1.7	1.0	2.8
Pulses	16	0.4	7	1.6	0.2	1.9
Vegetables	3	6.6	22	1.9	0.8	2.6
Fruits	6	6.2	47	1.6	0.0	1.6

Source: FAOSTAT 2001.

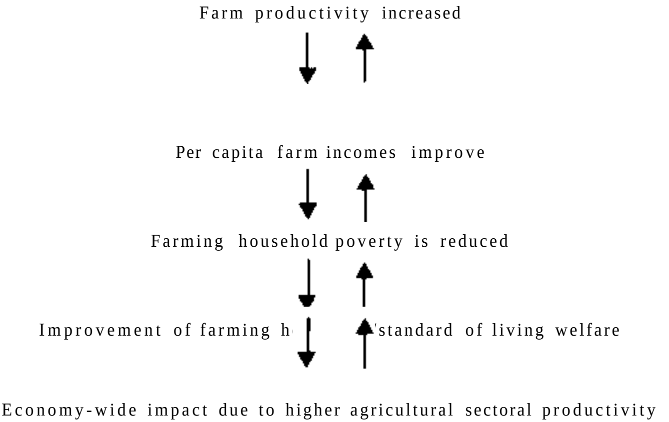


Figure 1. Relationship between yield/productivity and per capita incomes.

This would result in reducing the cost per unit of output to benefit farming and other sectors of the economy. It is therefore in the long-term interest of international research organizations working with national institutions to strive tirelessly to improve farm productivity in order to raise per capita incomes and therefore improve both household and national food security.

Table 2. Trends in Livestock Populations and Output in Sub-Saharan Africa, 1970-2000.

Species	Heads (in million) 2000	Average annual change 1970-2000 (%)
Cattle	219	1.5
Sheep	189	1.4
Goats	194	23
Pigs	19	3.2
Poultry	809	2.9
Product	Output 2000 (million tons)	Average annual change (%)
Total meat	8	20
Total milk	19	1.8
Total eggs	1	3.7
Cattle hides	0.5	1.7

Source: FAOSTAT 2001.

Enhanced economic benefits/impact from R&D

As farming productivity is increased and cost per unit of output in agriculture declines, other sectors of the economy benefit. Specifically most poor households and workers spend up to 50% of their disposable income on food. If food becomes relatively cheap, not only do households have an opportunity to save but also the demand for other goods and services in the rest of the economy is created.

In particular, food related wage cost increases in the economy are likely to decline which directly or indirectly could reduce costs in other industries of the economy. Agriculture is the mainstay of most sub-Saharan countries hence productivity gains in the sector creates opportunities for growth and diversification to generate additional employment in agro-processing enterprises and allied activities (Ehui and Delgado 1999).

Further, applications of technical change in the economy also affect the input/output price ratios. As farm products become cheaper due to increased productivity, the demand for certain factors in farming declines and this allows for the free movement of factors to other sectors of the economy. Factors like labor and capital might become cheaper as productivity in farming is increased by R&D. The movement of factors outside farming creates demand for agro-processing, diversification and growth in the economy as well as trade (Ehui and Delgado 1999). Increased trade generates additional foreign earnings for economic diversification and the purchase of inputs and more productive technology.

ICRISAT and similar R & D organizations can help develop technologies not only to benefit primary agriculture, but also processing, post-harvest industries that generate additional income, and employment opportunities to improve overall social welfare. R & D efforts should therefore be geared towards primary agriculture, and measures should be taken to develop technologies to benefit agro-processing and post-harvest industries to diversify the economy and create strong forward and backward linkages in the economy. There are major income and expenditure linkages between agriculture and the rest of the economy in most sub-Saharan countries. Available social accounting matrices (SAMs) for most countries underscore very strong income and expenditure linkages in the economy. A SAM is a comprehensive and consistent database/table that illustrates in an economy a circular flow of income and expenditure as well as factor income distribution and structure of the economy.

With increased private sector participation in the economy primarily through privatization and market liberalization, it is possible for R&D organizations to forge strategic alliances with private companies to promote agro-processing.

Enhance the role of biotechnology in food security

According to the Food and Agriculture Organization of the United Nations (FAO), biotechnology refers to "any technological application that uses biological systems, living organisms, or derivatives thereof to make or modify products or processes for specific use" (FAO 2002). The development of crop varieties and hybrids should comply with the FAO definition. However, over the last few years, there has been serious concern and fears over the use of genetically modified organisms (GMOs) to produce consumable commodities like maize, tomatoes, cotton, rice etc.

Fears are based on risks such as human safety, animal and plant life, transfer of toxins from one life form to another, the development of very aggressive weeds which may not be controllable as well as the loss of biodiversity (FAO 2002).

While ICRISAT is currently not engaged in GMO technology, it is important that farmers, food processors, consumers etc. are informed about the safety and health aspects of the products from R&D organizations.

At least the SADC Ministers of Agriculture and Natural Resources have agreed that a GMO legislation be in place in all countries and that information be provided to consumers and guidelines be developed to protect human beings, animal and plant life from the risks identified. FANRPAN will monitor this development in SADC to improve food security.

FAO, the World Health Organization (WHO) and Codex have established a committee to advise countries on biotechnology and GMO technology.

Whilst acknowledging the risks associated with GMO technology, there is potential to use this technology to increase farm productivity and develop marginal lands with appropriate technologies. Already GMO technologies in conservation, rice, maize, tomatoes and cotton are available to improve food security; and safety assurances are guaranteed to consumers.

Expand income diversification

By and large, agriculture in most sub-Saharan Africa countries is dominated by mixed farming. Consequently, farmers consider their various enterprises as a system to spread risks. In fact, "farmers typically view their farms, whether small subsistence units or large corporations, as units in their own right." (FAO 2001, p.7). Organizations whose mandate is mainly crop-based should ensure synergy among existing farming and non-farming enterprises at a household level. For instance the current mandate of ICRISAT does not necessarily exploit the livestock and cropping linkages, and off-farming activities.

Diversification of enterprises at a farm level not only minimizes production and income risks, it is itself insurance in the event some activities are affected adversely by poor climatic and market conditions. It is however, gratifying to note that ICRISAT is also exploring the development of livestock-crop linkages in its technology strategy. Developing technologies that exploit the already existing farming linkages and production mix will spread risks among farmers and possibly improve prospects for technology adoption. The millet, sorghum and legume farming systems that ICRISAT promotes are already operating under mixed production systems that also include livestock (cattle, sheep, goats, poultry etc), veldt products and yet biotechnologies developed by ICRISAT tend to ignore livestock-crop-veldt products relationships.

Assist to minimize the social costs of HIV/AIDS

The HIV/AIDS scourge has adversely affected sub-Saharan Africa. Besides huge losses of human capital, income, investment, savings and economic growth, the scourge is likely to affect the region's trade competitiveness and overall productivity, as skills, knowledge etc. are lost due to high mortality rates. The FANR sector will also be greatly affected, as technologies will not be easily developed due to budgetary constraints and a loss of technical, research and managerial skills. Labor supply is already reported to be a serious constraint in many SADC countries because of the continued absence from work due to sickness and death. Potential R&D investment in farming is diverted to medical expenses to contain HIV/AIDS. For institutions like ICRISAT, technologies that require less labor but still improve food security will be critical to minimize the social costs of HIV/AIDS. Both production and agro-processing technologies by ICRISAT together with national R&D institutions will need to explore labor saving techniques. Labor and capital are going to be increasingly scarce due partly to the HIV/AIDS pandemic.

In summary, institutions like ICRISAT supported by national R&D centers can play a role in improving food security and per capita farm incomes. Complimentary policies in infrastructure, extension, macro-economic environment, stakeholder/private sector participation in the FANR sector are also crucial for technology to raise incomes. Equity issues are also critical in R&D process lest countries aggravate income inequalities without corresponding policies to improve the marginalized farmers (World Food Summit, 1996, World Bank 2001).

FANRPAN's response to some of the food security challenges

On HIV/AIDS, FANRPAN is mobilizing funds on behalf of SADC to undertake an HIV/AIDS impact study in the FANR sector with a view to formulating appropriate household, sectoral, national and regional strategies. Studies will be carried out at these four levels. Both partial and economy-wide models will be used to analyze the impact of the disease. Competent regional and international policy research institutes will participate in the study.

On income diversification, FANRPAN is currently undertaking a "Trade Policy Study" to identify constraints to increasing regional agricultural growth and trade and potential tradables in each country to promote food security and integration. There are potential commodities like cowpeas, cassava, vegetables, spices etc. where intra-regional trade is very small and yet the markets could be developed with ease. Traditional traded commodities like maize, wheat and sorghum will continue but supply and demand situations also dictate the need to develop substitutes.

Finally, on communication and information, FANRPAN has a bimonthly newsletter, The Dialogue, which is used to disseminate information about policy changes, technology improvements, trade and conservation matters.

In conclusion, FANRPAN wishes to collaborate with institutions like ICRISAT to improve food security, farm productivity and contribute towards poverty reduction.

References

Altshul, HJ. 1998. *The impacts of post-harvest crop research on poverty alleviation:* Two *case studies from Northern Ghana.* Natural Resources International, Ltd, U.K.

Ehui, S and Delgado, C. 1999. Economy-wide impacts of technological change in agro-*food production and processing sectors in sub-Saharan Africa.* IFPRI, Washington, D.C, USA.

FAO. 2001. Statement on biotechnology. Rome, Italy, 2001.

FAO. 2001. *Farming systems and poverty: Improving farmers' livelihoods in a changing world.* FAO, Rome, Italy, 2001.

Freeman, HA, Rohrbach, DD and Ndjeunga, J. 2002. *The future of agriculture in the semi-arid tropics of Africa: An issues paper.* ICRISAT, Nairobi, Kenya.

Krueger, A, et al. 1988. *Agricultural incentives in developing countries: Measuring the effects of sectoral and economy-wide policies.* World Economic Review, Vol.2, pp 255- 271.

Sigwele, HK. 1993. *Food self-sufficiency versus food security.* Ministry of Agriculture, Botswana.

Sigwele, HK. 2001. Policy constraints affecting technology adoption in SADC: FANRPAN's potential role in linking and informing research and policy institutions. Paper to CIMMYT Workshop, Nyanga, Zimbabwe. December 3-4, 2001.

Weber, M, et al. 1988. *Informing food security decisions in Africa: Empirical analysis and policy dialogue.* American Journal of Agricultural Economics, pp 1045- 1052.

World Development Report. 2000/2001. World Bank, Washington, D.C, USA.

FAO. 1996. *World Food Summit.* 1996. FAO, Rome, Italy.

Annexure

About FANRPAN

FANRPAN, the Food, Agriculture and Natural Resources Policy Analysis Network is based in Harare, Zimbabwe. It was established in 1994 by the first Conference of Ministers in Agriculture of Eastern and Southern Africa. A full-time Secretariat was established only in May 2001 due to shortage of funds. It is an Autonomous organization in the region with legal personality and a "constitution".

FANRPAN operates in eight countries - Botswana, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe.

Lesotho, Mauritius, Seychelles and Swaziland are making preparations to join shortly; Angola and the Democratic Republic of Congo (DRC) will follow. The network is donor funded and currently depends on the United States Agency for International Development (USAID). Efforts are being intensified to diversify funding.

Board composition

• Botswana	FANR Ministry/Government
• Malawi	FANR Ministry/Government
• Zimbabwe	Private Sector
• Mozambique	Private Sector
• Tanzania	Policy Researcher
• South Africa	Policy Researcher
• Namibia	Farmers' Union
• Zambia	Farmers' Union
• USAID	Donor
• French Government	Donor
• SADCFANR Directorate	
• FANRPAN Coordinator/Executive Director - an ex-officio member	

A Five Year Strategic and Business Plan with core functions were developed. A communications strategy also developed to support the plan.

Technical committee

FANRPAN has established a technical committee to:

1. Consider and approve research proposals;
2. Set guidelines for appraising project proposals;
3. Maintain and monitor quality standards in FANRPAN' s products and services; and
4. Review papers, policy briefs.

FANRPAN'S Vision

We strive for excellence and to become a distinguished leader in policy research, analysis and coordination in food, agriculture and natural resources by 2020.

FANRPAN'S Mission Statement

FANRPAN's mission is to coordinate, influence and facilitate policy research, analysis and dialogue at the national, regional and global levels in order to develop the Food, Agriculture and Natural Resources sector through networking, capacity building and generation of information for the benefit of all stakeholders in the SADC region.

Objectives

- Promote appropriate agricultural policies in order to reduce poverty, increase food security and enhance sustainable development;
- Improve policy analysis, research and formulation of SADC research themes;
- Develop human and institutional capacity for coordinated dialogue among stakeholders;
- Improve policy decisionmaking through the generation, exchange and use of policy related information.

Key regional thematic areas by stakeholders

- Technology development and adoption so as to raise productivity and farm incomes.
- Specialization to improve efficiency and competitiveness based on natural resource advantage.
- Trade and market liberalization to improve access and investment opportunities across borders through removal of barriers.
- Capacity building to improve productivity and competitiveness.
- Stakeholder participation to improve relevance and appropriateness of policies and programs.
- Natural resource management for sustainable development.
- Information and communication management to information dissemination and feedback.
- Impact of HIV/AIDS on agriculture and natural resources.
- Land reform, access and poverty reduction.

Characteristics of the Southern African Development Community (SADC) region

- The SADC region is the poorest in the world accounting for less than 2% of global gross domestic product (GDP).
- The region accounts for about 10% of the world population. At least 40% of the population is based mainly in the rural areas and lives below the poverty datum line (daily per capita consumption of less that US$ 1.00). Absolute poverty is on the increase in this region.
- In general, agriculture accounts for about 30% percent of GDP, and 40% of exports.
- Agriculture employs about 70% of the population.
- Value-added production/agro-processing is very limited.
- There is poorly developed physical infrastructure hence high marketing and transportation costs.
- Limited active participation by non-governmental organizations in policy process, design, implementation, evaluation, hence poor policy ownership by stakeholders.

Gender dimensions in SAT's agriculture and their implications on research

Charity Kabutha[1]

Introduction

Africa's agricultural sector has performed poorly during the last three decades, moving from food self-sufficiency to dependence on external resources for one-fifth of its food. It has recently been described as a continent "uniquely vulnerable to food security" (Cohen 1995, cited in Blackden and Bhanu 1998). The sector's dismal performance has taken place in spite of substantial investments in national and international research organizations. This suggests that investments in agricultural research have not had a significant impact on the performance of the agricultural sector. This not withstanding, research continues to be viewed as a vehicle for growth and poverty alleviation in sub-Saharan Africa. Jiggins (1986) expressed a similar view that when the first international agricultural research centers (IARCs) were established, it was thought that their work "would help developing countries meet their aggregate food requirements through creation of an output surplus and a distribution of food and income such that malnutrition and hunger would be reduced". The fact this dream has not been realized is starkly reflected in Africa's food deficits over the last 30 years. Hyden's (1986, p.ll) summary indicated that in the 1970s, when Africa's population was expanding at an average annual rate of 2.8%, total food production in Africa was increasing at no more than 1.5%; food self-sufficiency ratios dropped from 98% in the 1960s to approximately 86% in 1980. On average, each person had about 12% less homegrown food in 1980 than they had 20 years earlier. With food production stagnating and demand, particularly for cereals, keeping pace with population growth, the volume of food imports between 1970 and 1980 increased by an average of 8.4%. In 1980, imports of food grains alone reached 20.4 million tons, costing African countries over US$ 5 billion (not including high ocean freight costs). Although food aid in Africa was 1.5 million tons (Blumberg 1992), large numbers of people remained hungry. Quisumbing et al. (1995) the figure of the world's hungry as 800 million people - all living in the developing world. Today, over 300 million of the hungry

1. Nairobi, Kenya.

are found in the semi-arid tropics (SAT), which is home to 850 million (or one sixth) of the world's population (ICRISAT 2000).

Outside research, other factors, including poor infrastructure, marketing difficulties, fluctuating prices and social constraints complicate the overall picture. Gender is one of these social factors, one with potential to negate or transform Africa's food security situation. Productive resources necessary for improving the performance of the agricultural sector are gender-based and in this design, women are highly disadvantaged despite their major role in food production in sub-Saharan Africa. It is in appreciation of this fact that Jiggins (1986) argued that food insecurity would continue as long as women's roles in agricultural production and food systems continued to be ignored or underestimated. Similar views were expressed by Blackden and Bhanu (1998). They argued that, if sub-Saharan Africa is to achieve equitable growth and sustainable development, one necessary step is to reduce gender inequality in access to and control over a diverse range of productive, human and social assets. The report recognizes that reducing gender inequality - a development objective in its own right - increases growth, efficiency and welfare.

In supporting Africa develop its agricultural sector, organizations recognize the multiple difficulties that militate against sustainable productivity. ICRISAT, a major actor in the semi-arid parts of Africa, fully recognizes the challenges ahead. Its mission is to "alleviate poverty and hunger, develop technologies for sustainable increases in food production, control plant pests and diseases and protect the environment through better management of natural resources". ICRISAT's commitment to development with a "human face" underscores the importance of bringing into focus social factors that form part of the solution to Africa's food challenge. Gender is a major consideration in this new thinking.

This paper examines the relevance of gender in agricultural research and development, gender-based constraints and their implications on agricultural technology development and management. It concludes by exploring ways of mainstreaming gender in research. This paper has not confined itself to the SAT, but borrows relevant examples from the medium and high potential areas of sub-Saharan Africa, examples that have application in the semi-arid areas. The paper however makes reference to some of the unique features of gender issues in SAT, features which include the dominance of men in agriculture, including the food sector while women have separate plots on which they grow food but provide labor in plots owned by men.

The gender concept

Gender is a household resource and power relationship between men and women and is characterized by negotiation and conflict. Gender is used as a socio-economic variable to analyze roles, responsibilities, constraints and opportunities of those involved in development. A gender perspective in development sees women and men as playing different roles in society, and therefore, having different needs.

Almost in all cases, gender relationships are unequal, with men wielding more power and authority than women in the spheres of production, reproduction and decision-making inside and outside the household. It is reflected in the different roles, responsibilities and entitlements for men and women. Gender is part of household dynamics that are socially constructed and not derived from nature or biology as often erroneously assumed. With the increasing recognition of the importance of household relationships in food production, the traditional view of households as homogenous units with pools of resources available to all members of the household and to which all members contribute has been challenged. Households are characterized by deeply unequal sharing of resources, benefits and responsibilities, a situation that negatively affects agricultural technology adoption and productivity.

Gender is dynamic, changes with time and is culture specific. Gender is not synonymous with sex since sex is a fact of biology that differentiates people on the basis of male and female. It is universal and does not change.

Gender is associated with many other concepts such as Women in Development (WID), Gender and Development (GAD), gender equity and equality, practical and strategic needs among others. Some of these concepts are briefly discussed in Annexure 1.

Why gender matters

It is now widely accepted that gender matters in development, a view backed by economic and social facts, particularly in agriculture as demonstrated below.

Women and men are active participants in African agriculture

In a region where both men and women work together in agriculture, targeting both becomes a prerequisite for success. Estimates from the Food and

Agriculture Organization of the United Nations (FAO 1985) show **that** women account for more than half the labor required to produce three-fourths of food in sub-Saharan Africa. Aggregate data suggest that African women perform about 90% of the work of processing food crops and providing household water and fuelwood, 80% of food storage and transport from farm to village, 90% of hoeing and weeding and 60% of harvesting and marketing (FAO 1985; World Bank 1989 cited in Quisumbing et al. 1995). In 1989, the World Bank presented a similar situation for Kenya (Box 1). It is, however, important to recognize that there are major variations within the continent. In the Sahel region for example, men predominate in agriculture, including the food sector while women have separate plots on which they grow household food while at the same time providing labor on plots owned by their husbands. In much of eastern Africa, women dominate the food sector. What this means is that gender relationships and patterns are area specific and a situation in one area cannot be generalized.

Box 1.

"Development depends considerably on the productivity of women farmers. Agriculture is the core of Kenya's economy, smallholdings are the core of Kenyan agriculture, and women are the core of the smallholders.... Smallholder agriculture accounts for three fourths of the total production (agriculture contributes about one third of GDP}, including most major cash crops as well as food marketed or consumed at home. At least two fifths of Kenya's smallholdings are managed by women (and they have substantial influence over the rest) and women generally manage food production and participate in non-food cash crops" (World Bank, 1989b).

Although there is a clear division of labor within and between crops in sub-Saharan Africa, both men and women play substantial economic roles (Blackden and Bhanu 1998). In many cultures, men clear the land; women are responsible for weeding and processing. Men are responsible for marketing, particularly of cash and export crops, while women are in charge of family nutrition and are therefore relegated to the subsistence sector, in particular to food crops and agro-processing (IFAD 2001). This fact underlines the need to work with both men and women.

Inadequate extension services to women reduce productivity

Extension education is critical to adoption and effective management of agricultural technologies. Highest levels of efficiency have been registered in situations of direct contact between extension agents and farmers. This new understanding has come with emerging evidence that information given to men or women does not necessarily reach other members of the household who are involved in farm operations.

Fortmann (1982) established that husband-wife communication of extension messages in Tanzania was ineffective, a finding supported by Koons (1988) and Winrock International (2001) in Cameroon and Kenya, respectively. There is, however, less consensus on what happens when extension information targets women. Carloni's work in Kenya (1987) and the World Bank (1989b) in Nigeria stated that when extension messages target women, productivity rises. This latter finding has, however, been challenged by results of a gender-based assessment on the impact of an agricultural project implemented by Winrock International in Kenya (2001) where results revealed that in areas where men make major decisions on whether new technologies can be introduced or not and the types of inputs to be used, productivity does not necessarily go up despite training women in the different technologies. This new finding points to the need to involve both spouses in extension education.

Emergence of new African households headed by women

A new phenomenon of female-headed households has emerged in Africa and is fast changing the African household structure and landscape. Available information indicates that the proportion of female-headed households is on the increase. It ranges from 5% in Burkina Faso to 46% in Zimbabwe (FAO 1995, cited in Madhuchhanda and Mukhopadhyay, 2000). In countries like Lesotho, over 70% of farming households are headed by de jure or de facto female heads. In Eritrea, the figure is as high as 46%.

Female-headed households are categorized as de facto and de jure. Where women head households because their husbands are away from home for prolonged periods, the women are referred to as de facto heads. In most cases, these women often have to consult their husbands for major decisions such as introduction of new technologies, an arrangement that could delay adoption of such technologies. Women who head households for reasons ranging from never married, divorced or widowed are known as *de jure* heads. While women heading such households might have the advantage of making most decisions, many (but not all) are constrained by inadequate resources such as land, credit and other necessary inputs, all of which hamper adoption of technologies.

Although not all households headed by women are poor, comparatively few achieve security through remittances from wage-earning menfolk (Jiggins 1986). Female-headed households, whether *de facto* or *de jure,* are commonly characterized by smaller land holdings, smaller family sizes and fewer number of farming adults, and are relatively undercapitalized. In Kenya, Sorensen (1990, cited in Blackden and Bhanu 1998) revealed that female-headed households had half the propensity of male-headed households to adopt tea. Since in Kenya around one-third of rural households are female-headed, this diminished capacity is, in aggregate, substantial. Similar findings have been recorded in Zambia where the female-headed households are least advantaged in terms of access to factors of production, consequently, their farming practices, problems and priorities are different from those of male farmers. In an agricultural system where some of the key tasks (such as cutting of trees and for slash-and-burn cultivation) are gender-specific, the traditional pattern of land preparation undergoes great modification in the case of female-headed households who do not have access to required male labor. Due to male labor shortage, female-headed households normally prepare smaller fields in sites where big trees are in abundance, often near the village where the forest has not fully regenerated. The insufficient amount of ash in such fields directly results in poor yields, and less food for the family (Sikana and Siame 1987, cited in Blackden and Bhanu 1998). This is a new client for research and development (R&D), one whose needs and preferences differ significantly from those in households where there is an adult man. It is important to fully understand them at the diagnosis and design stage of research and implementation of programs.

Women are as good farmers (if not better) as men

Not working with women represents a missed opportunity for R&D since women have demonstrated their capability in production. It is, however, also important that R&D takes into account new evidence that shows that differences in access to key inputs can lead to marked productivity differentials between plots controlled by men and women. These resource differentials impose a large opportunity cost to society in terms of forgone output and incomes, the magnitude of which is only now being realized. Quisumbing et al. (1995), however, points out some of the shortcomings of the approaches used to calculate productivity. She particularly highlights a number of difficulties such as the fact that the simulations do not show how input levels can actually be increased, difficulties in defining appropriate measures of productivity in different farming systems, omission of individual characteristics in attempts to measure productivity differences by sex and the lack of clarity regarding measurement of sex and gender differences. While these cautions provide opportunities for further work, there is clear evidence of gender differentials in productivity as illustrated here.

In Burkina Faso, as in other parts of Africa, different members of the household simultaneously grow the same crop in different plots. Factors of production such as labor and fertilizers are, however, not equitably allocated, resulting in inefficiencies that lead to significant yield differentials. On average, yields in women's fields are about 18% lower than in men's plots and for sorghum, the yield is 40% less. It has, however, been observed that by reallocating resources between the plots controlled by men and women in the same households, yields in women's plots can be improved significantly and the agricultural output in the family can be increased by 10-20% (Udry et al. 1995). Saito et al. (1992, 1994) showed that the mean gross value of output per hectare in male-managed plots in Kenya was 8.4% higher than in female-managed plots, although simulation exercises suggest that if women had the same access to resources as men, their gross value of output would increase by about 22%. Similar results had been recorded by Moock (1976) who measured maize output from a sample of 152 Kenyan farmers, including 51 female-headed households and found that when the factors of agricultural intensification - credit, fertilizer, schooling, extension contact and fertile soils - were statistically controlled, women farmers raised about 7% more maize than men farmers. In Moock's study, women in reality raised 4% below their potential. Thus total maize yields in the district were below potential because women had less access to inputs than men (Blumberg 1992). In contrast, in areas where the level of agricultural input services was much higher and aimed largely at men, women lagged behind (Blumberg 1992). This is further supported by studies that have measured productivity of men and women farmers without attempting to take into account women's lower access to inputs, extension, education, fertile soils etc. These studies have found women to be less productive; for example, Moock (1981) found a 15% productivity gap in Kenya. These results underscore the fact that inequitable distribution of productive resources between men and women undermines the overall agricultural productivity of sub-Saharan Africa.

Women have also demonstrated great potential for innovation. When Staudt (1975-76, 1978, 1985) addressed men's and women's ability to innovate, she found that where neither men nor women had much access to agricultural input services such as extension and credit, women tended to adopt improved maize earlier and grew more diversified crops than men. These results suggest that women may be better farm managers than men, and might have developed superior expertise in the crops (maize, beans, cowpeas) on which the analysis was done ((Tibaijuka 1994)). This provides a great opportunity for R&D.

Ignoring gender is inefficient

Jiggins (1986) reported increasing evidence from agricultural project and program evaluations that insufficient attention to gender tends to increase or reinforce gender inequities in ways which hold productivity and welfare below the potential (Carloni 1983; Dey 1983; Jones 1982; Pradhan 1983a). This claim has been supported by Blackden and Bhanu (1998) who report the growing recognition that gender inequality significantly constraints economic growth. These findings are well illustrated by an example from Burkina Faso (Box 2).

Box 2.

Resources allocated inefficiently across plots controlled by different members of the household reduce overall productivity Plots controlled by women are farmed less intensively than similar plots controlled by men in the same household and simultaneously planted with the same crop. Much less male labor per hectare is devoted to plots controlled by women than to similar plots controlled by men. Child labor and unpaid exchange labor are also applied intensively to plots controlled by men. Lastly, virtually all fertilizer applied to a plot results in progressively smaller increases in output. The less intensive application of resources on women's plots results in lower yields, One study estimates that the value of household output could be increased by 10-20% by reallocating currently used inputs across plots (Alderman et al. 1995),

Denying women benefits reduces productivity

Gender imbalances and lack of incentives for work done often lead to decline in agricultural production. There is now growing evidence showing that when not compensated, women tend to direct labor toward activities under their own control even when forgone activities are more profitable as reported by Blumberg (1989) and Kabutha (1998).

A Kenyan sample survey compared differences in maize yields in male- and female-headed households due to weeding practices (weeding is a female obligation in Kenya). In female-headed households, weeding increased yields by 56% whereas in male-headed households the increase was only 15%. Since other factors were similar, the difference in yield increase appeared to have been due to lack of incentives for women to work on holdings whose output was controlled by men. The national maize loss in Kenya due to the effect of disincentives is estimated to be about the same as maize gain by application of phosphate and nitrogen fertilizers (Demery et al. 1993 cited in Madhuchhanda and Mukhopadhyay 2000).

Another relevant example is the SEMRY rice project in Cameroon. The project found evidence of household production decisions that led to sub-optimal production, and failure to maximize income. This resulted from conflict over the level of compensation women got for their labor. Men traditionally have the right to income earned by their wives and control income from rice sales, though women are expected to contribute their labor. In this project, women's willingness to contribute labor to rice production depended on their being compensated significantly above what they could earn from low-return subsistence crops (Blackden and Bhanu 1998, adapted from Jones 1986).

Similar findings were recorded by Kabutha (1998) who found that in the South Nyanza Sugar (SONY) growing area of Kenya, women and other members of the family refused to work on family farms from which there was no compensation. Men kept all the money even when they had contributed little to sugar-cane production forcing women to sell their labor for wage in other people's farms. This gender dimension calls for household-level negotiation and compromise in the way those who contribute to production will benefit from their input. It is a dimension R&D cannot ignore because of its potential to derail technology adoption and overall food production.

Women and men have different preferences for technologies

When women farmers gain better access to diverse new planting materials, they demonstrate a remarkable ability to experiment creatively and share results enthusiastically among themselves. This is one of the findings of a recent participatory breeding project in Sierra Leone (launched by CARE and funded by a mining company but managed by farmers). The farmers organized themselves around clubs, which distributed small packages of planting material. Members chose from among 54 varieties of rice, cassava, sweet potato, oil palm, mango and maize. From 750 farmers in 1990, the number rose to 4500 people in 75 villages by 1995. At least 18 varieties had been identified and adopted by the end of the project (CGIAR 1999). This means that even within the same household, different members could have differing interests, priorities and preferences. Availability of appropriate options will determine the degree to which technologies are adopted.

Women and men have different knowledge bases

Men and women have differing knowledge and skills regarding their own environment and each is therefore an important source of such resource in their own right. Through their own close contact with nature, women develop a much deeper knowledge about the traditional medicinal plants and herbs, which are a part of their diversified home gardens and are also more knowledgeable about forest resources. In Sierra Leone, women for example, were reported to know 31 uses for forest species on fallow land and forests whereas men knew only 8 (FAO 1989). In Oboto, Nigeria, the women lead the Odo-Orisa festival, which highlights the need to conserve the Odo-Orisa stream and watershed. Case studies on women rice farmers in Cameroon (Jones 1982), Senegal (Linares 1981) and Sierra Leone (Karimu and Richards 1980) indicate an enormous range of skills and knowledge among women, skills that are passed through generations, including detailed knowledge on soil types, toxicities, salinity conditions and water management. As plant breeders, women domesticate wild species, select germplasm and save seed in small farm-production systems and often bear the primary responsibility for maintaining and reproducing the world's landraces of crops such as beans, cassava, fonio, bambara groundnuts, millet and many minor species. They are also conversant with seed characteristics, agronomic practices for weed management and erosion control and maintenance of soil fertility, and in addition manage labor requirements efficiently to reduce seasonal pressures (Mudhuchhanda and Mukhopadhyay 2000). The Rwanda bean project is yet another example of women's use of their indigenous knowledge base to make rational choices (Box 3).

Box 3.

Scientists at the Institut des sciences agronorniques du Rwanda (ISAR) and the Centro Internacional de Agricultura Tropical (CIAT) in Colombia collaborated with local women fanners to breed bean varieties. Previously, the breeders' predictions of the two or three bean varieties that displayed most potential under actual growing conditions had resulted in mildly successful increases in bean productivity. In this collaboration, the women farmers were invited to examine more than 20 bean varieties at the research station and take home and grow the 2 or 3 they thought most promising. The women planted these varieties using their own methods or experimenting with new varieties. Although the women's criteria for selection were not confined to yield, which had been the breeders' primary measure for ranking, the selections of the women farmers outperformed the selections of the bean breeders in terms of yield by 60-90%. Farmers were still growing their own choices six seasons later (Sperling and Ntabomvura 1994, cited in Quisumbing etal.. 1995).

Men and women are affected differently by external shocks such as globalization and HIV/AIDS

Although grounded in culture and social systems, gender relations and entitlements are greatly influenced by external forces. Globalization and HIV/AIDS constitute by far the most important changes and shocks during the last two decades. The duo have left behind a trail of misery in form of growing deficits in food production and poverty, all with gender dimensions. They have also altered the known and predictable gender paths and trends.

Globalization has focused on economic efficiency programs that strive for an arrangement of resources in ways that provide the greatest total output through removal of market distortions so that every input and output reflects its true economic value (or opportunity cost) to the whole economy. The principles have however ignored market distortions caused by gender constructs such as unequal terms of market participation. Oslo (1994) revealed "gender imbalances in access to and control of economically productive resources (notably land, housing titles, labor, financial services, legal services, extension, transport infrastructure, urban services) lead to a lower response to economic incentives than would be the case if these differentials were reduced." These gender differentials have resulted in what has been described as "missed" economic potential.

Similarly HIV/AIDS, which has wreaked havoc on food production, has negatively affected women's overall productivity because on the whole, households have had fewer resources to invest in production including labor and finances. Finances have diminished due to diversion of resources to loss of earning potential due to sickness and medical expenses. Care of the sick has also resulted in reduced time for food production. Women assume heavy responsibility in this task because of their traditional role as health providers. These new dimensions underline the need for R&D to take into account major structural and social changes as part of the initial diagnosis and problem identification.

The potential effect of these social changes on technology adoption and management can be built into the design and implementation of programs. An additional way in which R&D could respond to the scourge is beginning to develop technologies that meet the circumstances of the new clients - children and the old.

Gender-based constraints to technology adoption and productivity

While the importance of mainstreaming gender in R&D in now appreciated, making it work still remains a major challenge. A logical way to start is to ensure a sound understanding of gender-based constraints, which provide the basis for intervention.

Women's limited access to and control over land

Access to land and security of tenure are major factors in food production because decisions on technology adoption are influenced by access to land and security of land tenure. Individuals with insecure tenure will generally be less likely to invest in new technologies that require resources such as capital

(Doss 1999). Where tenure is secure, farmers are more inclined, for example, to invest in slower-growing tree crops, productivity enhancing inputs or more labor-intensive land conservation practices, thereby raising both productivity and the quality of land. Where tenure is insecure because land is titled or disputed, there is multiple and overlapping ownership or rights are unclear, uncertainty discourages the investments needed to improve land productivity. As investments in land also improve its quality and permit its sustainable use, failure to invest can have negative environmental impact. Comparing the performance of squatters on state land (insecure tenure) and titled farmers (secure tenure) in Thailand, Feder et al. (1988, cited in Panayotou 1993) found that secure tenure had a larger volume of investment, higher likelihood of land improvements (contributing to its sustainable use), more intensive use of variable inputs and higher output per unit land.

The fact that few women in Africa have secure and independent rights to land despite their significant role in agriculture, leads to low agricultural productivity. In most places, women cannot legally or customarily inherit wealth and property, including land. They obtain rights to land through men, generally through their husbands and sons. In Cameroon for example, land registers show that less than 10% of women hold land titles and in the North West Province this figure is only 3.2%, representing barely 0.1% of the registered land mass. In 1998, the Federation of Kenya Women Lawyers (FIDA 1996) reported that only about 1% of women in Kenya own land. There are, however, exceptions to this rule.

Exceptions are common in countries where matrilineal inheritance traditionally dominates, a system that accords women the right to land exists for example in Cote d'lvoire, Ghana, Malawi and Zambia. In Burkina Faso, The Gambia and Nigeria, girls are typically given a plot of land for their own needs or for their future family's needs. Nevertheless, even in these areas, because of increasing pressure on land, daughters tend to receive "movable or more liquid assets while land tends to be concentrated in the hands of men (IFAD 2001). In a few other countries, such as Eritrea, the land policy makes it possible for women to acquire land although even here, women end up with smaller pieces of land than men do (Government of Eritrea 1994). Muslim law accords women the right to acquire land directly (women's right to land is only one-fifth that of men). In the rest of Africa, most women have usufruct rights to land that are held by their husbands or are communally held. It is therefore recommended that analysis of women's right to land should focus on both security of access and land ownership. A statement made by the former President of Tanzania, the late Mwalimu Julius Nyerere, graphically captured the disadvantaged position of women with regard to land (Box 4).

> Box 4.
> "The women of Africa toil all their lives on land they do not own, to produce what they do not control and at the end of their marriage through divorce or death, they can be sent away empty-handed"
>
> Mwalimu Nyerere, former President of Tanzania. African Preparatory Conference, Third World Conference on Women, Arusha, Tanzania, 1994.

Women's limited access to extension education

Access to appropriate information may have a significant impact on agricultural productivity. However, the level of usefulness of such extension information depends on both access to the source of that information by farmers and its quality and appropriateness (Doss 1999).

In Kenya, Ongaro (1990) associated extension education with output, producing increases of 7-18%. In contrast, Moock (1976), who examined farmer efficiency in Kenya, established that use of extension services resulted in higher yields for men but not for women. This association was, however, not explained and could perhaps be linked to either less information or information that was qualitatively lower in the case of women; it could also have resulted from under-use of other inputs.

In terms of access to extension education, there are distinct gender differentials. Women in Africa continue to receive much less extension education than men, for example, in 1990 aggregate data (Swanson et al. 1990, cited in Blumberg 1992) revealed that only 7% of the time and resources of extension organizations were devoted to women farmers. Saito et al. (1994) presented data for Kenya, Malawi, Nigeria, Tanzania and Zambia, showing that irrespective of the level of farm contact, fewer women than men were reached by extension agents. In response to this disparity, many organizations are using women groups to improve access. While positive results have been recorded in many cases under a women-focused extension model, there are also indications that improving access to technology and information to women alone may not necessarily bring about improved productivity of women because they may lack capacity to use their knowledge and skills due to other gender related constraints such as access and control over productive resources. Mukhopadhyay and Pieri (2000) support this view when they state that women are disadvantaged in applying extension messages because of their inability to procure inputs and also to get them at the right time in the right place. Gender differential in access to extension education is reflected in Table 1.

Table 1. Access to extension by gender.

Country	Year	Male	Female
Kenya	1989	12	9
Malawi	1989	70	58
Nigeria	1989	37	22
Tanzania	1984	40	28
Zambia	1986	60	19

Source: Saito et al. 1994

Women's limited access to equipment and appropriate technology

Ownership of farm tools and implements influences food production since those with the tools are able to prepare the land in time and are able to take full advantage of rains. Women can, however, use these items when not in use elsewhere. Female farmers in general own fewer tools than men and are therefore likely to have lower yields than male farmers. (Quisumbing et al. 1995) reminds us that most new technologies available to women have often been inappropriate to their needs. Women's inability to control these implements is considered a constraint in the adoption and effective management of research technologies. A study carried out in the Gambia in 1970s reflects this disparity in ownership of tools and farm implements.

Table 2. Percentage owning tools.

Tool	Men	Women
Plough	8.2	0.0
Seeder	**26.9**	0.6
Weeder	12.4	0.2
Multipurpose implements	18.1	0.4

Source: Saito et al., 1994.

Women's heavy workloads limit technology adoption and productivity

Time is a major factor in the adoption of technologies. Competition for women's time between reproductive and productive work and their obligation to provide unpaid family labor for husbands can cause inefficiency in women's farming, particularly during seasonal labor bottlenecks. In both Ghana and Nigeria, women have been found to be unable to carry out important operations on their land in time because they had to work for their husbands. In Burkina Faso, men can oblige women to work on their fields even on days when the women customarily work on their own land, thus taking time away from their farming activities. This is made worse by the fact that due to lack of financial resources and gender division of labor within the household and the community, women have reduced access to the work of other individuals. The emergence of the HIV/AIDS pandemic has complicated the situation even more because women spend even fewer hours on farm work due to rising demand for nursing and care for the infected.

Heavy workloads have implications for R&D. Technologies that are labor-intensive risk non-adoption by women due to their heavy workloads. A strategy to address this constraint could explore the possibility for development of technologies that are not labor-intensive but which reflect women's other preferences. The statistics in Table 3 highlight the differential time use for men and women across Africa.

Table 3. Average daily working hours in economic activities by gender.

		Agriculture	Non-agriculture	Total
Burkina Faso	Men	7.0	1.7	8.7
	Women	8.3	6.0	14.3
Kenya	Men	4.3	3.8	8.1
	Women	6.2	6.1	12.3
Nigeria	Men	7.0	1.5	8.5
	Women	9.0	5.0	14.0
Zambia	Men	6.4	0.8	7.2
	Women	7.6	4.6	12.2

Source: Saito et al., 1994.

Although with variations, the phenomenon of women's heavy workloads holds in much of Africa as statistics on Uganda, Tanzania and Cameroon further illustrate.

Uganda: Women have very heavy workloads; they work longer hours than men between 12 and 18 hours per day with a mean of 15 hours. This is in comparison with an average male working day of around 8-10 hours (World Bank 1993b)

Tanzania: The average woman has less leisure (2 hours per day) than the average man (4.5 hours per day). In economic activities, women have a greater labor input than men - 52% vs. 42%. Women are involved in almost all the activities on the farm as well as housework (in which men hardly participate). Even in traditional male activities such as cash crop farming, women were found to make significant labor contribution (Tibaijuka 1994).

Cameroon: In the Central Province of Cameroon, men's total weekly labor averages 32 hours, while women's is over 64 hours. Even though much of the disparity results from differences in domestic labor hours - 31 hours a week for women and 4 for men - a significant difference was also observed in agricultural labor hours: 26 hours a week for women and 12 for men (Henn cited in Poats et al. 1988)

Women's limited access to credit

Credit is a clear prerequisite for adoption of improved technology including seeds, especially hybrid seeds and fertilizers (Doss 1999). Existing data suggest that the poor in general have little access to finance and that women's access is much lower than that of men. Women's World of Banking estimates that fewer than 2% of low-income entrepreneurs have access to financial services (WWB 1995). In Africa, women receive less than 10% of the credit to small farmers and less than 1% of the total credit to agriculture (UNDP 1995, cited in Blackden and Bhanu 1998)).

A survey conducted in Kenya shows that only 3% of female farmers had obtained credit from formal institutions compared with 14% of male farmers, and 5% of female farmers obtained credit from a bank. Not only did a lower number of female farmers obtain institutional credit, but also the loans they had got were much smaller than those given to men. The average size of loans to women was 42% of those of men in Nigeria, and 61% of those given to men in Kenya (Saito et al 1994, cited in Madhuchhanda and Mukhopadhyay 2000). This constraint has implications for Africa's food production as it limits the ability of women to buy inputs and adopt technology and hired labor. While research organizations may lack both the mandate and the capacity to handle credit programs, they have an opportunity to work with others currently operating such systems and who clearly have a comparative advantage over research institutions.

Making gender work for research and development

Differences in gender roles and power relations within households influence the chances of adoption of agricultural technologies and effective management by farming households. This finding is itself a compelling argument for incorporating gender in Research and Development (R&D) besides growing understanding that incorporating gender in R&D harnesses the productivity potential of men and women particularly when client preferences, constraints, capacities, roles as well as the differential impacts of technologies on men and women farmers is adequately taken into account. However, making R&D responsive to gender is a long process, one that has to be learned and implemented progressively. It needs institutional capacities and commitment by way of policies and institutional systems that support program level work. Some of the main steps for incorporating gender in research and development programs are outlined below.

Gender analysis

Gender analysis assists researchers and development agents to better understand gender roles, responsibilities and other dynamics within households. The process reveals constraints that hamper adoption and effective management of technologies. These constraints provide a basis for intervention by translating them into opportunities. The intervention process includes building these constraints and preferences into the design of research and development work. Household level clients include men and women within male-headed households and women within female-headed households. Knowledge on what women and men do, who can use household resources without constraints and who has the time to participate in technology trials and the most appropriate timing for such events all constitute critical information necessary to develop technologies with high potential for adoption. Gender analysis provides information on division of labor, access to and control over productive resources and sharing of benefits.

The method seeks diverse information such as: Who does what? Who has what? Who decides? How? Who gains? Who loses? When we ask these questions, we also ask: Which men? Which women? Gender analysis therefore breaks down the divide between the private sphere (involving personal relationships) and the public sphere (deals with relationships in wider society).

Some of the key sets of information captured through gender analysis include workloads for different members of households, technology preferences, access to and control over production resources and how benefits are distributed within households and overall power and decision-making processes within households.

Integrating gender constraints into R&D design

This is perhaps the most difficult part of gender mainstreaming but one that is important in determining the degree to which technologies reflect the different needs of men and women. Some examples of such integration could include the following:

- Where labor is a constraint, scientists could explore possibilities for developing varieties that are less labor-intensive. Concurrently, redistribution of labor within households could also be negotiated with all members of households.
- In cases where men and women have different technology preferences, scientists are encouraged to explore elements that could be included in new technologies being developed. Alternatively, with the needs expressed, it is also possible to search for such characteristics among already developed varieties, providing more than one technology to a household to give choices to different members.
- On access to and control over productive resources, scientists have a number of options, including negotiation for redistribution of household resources in ways that are just and development of technologies that are less demanding in terms of inputs.
- On benefits, research has consistently demonstrated that where a category of family members is not adequately remunerated for its work, the members withhold their input in subsequent seasons, thus hampering food production. This issue should be discussed at the initial stages of technology transfer to create greater understanding within households. An increase in income from agricultural production has been shown to wreck rather than build families.

Discussions

While incorporating gender into R&D, broad issues, some of which are reflected in following questions, could be considered.

I. How to link development and delivery of technology to farmers' (men and women) differential preferences and capacity to utilize them in order to improve food security and incomes.
   a. Does this call for a basket/options for men and women (crops, crop/ livestock management systems), taking into account the socially inherent resource constraints for women and the diversity of households and socio-economic status?
   b. How should research make use of the gained insights on impacts and implications of gender relations on technology choice?
   c. What types of institutional arrangements can bring about greater access to benefits for most of the poor, who often tend to form female-headed households?

Thoughts from the author

A basket of technologies to accommodate different needs? Gender-based preferences are a reality at the household and farm levels and to meet diverse needs, a basket of technologies from which different clients can pick their preferences is recommended. Availability of right choices will lead to increased adoption of technologies and improvements in food production. Preferences often reflect social roles and responsibilities. For example, women are likely to be interested in varieties that are fast maturing, have low labor demands and are fast cooking. On their part, men might prefer high yielding varieties even when they are labor intensive and late maturing. In practice, each client could select two or three varieties to meet different needs. The message for scientists is that no single variety will meet all these diverse needs.

How to use lessons from impact and constraints to improve technology choices? Gender mainstreaming is about aligning gender-based lessons and constraints with client needs and preferences. As an illustration, a sweet potato variety grown in central Kenya was poorly adopted because of its watery nature. To improve potential for adoption, scientists would work on reducing the constraining element - the watery nature of the variety. Other constraints, such as labor and resources would be handled in the same way.

Institutional arrangements necessary to reach the poor. Different organizations have different mandates and strengths and no single organization can be everything in a given situation. To reach the poor with appropriate technologies, research institutions would need to work with such organizations as non-governmental organizations (NGOs) and community based organizations, which have skills in needs assessments and identification of disadvantaged groups. Besides, these two groups also facilitate delivery of services such as credit, a clear prerequisite in adoption of new technologies and closely work with government extension systems, which, although incapacitated by inadequate logistics, have a rich technical capability.

II. Should research focus on more value addition including coming up with different ways of utilization of typical women or subsistence crops (sweet potatoes, pigeon peas and sorghum/millets) to enhance food security or make an attempt to commercialize them?

Promotion of women-specific crops or an open field for all? Having an income to purchase additional food to supplement what families get from their farms is increasingly being recognized as an aspect of food security. This in part explains the increasing focus on dual purpose crops that provide food and income for households, thus challenging and hopefully ending the traditional dichotomy between subsistence and commercial farming except in industrial crops such as sugar-cane, cotton, palm oil etc.

Conclusion

This paper has examined and demonstrated that inadequate attention to gender in research and development results in low levels of adoption of agricultural technologies and subsequent low productivity. The fact that men and women have different social roles and responsibilities and therefore different criteria for preferred technologies points to the need for a basket of options from which men and women can choose. Similarly, men and women have different constraints to technology adoption and management. Women are particularly disadvantaged with regard to access to productive resources such as land, time, extension education, farm implements and cash to buy inputs. For technologies to be attractive to different clients, scientists will need to align technology adoption constraints to the circumstances and preferences of different clients.

The process of incorporating gender into research and development logically starts with gender analysis, which reveals gender-based constraints that hamper adoption of technologies. Gender mainstreaming is about reducing these constraints, for example, holding labor demands on a technology to a minimum will make it attractive to women. It is also important to note the important role of institutional support and back up, through policy and institutional systems that promote and sustain gender mainstreaming in research.

The need for continued research in different areas of gender cannot be overemphasized. One important area for research focuses on gender and productivity, particularly within an environment destabilized by globalization and HIV/AIDS. Support is also needed in the search for success stories in gender mainstreaming and sharing the same with those struggling with gender mainstreaming.

References

Agarwal, B. 1997. Gender, environment, and poverty interlinks: Regional variations and temporal shifts in rural India. 1971-1991. Institute of Economic Growth, Delhi, India.

Agarwal, B. 1994. Gender and command over property: A critical gap in economic analysis and policy in South Asia. Institute of Economic Growth, Delhi, India (Reprinted from World Development, Vol. 22, Agarwal. Pp. 1455-1478, 1994).

Alderman, J, Hoddinott, J, Haddad, L, and Udry, C. 1995. Gender differentials in farm productivity: Implications for household efficiency and agricultural policy. Food and Consumption Division Discussion Paper 7 (Washington, D.C.: International Food Policy Research Institute, 1995). In: Quisumbing, A. R., 1995.

Blackden, CM, Bhanu, C. 1998. Gender, growth and poverty reduction: Special program of assistance for Africa, status report on poverty in the sub-Saharan Africa. In collaboration with the Poverty and Social Policy Working Group of the Special Program of Assistance for Africa. World Bank Technical Paper No. 428. World Bank, Washington, D.C.

Blumberg, RL. 1992. African women in agriculture: Farmers, students, extension agents, and chiefs. Development Studies Paper Series (Winrock International Institute for Agricultural Development).

Blumberg, RL. 1989. Making the case for the gender variable: Women and the wealth and well-being of nations. Office of Women in Development, U.S. Agency for International Development, October, 1989.

CGIAR Program on Participatory Research and Gender Analysis. 1999. Crossing perspectives: Farmers and scientists in participatory plant breeding.

Second class citizen. 1996. The FIDA Annual Report on the Legal Status of Kenya for 1996.

Doss, CR. 1999. *Twenty-five years of research on women farmers in Africa: Lessons and implications for agricultural research institutions* (with an annotated bibliography). CIMYYT Economics Program Paper No. 99-02.

Eastern and Southern Africa Management Institute. 2000. *Gender training of trainers.*

ICRISAT 2000. Reducing poverty through agricultural research for development in the *semi-arid tropics (sat): Science with a human face.* ICRISAT, Pantacheru, A.P. India

IFAD. 2001. *Assessment of rural poverty in Western and Central Africa.* International Fund for Agricultural Development, Rome. December, 2001. 130pp.

Fortmann, L. (1976). *Women and maize production: Some Tanzanian observations.* Dar-es-Salaam, Tanzania: Protein Calorie Advisory Group of the United Nations. (In: Doss, CR. 1999).

Fortmann, L. 1992. *Women's work in a communal setting. The Tanzanian policy of Ujamaa.* In: Edna G. Bay (ed). Women and Work in Africa. Westview Press, Boulder, CO, USA.

Jiggins, C. 1986. *Gender-related impacts and the work of the International Agricultural Research Centers (CGIAR).* CGIAR Study Paper Number 17.

Moock, PR. 1976. *The efficiency of women as farm managers: Kenya.* American Journal of Agricultural Economics 55(5):831-35. (In: Doss, RC, 199)

Mukhopadhyay, M, Pieri, C. 2000. *Women in sustainable land and crop management in sub-Saharan Africa.* Rural Development Department, World Bank, Washington D.C.

Ongaro, WA. 1990. *Modern maize technology, yield variations and efficiency differentials: A case of small farms in Western Kenya.* Eastern Africa Economic Review 6(1): 11-30. (In: Doss, R.C. 1999).

OXFAM. 1999. *A guide to gender analysis frameworks.*

Quisumbing, AR, Brown, LR, Feldstein, HS, Haddad, L, Pena, *C. 1995. Women:* the *key to food security.* Food policy report. The International Food Policy Research Institute, Washington D.C.

Ram, Rati and Ram D Singh. 1988. *Farm households in rural Burkina Faso:* Some *evidence on allocative and direct returns to schooling,* and male-female labor *productivity differentials.* World Development 16(3): 419-424. In: Blumberg, R.L. 1992. African Women in Agriculture: Farmers, Students, Extension Agents, Chiefs.

Sigot, AJ. *Discourse on gender and natural resource management.* From Towards Common Ground: Natural Resource Management in Africa.

Staudt, Kathleen. 1975-76. *Women farmers and inequities in agricultural services.* Rural Africana (winter). In: Blumberg, R.L. 1992. African Women in Agriculture: Farmers, Students, Extension Agents, Chiefs.

Tibaijuka, A. 1994. The cost of differential gender roles in African agriculture: A case *study of smallholder banana-coffee farms in Kagera region,* Tanzania. Journal of Agricultural Economics, 45(1). In: Mukhopadhyay, M, Pieri, C. 2000

United Nations. 1999. *Improvement of the situation of women in rural areas.* Report of the Secretary General, General Assembly Economic and Social Council.

Urdry et.al Al, 1995. *Gender differentials in farm productivity:* Implications for household efficiency and agricultural policy. Food Policy, Vol.20, No. 5. In: Mukhopadhyay, M, Pieri, C. 2000

Van Koppen, B. 2001. *Gender analysis for improved irrigation performance.* International Institute for Water Management (IWMI) Africa Regional Program.

Winrock International Institute for Agricultural Development. 2001. *Gender-based assessment of gender impact of the Agricultural Development Support Project* (ADSP). Unpublished.

World Bank. 1999. *The World Bank 1999 Annual Report.*

Annexure 1. Gender concepts

• Women in Development (WID)

Women in Development (WID) is an approach to development that was widely used until the end of the 1980s. It focuses on women and their specific situation as a separate group but fails to recognize that women live in a system where men have the power and authority over day-to-day decisions. This recognition now challenges the approach of working with only women who have to seek authority and request resources under the control of men to implement knowledge and skills gained. Leaving men out of these arrangements has been shown to significantly reduce the level of adoption of technologies and subsequent management of the same.

• Gender and Development (GAD)

This concept represents a growing awareness that sustainable development must include the full and equal participation of both women and men. It recognizes that men and women affect development projects differently and that the projects in turn affect them differently. Involvement of both groups in the identification of problems and solutions is now considered imperative if the interests of the community as a whole are to be furthered. In addition, it acknowledges that because of different gender roles, men can constrain or expand women's options.

The gender approach in development does not focus on "women's issues"; rather, it helps to improve the understanding of roles and interrelations of men and women and the constraints they face. Using this perspective, the gender approach helps to promote sustainable equitable patterns of development. The concept has, however, gone through major changes during the last two decades. The WID concept was conceptualized in early 1970s succeeded by Women and Development (WAD) and finally gave way to GAD around 1985.

- **Practical gender needs**

These are needs identified by men and women and which arise out of customary gender division of labor. They are often concerned with inadequacies in living conditions such as firewood, health and water. While practical interventions can increase women's participation in the development process, they are unlikely to change gender relations and, in fact, may preserve and reinforce inequitable division of labor (OXFAM 1999).

- **Strategic gender interests**

Strategic gender interests reflect a challenge to the customary gender relations and imply a change in relationship over power and control between women and men. They are long term and aim at equalizing gender-based disparities in diverse areas. Addressing strategic interests may challenge the prevailing balance of power between women and men.

- **Gender equity**

Gender equity is about fairness and justice based on the needs and circumstances of men and women. The concept recognizes that the situations of men and women are different and that the two groups require different sets of responses in order for them to benefit from development opportunities. For example, non-residential training will be more attractive to women who need to remain near home due to domestic responsibilities while men would not be affected by the location of such training. Understanding the differential gender preferences and accommodating them is what gender equity is all about. Affirmative actions are a means to redress disparities accumulated over time.

- **Gender equality**

Equality between women and men is about sameness and being at par. It is a matter of human rights and condition for social justice. While this is a desired goal, it is not easy to achieve in practice.

- **Empowerment**

Empowerment is about people (men and women) gaining ability to undertake activities, to set their own agendas and change events. It implies enabling people to understand the reality of their situation, to reflect on the factors shaping that situation and most critically, take steps to effect changes to improve it. Empowerment of women means "adding to women's power" in recognition of the huge differentials that currently exist. An empowerment focus involves the radical alteration of the structures that reproduce women's subordinate position as a gender. In research and development, women's empowerment would ensure that their needs are built into the design and implementation of the activities of those sectors. Empowerment is about removal of barriers that keep either men or women down.

Annexure II. Gender mainstreaming

Gender mainstreaming ensures that needs, entitlements and experiences of men and women are taken into account in every project, program and within institutions. Gender mainstreaming leads to R&D efforts working with men and women with full understanding of individual constraints and potentials.

- **Gender analysis**

To firmly ground R&D, gender analysis becomes a necessary process as a first step. This is a methodology for study of the different roles of women and men, the differences between their respective levels of access to and control over resources and the consequent variations in constraints, needs, priorities and opportunities. Ultimately, gender analysis helps identify gender-based inequalities between women and men in addition to differential impact of development initiatives on women and men.

The method seeks diverse information such as: Who does what? Who has what? Who decides? How? Who gains? Who loses? When we ask these questions, we also ask: Which men? Which women? Gender analysis therefore breaks down the divide between the private sphere (involving personal relationships) and the public sphere (deals with relationships in wider society).

• Components of gender analysis

Division of labor - who does what?

In gender analysis, three forms of work are analyzed - reproductive, productive (on and off farm) and community work. Understanding the entire workload for women and men assists scientists identify clients who have time or alternatively, use the results of analysis to negotiate for work redistribution within the family. This can also influence the type of technology developed - that which is not labor-intensive.

> **Reproductive work.** This category includes the care and maintenance of the household and its members. Such work includes cooking, washing, cleaning, nursing and looking after children. Although this form of work is necessary, it is rarely valued in comparison to productive work. It is normally not paid for and is not reflected in conventional economic statistics. Women mostly carry out this form of work.

> **Productive work.** This form of work includes production of goods and services for income or subsistence. This work is recognized and **valued.** Within agriculture, it would include crop and livestock production, agroforestry and business among others.

> **Community work.** This form **of work is carried** out by society for communal benefit. It includes clearing of roads, water canals etc.

Access to and control over productive resources

Access refers to ability to use while control reflects power and authority. Resources are needed to carry out work analyzed under division of labor. The resources could include skills and knowledge, financial resources to buy seeds or seedlings, equipment such as shovels, land etc.

Access to and control over benefits

Work generates benefits in a variety of forms. Farming produces food, fodder, fruits, firewood and timber for building and for sale. Of interest to researchers and development workers is the relationship between those who do the actual work and those who control benefits. Failure to benefit from one's input creates disincentive that leads to withdrawal of support.

Tools of gender analysis

Tools of gender analysis are often referred to as frameworks of analysis. A large number of these frameworks exist but this paper illustrates a few, including the Harvard Framework, Gender Analysis Matrix and Women's Economic Empowerment.

Annexure III. Tools of gender analysis

Gender Analysis: Harvard Framework and Gender Analysis Matrix

Name of Community:______________________District:___________Date:_________

A: Division of labor

All types of labor are analyzed in order to establish total workload since this can act as a barrier to adoption.

Reproductive work

#	Type of work	Male adult	Female adult	Male child	Female child
1.	Fetching water				
2.	Child care				
4.	Fetching firewood				
5.	Cooking				
6.	Washing dishes				
7.	Washing clothes				

Productive work

#	Type of work	Female adult	Male adult	Female child	Male child
1.	Land preparation				
2.	Planting maize				
3.	Planting fodder				
4.	Feeding of animals				
5.	Spraying				
6.	Harvesting				
7.	Marketing				

Community work

#	Type of work	Male adult	Female adult	Male child	Female child
1.	Clearing water canals				
2.	Removal of algae				
3.	Soil and water conservation on public land				
4.	Construction of cut-off drains				
6.	Development meetings				
7.	Attending funerals, wedding				

Daily calendar (time use)

This tracks how men and women spend their time on a day-tto-day basis. It provides useful information on who is overworked, whom to work with on what kind of work etc.

Woman's daily calendar

Wake-up time ————————————→ Sleep

Man's daily calendar

Wake-up time ←———————————— Sleep

B: Access to and control over productive resources

		Access				Control			
#	Resources	FA	MA	FC	MC	FA	MA	FC	MC
1.	Training on animal husbandry								
2.	Farm implements - draught animals								
3.	Time								
4	Money								

FA = female adult; MA = male adult; FC = female child; MC = male child.

C: Access to and control over benefits

		Access				Control			
#	Benefits	FA	MA	FC	MC	FA	MA	FC	MC
1	Skills and knowledge								
2.	Milk								
3.	Money from sale of farm products								
4	Manure								

FA = female adult; MA = male adult; FC = female child; MC = male child.

Gender Analysis Matrix

Identify a community project currently under implementation. Use the Gender Analysis Matrix to assess the differential gender impact of the project

Category of group	Food	Mosquito nets	Labor	Income	Skills	Decision making	Culture
Men							
Women							
Boy child							
Girl child							

Women's Empowerment Framework

Level of equality

- Control - fully in-charge
- Participation - actively engaged
- Conscientization - beginning to realize levels of inequalities
- Access - basic survival
- Welfare (emergency situations)

HIV/AIDS and African agriculture

Tim Quinlan and Alan Whiteside[1]

Introduction

This brief for this paper was to:

> "Broadly review the latest data on the incidence of HIV/AIDS, projections over the next 20 years, and the perceived impacts on smallholder agriculture and food security."

The brief includes a focus on "what are the impacts of HIV/AIDS on labor, household assets, productivity, incomes, nutrition, social networks", with a view to indicating the implications generally for the work of agricultural research institutes. ICRISAT's own operational focus is the semi-arid tropical region of Africa in view of HIV/AIDS. The paper is intended to contribute to discussions within ICRISAT about its future activities.

HIV/AIDS in Africa

The HIV/AIDS pandemic must be considered in any discussion on Africa. There is evidence that the pandemic will threaten the social welfare and economic life of many of the continent's inhabitants. It is estimated that 28.5 million sub-Saharan African's are infected with HIV and, in 2001, 3 million died of the disease (UNAIDS 2002). Furthermore, any discussion of HIV/AIDS, particularly in relation to existing socio-economic agendas and programs such as those of ICRISAT, is ill served if two important qualifications are not noted at the start.

First, the bleak predictions in many media presume no intervention or ineffective intervention. Secondly, reporting the prospects is really only of value if it presumes a commitment that the pandemic can be managed and contained, and a recognition that the scale of the pandemic demands intervention in some form by many agencies. We should not be ignoring experiences and reports of the tragic consequences of HIV/AIDS, but we

1. HEARD (Health Economics and HIV/AIDS Research Division) School of Economics and Management, University of Natal Durban, South Africa.

should also recognize that the purpose is to encourage informed and considered interventions to mitigate the impacts of the pandemic in Africa.

These provisos, we contend, are useful premises for assessing the pertinence of HIV/AIDS to research and development programs that are not specifically focused on health issues generally or HIV/AIDS in particular. We refer here to the multitude of institutional and project-based programs in Africa that, in one form or another, address scientific and development concerns and operate under the rubric of various international agendas (e.g. "sustainable development"). ICRISAT is one of many organizations whose operations impinge on and, at the same time, may be affected by HIV/AIDS, but it needs first a foundation on which to answer the questions of how, why, and to what extent.

One illustration of this need is the difficulty of generalizing the impacts of HIV/AIDS on an area as wide as "the semi-arid tropics" of Africa. For instance, the relevance of discussing HIV/AIDS may seem obvious to ICRISAT researchers in Malawi, Uganda, Zambia and Zimbabwe, in view of everyday experience of how HIV/AIDS is devastating people's lives and of the known high prevalence of HIV in these countries. However, it may not seem so pertinent to researchers in countries such as Mali or Ghana where effects of the pandemic are not always evident. The obvious answer is that the need for coordinated, informed and well-directed intervention is essential in the countries of the semi-arid tropics (SAT) where HIV/AIDS prevalence levels are very low, precisely to avoid the tragedies unfolding elsewhere.

The management of an epidemic in a country, whatever the prevalence rate, requires a "multi-sectoral" response; and that means many agencies can and should contribute to this effort. In the sections below we outline aspects of the HIV/AIDS pandemic that are pertinent to ICRISAT. These aspects, it may be noted, mirror the steps that can be taken by an organization to formulate an intervention. Broadly speaking the steps are:

a) Appreciate the potential threat of the HIV/AIDS pandemic in Africa.
b) Consider how the pandemic may affect the work of an organization.
c) Assess how the pandemic is actually affecting the organization's work.
d) Reformulate programs and projects in ways that incorporate HIV/AIDS management as a significant factor.

This paper provides a starting point for these steps, but only a starting point. ICRISAT is a better place to consider steps b) to d) than we are.

HIV/AIDS incidence and projections in Africa

HIV infection precedes the onset of AIDS. Accordingly, projections of the spread of an epidemic highlight a rapid growth in infection followed in due course (incubation period ranging from 5-8 years in individuals - longer depending on form of intervention) by growth in AIDS-related sicknesses and deaths (Figure 1).

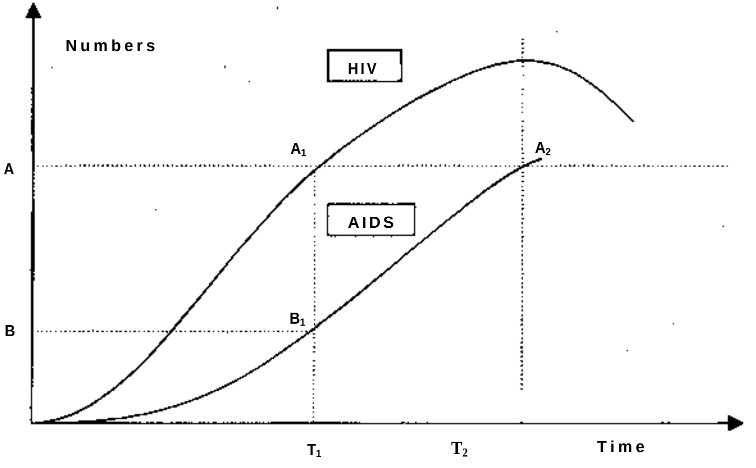


Figure 1. The two epidemic curves.

The figure presents an ecological model. The premise is that any epidemic growth curve must level out at some point simply because there are fewer individuals to be infected and many who could infect others are incapacitated by illness and dying. Similarly, the AIDS growth rate must level out as the potential number of individuals in a population who can be infected decreases, and as the population size diminishes due to death by AIDS-related illnesses.

The reality in Africa is that estimations and empirical evidence indicate that the HIV infection rates are still climbing, and even where there has been a downturn in HIV prevalence levels of illness and death remain high. Figure 2 highlights this trend for several countries in southern Africa where the disease is acknowledged to be spreading more rapidly than in many other regions of the continent.

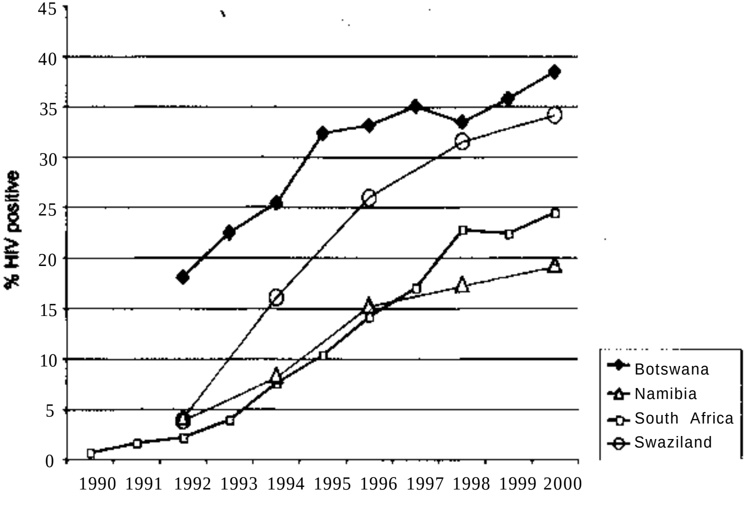


Figure 2. HIV infection rates in southern Africa.

Reporting, surveillance and modeling of the impacts of the pandemic have become well tuned in southern Africa. This is not to say that the monitoring and evaluation are as good as is possible; simply, that the evidence from this region is useful for illustrating the potential impacts of the pandemic in the SAT region and Africa generally. One alarming projection, presented in Figure 3 and based on analysis of the epidemic in Botswana, is the profound effect of an HIV/AIDS epidemic on the demographic composition and structure of a population. The Botswana case is a useful template in that the current population demography is common throughout Africa: a "pyramid" demographic pattern due to high fertility rates and high birth rates, such that the majority of the population is "young", coupled with relatively high adult mortality rates due to poverty and extant conditions for the majority of Africans, such that relatively few people live into "old age".

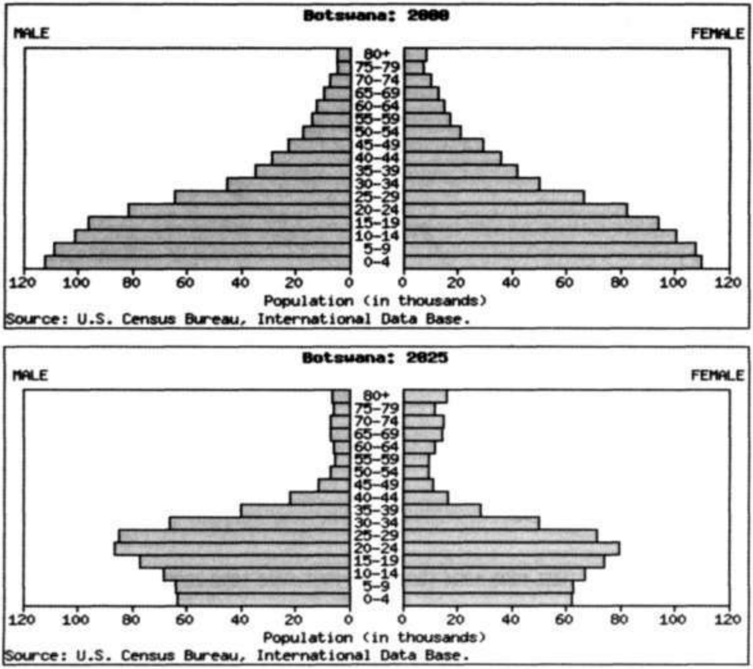


Figure 3. Projected changes to the demographic composition of Botswana's population (2000 and 2025).

The projected demographic structure in 2025 reveals marked changes. Three significant trends are indicated:

1) A much smaller proportion of infants and children (due to a combination of lower fertility rate arising from high HIV infection rates and related illness in the adult population and higher infant and child mortality rate due to mother-to-child transmission (MTCT) of HIV).
2) A majority of "youth" in the population (due to markedly higher death rates from AIDS in adults).
3) A small but significant imbalance between adult men and women (due to women being more susceptible to HIV infection than men).

With regard to the last point above, a combination of factors makes women, generally, more vulnerable than men. Many social and cultural practices that contribute to the spread of HIV/AIDS affect women in particular. Women are often economically dependent on men for survival and so they are less able to make decisions independently about how to protect themselves (Heise et al. 1994). Furthermore women are biologically more susceptible than men to infection [Whiteside and Sunter 2000:10-12; Barnett and Whiteside 2002:85). We have drawn out the potential changes to a country's demography and, in particular, the susceptibility and vulnerability of women because, as we discuss later, they bear directly on the ICRISAT's consideration of its current and future agendas.

For now, demographic projections of the sort in Figure 3 require some qualification. The intimation that the populations of countries will be smaller than they are now is misleading. There is no evidence to date that the HIV/AIDS pandemic has reduced the size of a national population. Instead, what can be inferred is that national populations will continue to grow, but at a slower rate and, therefore, they will be smaller than would have been the case if there was no HIV/AIDS.

Nonetheless, a simple fact cannot be ignored: life expectancy in many countries could drop drastically; indeed, it is to be expected if one acknowledges the manner in which life expectancy is calculated. Calculations inevitably group infant and child mortalities with those of adults. However, HIV/AIDS infections occur largely and initially amongst the sexually and economically active population; that is amongst the youth and young adults, of whom many will die of AIDS before reaching old age (Figure 4).

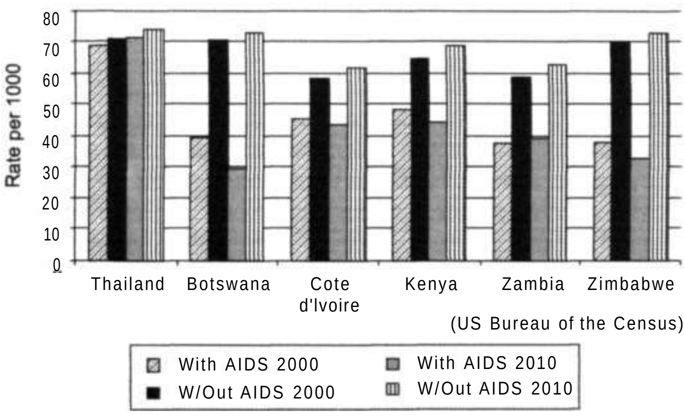


Figure 4. Life expectancy in selected countries for 2000-2010.

In Figure 4, we have not focused solely on SAT region countries for two reasons. First, our purpose is to indicate a general pattern for sub-Saharan Africa as a whole. Secondly, we wish to draw attention again to our contention at the beginning of the paper that an HIV/AIDS epidemic can be managed to the extent of reversing earlier projections. To make this point we have included Thailand as illustration. Thailand (as well as Uganda's) renowned success in containing HIV/AIDS is acknowledged to be due to "political will" (Hickey 2002).

To summarize, we have outlined the potential impacts of HIV/AIDS on the demography of national populations in Africa. There will be wide variation, even within the SAT region, in the demographic consequences of the pandemic. Nonetheless, the key point here is that HIV/AIDS poses a significant risk to the health and welfare of Africa's inhabitants. The general question that follows is how could the pandemic affect society in general. The specific question is, how could the pandemic affect particular aspects of society such as rural livelihoods in the SAT region of Africa. We address these questions in the next section.

Potential impacts on African farmers and farming systems

Analyses of sero-prevalence surveys commonly draw attention to the probability of infection amongst different sections of a population. For instance, the results often highlight that rates of HIV infection are highest amongst the 15-25 year old individuals and lowest amongst people over the age of 70 years. Answering the question, why this is the case, leads to assessment of susceptibility. Susceptibility refers to the particular circumstances that affect the chances of a person getting infected; for example, living conditions and lifestyles. The value of introducing the concept of susceptibility is that it helps to identify conditions in society, behavior, cultural practices, attitudes and beliefs that contribute to the spread of HIV/AIDS. However, assessments of susceptibility do not, by themselves, answer questions about the impacts of HIV/AIDS on society or particular features of it. To address impacts beyond infection of people, assessments often use the concept of vulnerability. Vulnerability refers to the extent to which increased illness and death in a population will adversely affect the social and economic fabric or segments of it. Distinguishing between probability, susceptibility and vulnerability allows researchers to explore the varied impacts of HIV/AIDS on different aspects of society (Barnett and Whiteside 2002: 88-97).

The pandemic is transmitted primarily by heterosexual intercourse in Africa. In general the pattern of infection is that men in their mid- to late 30s fall ill and die while mortality peaks earlier in women. The implications of this for farming in the SAT region will depend on the relative roles of men and women in the production process. Furthermore, an infected woman may transmit HIV to her children during pregnancy at birth or through breast-feeding.[2] However, much depends on the living conditions and lifestyles of people (Brummelhuis and Herdt 1995).

In view of the dependence of many rural farm households upon off-farm sources of income, notably occasional or frequent migrant work by a husband, mobile men are also susceptible to infection. In sum, many of the precursors for escalating transmission of HIV exist throughout the SAT region. However, in the absence of any detailed data on incidence and prevalence of HIV/AIDS in particular localities, and recognizing that there is likely to be wide variation between localities (due to differing socio-economic circumstances), attention must focus more generally on the vulnerability of farm households in the context of an HIV/AIDS epidemic.

Throughout Africa and not just in the SAT region, the general poverty of rural communities ensures that many farm households are vulnerable to escalation of illness and death (Bond 1998, Egal and Valster 2001). Once a husband or wife or, indeed, a baby is infected, an increasing proportion of household resources inevitably get diverted. The costs of providing care for the sick can consume limited household cash incomes and reserves and, in their absence, entail selling of assets in order to provide care. Reduction in labor productivity due to illness, on the one hand, and provision of care, on the other, can strain a household's capacity to produce foodstuff and cash crops. The need to re-allocate household labor can affect the rearing of children. For instance, children, particularly girls, may be withdrawn more frequently from school to assist with farm activities. The consequences over time have been usefully portrayed by Barnett and Blaikie (1992) in Figure 5.

More generally, illness and death affects the surrounding community. For instance, reliance on kin in times of need is a longstanding social welfare mechanism throughout much of rural Africa. Households that are not directly affected by illness and death can incur increasing and substantive demands to provide assistance in the form of cash and labor.

2. South African research suggests that there is a 30% probability of mother-to-child transmission (MTCT) if there is no intervention. Intervention in the form of anti-retroviral drugs has been shown to reduce MTCT by 50% (Skordis and Nattrass 2001).

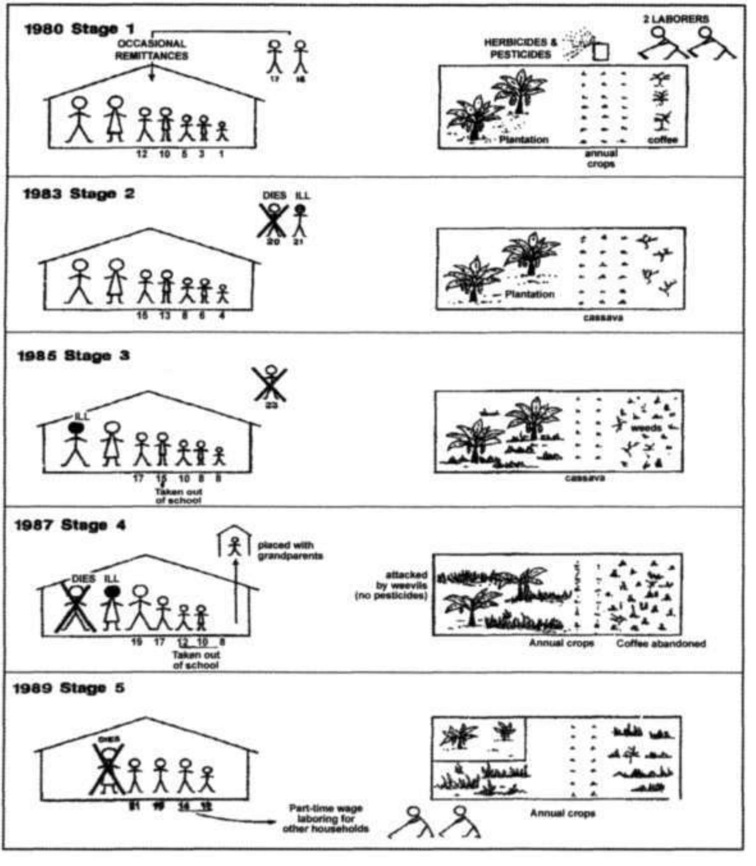


Figure 5. The impact of illness and death on cropping patterns in rural Uganda, 1989.

At this point, it is important to note that people's responses to HIV/AIDS may resolve some immediate socio-economic effects, but with further potentially detrimental consequences on others. For instance, in one locality in Zimbabwe, there is evidence that orphans are being brought into households to be deployed as herd boys (J Alumira, personal communication).[3] That may be appropriate from the perspective of the community, but it also means diminished education opportunity for these boys who are a particularly vulnerable segment of the population. In a different vein, if an epidemic spreads widely throughout a locality, households that are providing support to the households of infected kin may themselves become vulnerable in the sense of being forced to disperse limited resources on which their own members depend.

In sum, the impacts of HIV/AIDS can be many and varied. African farm households generally are vulnerable to increased poverty and distress because of their limited resources. We suggest, furthermore, that farm households in semi-arid areas are particularly vulnerable because environmental conditions already stretch the capacity and capabilities of farmers. For example, where there is a high demand for labor at key times of the year and if a person or family is unable to supply that labor, then an entire year's production can be lost. This is particularly the case where rainfall comes in a concentrated 6-week spell (Barnett and Whiteside 2002: 230). The range of potential effects of HIV/AIDS on farm households coupled with responses to it are summarized in Figure 6.

FOOD SECURITY	INCOME	LABOR
• Eat cheaper foods • Reduce consumption • Call in social & familial obligations (send children to relatives) • Eat wild foods • Beg	• Diversify income • Children leave school • Migrate • Borrow (from informal sector/relatives) • Sell assets (dissaving) • Use savings or investments (dissaving) • Beg	• Reallocate labor - e.g. work extra hours • Hire labor & draft animals • Decrease cultivated areas • Call in social & familial obligations (ask relatives to help) • Diversify income

Figure 6. Effects of HIV/AIDS on rural household economy.

3. Jane Alumira, ICRISAT, Matopos Research Station, Bulawayo, Zimbabwe.

A recurring theme in discussions of this nature is the role of off-farm employment and income. Simply put, a potential outcome of the escalation of HIV/AIDS in rural communities is more migration of people to urban areas, either temporarily (to obtain additional income) or permanently (following collapse of the rural household's capacity to sustain agricultural production). The degree to which HIV/AIDS contributes to urban migration is debatable (Douglas et al. 2001), as is the potential for urban industries to provide employment as the pandemic decimates workforces (Barnett and Whiteside 2002:242-270). Nonetheless, the potential for HIV/AIDS to affect the economic inter-relation between farm production and off-farm income cannot be ignored. We highlight this point, even though we recognize that there is as yet very little information or indication of clear trends (cf: Barnet and Haslwimmer 1993).

To summarize, HIV/AIDS threatens the existence of many rural African settlements, let alone local farming systems. Equally, however, any assessment of the impacts of the pandemic cannot ignore the fact that people will and do respond with further effects on the form and content of farming. In Africa, the traditional social welfare mechanism of extended family support is emerging as a key factor. Although a large-scale epidemic in a country, as seen in Uganda, may effectively destroy that "safety net" in many localities, it remains for the majority of rural residents the principal means to cope with HIV/AIDS. Dan Mullins (personal communication)[4] has portrayed the issue succinctly (Figure 7).

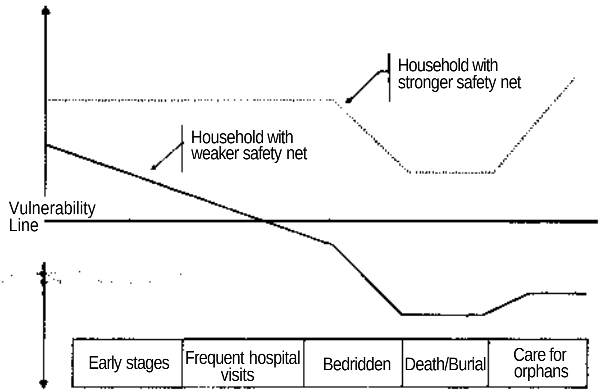


Figure 7. Effect of HIV on household security.

4. Dan Mullins, Oxfam Regional Office, Pretoria, South Africa.

An HIV/AIDS epidemic in a rural area is likely to result in the disappearance of some households; others are likely to be severely stressed yet survive. Yet, it is also possible that new forms of households may emerge.

Implications for agricultural research programs

There are three themes that we draw from the preceding text to guide discussion on how agricultural research programs might respond to the HIV/AIDS pandemic in Africa. These are:

a) The pandemic can be managed and contained.

b) African farm households, irrespective of location and situation, do and will respond to the pandemic in ways that modify (to a greater or lesser extent) the existing farming system.

c) The impacts of HIV/AIDS are wide-ranging and varied, with noticeable effects on particular segments of a population.

These themes suggest three immediate questions for agricultural research programs:

1) What are their possible contributions to management of the pandemic?
2) What household response factors should be considered in the design of projects, in order to ensure that projects provide appropriate support to farm households?
3) Can programs be designed in ways that serve a range of agendas, notably agricultural research/productivity agendas and broader social health and welfare support in relation to HIV/AIDS?

With regard to the first question, an appropriate answer requires an understanding of broader agendas that are shaping national and regional responses to the pandemic. We refer here to the impetus globally and within countries for a "multi-sectoral" response to the pandemic (Figure 8). HIV/AIDS was initially conceived as a "health issue", and responses were driven by medical science. However, in the light of difficulties in finding effective medical therapies and the wide-ranging socio-economic effects of HIV/AIDS, the pandemic soon came to be acknowledged as a "social issue" as much as a "health issue". Initially, programs in this vein were driven by efforts to prevent the spread of HIV/AIDS given that medical science was unable to control the pandemic; thus the emphasis on changing people's attitudes to the pandemic and sexual behavior.

Determinants	**Macro environment**	**Micro environment**	**Sexual behaviour**	**Biomedicine**
Interventions	Social policy - redistribution Legal Reform Human Rights Taxation Debt relief Terms of Trade	Social Policy Economic Policy Legal Reform Employment Legislation	Behaviour change communication Change beliefs, attitudes, 'mindsets' Condom promotion and marketing	STD treatment Blood safety Anti-retroviral therapy during pregnancy Provision of condoms

Figure 8. HIV/AIDS - A health and a social issue.

As the pandemic unfolded, it became apparent that HIV/AIDS infected, and affected, different segments of populations in complex and different ways. Sero-prevalence and other surveys showed that there were discernible patterns of variation in the spread of HIV/AIDS, and in its biophysical and socio-economic effects on individuals, communities and organizations. Consequently, that variation was addressed in terms of susceptibility and vulnerability to highlight socio-economic determinants of the pandemic. Accordingly, responses emerged that sought to mitigate the varied effects of the pandemic by changing the social environment. For instance, fears in most countries about the dangers of isolating HIV positive individuals, and acknowledgement that they could live productively for many years, inspired legal reform and legislation to protect people living with HIV/AIDS. Equally the scale and scope of poverty across the African continent has been drawn into public debate as a significant determinant of the pandemic.

These developments indicate how the demand for a multi-sectoral response has emerged internationally. This is not to say that the response is well defined and implemented in all quarters of the world. Research and intervention into the biomedical aspects of HIV/AIDS is well defined. There are gaps in medical scientific knowledge, but the general and specific problems and issues have been established. For instance, there is funding to support a range of vaccine research projects; HIV transmission via blood transfusion is largely controlled; and there has been considerable progress in preventing MTCT. However, initiatives to address the socio-economic determinants of the pandemic are still being debated and formulated. For instance, the need for coordinated, cooperative interventions between many agencies and organizations has been acknowledged, and this is reflected in Africa by the growing number of national HIV/AIDS strategic plans and regional strategic frameworks (Bjorkman 2001; Commonwealth 2001; International HIV/AIDS Alliance 2001; Stover and Johnson 1999; WHO 2001).[5] The relevance of these developments is that they indicate issues, themes and approaches for agricultural research programs to consider. Nonetheless, these frameworks alone are inadequate for they do not necessarily resonate with the actual circumstances and problems extant in rural localities. In other words, these frameworks provide a conceptual basis, but actual responses need to be formulated in relation to the work of programs on the ground in rural areas.

With regard to consideration of what would be appropriate support to farm households, local level research would be, of course, essential. Nonetheless, there are general trends that merit attention depending on the locality in which research is conducted. We provide three illustrations.

Firstly, we have highlighted the possible recourse of rural residents to the "safety net" of the extended family, coupled with the demise of households and emergence of new forms of households. A revival of "traditional" social norms coupled with innovation in social organization may challenge the premises of agricultural projects.

Secondly, we have indicated that women are more susceptible than men to HIV infection and that women in rural settlements may be particularly vulnerable to the socio-economic consequences of HIV/AIDS epidemics. Notably, they are vulnerable in the sense of carrying the burden of care for sick and dying members of a family as well as maintaining farming activities, particularly if the national government attempts to defray the costs of HIV/AIDS care onto citizens by promoting home-based care. Furthermore, they may be vulnerable in the sense of being left destitute without support if husbands and children succumb to the AIDS in strongly patriarchal communities. Gender, in short, is a pertinent factor in the context of agricultural research and development programs that seek to empower women or focus on them to be farmers. Such interventions may be well

5. Some African countries have established national AIDS commissions or councils within government to co-ordinate interventions. There are regionally oriented initiatives such as the International Partnership against AIDS in Africa (IPAA) which seeks to co-ordinate HIV/AIDS management initiatives in a number of East and West African countries, and is intending to do the same in some southern African countries.

intended, but the capacity of women farmers to sustain their involvement in agricultural projects may be diminished significantly by HIV/AIDS.

Thirdly, the relationship between the spread of HIV/AIDS throughout a locality on the one hand and, on the other, of rural-urban migration and reliance upon off-farm work and incomes to support the rural home, cannot be ignored. Migration and off-farm activities are a common economic trend throughout much of Africa. HIV/AIDS is potentially a factor that can exacerbate that trend, indeed, threaten the off-farm economic basis for smallholder agriculture. For instance, there may be increased reliance of rural households upon migrant/urban work for income as their capacity to grow food and earn incomes from farming is diminished by shortages of labor. Alternatively, sickness and death of a household member who sends cash remittances to the rural home may threaten the viability of the rural household to the point that it relocates itself to urban areas in order to survive or dissolves (with members such as children being sent to live with various relatives) and becomes part of one or more other households.

Consideration of local-level factors in relation to national and regional strategic HIV/AIDS plans must also take into account cross-cutting development frameworks that are guiding many local level interventions in rural sub-Saharan Africa. We refer here to broad geo-political agendas such as the continuing quest for "sustainable development" and improvement of democracy and governance in Africa. The sustainable development ethos under the rubric of "sustainable livelihoods", for example, drives a multitude of natural resource management and local economic development initiatives in Africa. Our point is not to go into these programs in detail, but to indicate that why they are pertinent factors in any consideration of how the design and implementation of agricultural research programs could begin to frame their contribution to a multi-sectoral response to HIV/AIDS.

In the first instance, "sustainable livelihoods" programs and "integrated natural resource management" programs overlap with agricultural research and development programs because, in one form or another, they seek to answer two key questions:

1) What sort of livelihood (s) is/are feasible in a locality in a particular set of circumstances?
2) What sort of livelihood(s) will contribute to improvement of the quality of life in, and condition of, an environment over time?

Admittedly, a research programmed that focuses on technological innovations is not necessarily as focused as a development-oriented programmed is on the application of (appropriate) technology in a particular context. The point is, however, that different programs seek a general common goal even though they may contribute different inputs. Secondly, HIV/AIDS is inevitably a key consideration in many development-orientated programs in Africa, because of the pandemic's profound social and economic implications. This is not to say that HIV/AIDS is the only significant health variable; malaria, cholera and other health factors may be more important in certain circumstances. However, even in circumstances where HIV/AIDS is not a predominant health factor, the threat that it could become so entails due consideration. These points infer that organizations such as ICRISAT need to begin a process of reflection that covers a wide range of themes and issues. The prospect may appear to be daunting, but there are established parameters and guidelines.

For instance, an underlying imperative of the various international development agendas is that organizations should adopt an adaptive operational and management framework. We use the term "adaptive" in contrast to traditional management techniques. The logic of the traditional management is that patterns and trends in an economy can be predicted accurately enough to permit managers to formulate medium terms plans with appropriate interventions, and adhere to them. At the risk of caricature, orthodox management tends to view changes to plans, in response to errors in predictions, as a weakness of management. Consequently, managers are directed to stick to prescribed plans rather than question whether the management approach itself may be wrong in the circumstances. In contrast, an adaptive management approach emphasizes the importance of management adapting its actions and responses in order to proceed incrementally towards a goal, and in the light of changing circumstances. The tools required are those that enable management to monitor indicators of change and progression, and regular creation of possible scenarios following specified interventions.

The rationale for "adaptive management" stems from a common theme of many current global agendas: to counter particular social, economic and political patterns and trends, and to define alternative long-term goals. These include, for example, promoting democratic governance (in countries that do and do not have a record in this vein); encouraging environmentally sensitive economic activities (at root, doing "development" differently from how it was conceived and done in the past); and setting uniform trade and commodity standards as an alternative to tariff barriers. Furthermore, there is considerable leeway as to how these goals are to be achieved. The emphasis is on incremental development: innovation, direct reference to the context in which an initiative is implemented, and revision of projects and programs as progress is made and as conditions change.

This approach resonates with concern about the HIV/AIDS pandemic because the diverse effects of the latter are very difficult to predict accurately; innovative interventions are necessary to prevent its spread as much as to reduce its impacts; collaboration and coordination of different agencies is required in many instances; and the plans and procedures must be revised, even supplanted, as success in particular quarters is achieved or if unanticipated impacts occur.

The potential for undirected, ill-defined changes to management plans is contained by a framework for intervention that has been developed, indeed, is still being elaborated, by environmental management agencies. We refer here to what is often cited as "integrated" strategic planning and management. The logic of this framework is presented in schematic form in Figure 9. It draws

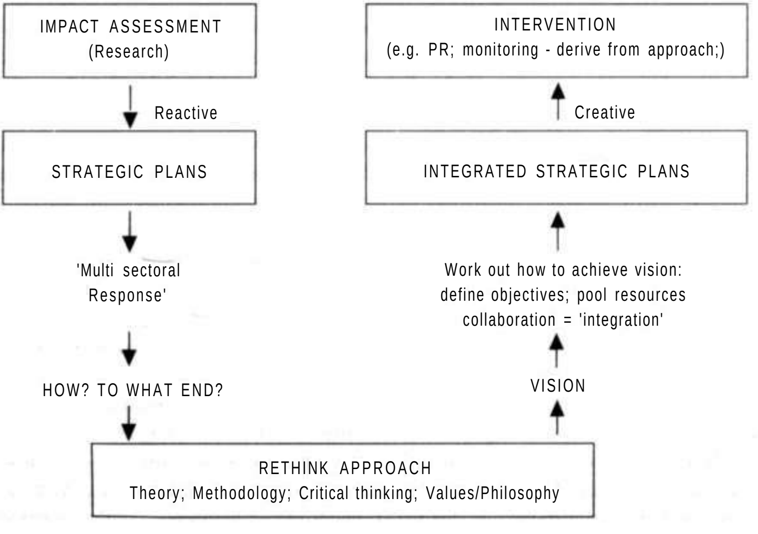


Figure 9. Integrated strategic planning.

upon the history of innovation in response to a concern that was as large 30 years ago as HIV/AIDS is today; namely, environmental degradation. Then, as now in HIV/AIDS research, the emphasis was a doing "impact assessments", to find out the nature, scope and magnitude of the problem.

Impact assessments were largely a reactive response to a perceived problem, and their purpose was to provide information that would inform the design of plans to resolve the problem. Impact assessments have proved useful for indicating possible responses to a problem at the level of a project. Equally, however, the recommendations that flow from them invariably highlight the fact that the issues being confronted at a project or local level are simply a manifestation of a much larger problem that is actually to big for a single agency, to resolve. Consequently, there is demand for a "multi-sectoral" response - coordinated action by many different agencies at different levels of society. It is at this point that HIV/AIDS researchers, like environmental scientists, have encountered the difficulty of harnessing a wide range of skills and resources. As much as the need for a "multi-sectoral" response may be acknowledged, it also inspires questioning and debate about how to do it and to what end as agencies attempt to understand what they are being asked to do, what they should do and why they should collaborate with other agencies.

That debate, on a large scale, has inspired substantive re-thinking, amongst scientists and policy makers, of how to organize research, planning and management of big problems such as HIV/AIDS and environmental degradation. The outcome has been a broader framework rather than an alternative. It begins with stating a vision; essentially, an idea of what the coordinated efforts of many people should achieve, be it improving the quality of life/an environment or ensuring care and support for children orphaned by HIV/AIDS. The vision simply starts a process of unpacking its elements, working out manageable objectives and the means to achieve them, and defining each initiative in relation to the broader aim and to other projects directed to the same end. "Integration" is commonly the term used to describe this process (holistic being the more philosophical and idealistic representation).

As is indicated in Figure 9, the formulation of integrated strategic plans summarizes the switch in approach, notably for collaboration between, and coordination of research, research, planning and management agencies, to serve practical goals and a long-term vision. That is fundamentally a creative rather than a reactive approach that results in interventions, which are subordinate to an overall aspiration. In practice, procedures like impact assessments acquire a new use; for instance, as means to monitor the effects of interventions and to indicate when modifications are necessary (i.e. adaptive management). Methodologies such as participatory research inform program and project designs because the emphasis is on promoting collaborative, creative ventures. In sum, we suggest that agricultural research programs can be designed in ways that serve a range of agendas, including global concern about HIV/AIDS.

Conclusion

Our purpose has been to show that HIV/AIDS is a significant cross-cutting factor in research, planning and management of development in Africa, in the SAT region. HIV/AIDS is not the only significant health factor to take into consideration. However, even in contexts where other factors are as or even more pressing, HIV/AIDS cannot be ignored because of the multiple threats it poses to society in general.

Those threats generate considerable uncertainty about how to respond in an effective, constructive way. We have indicated that an answer begins by recognizing that profound, on occasion, rapid societal change underlies that uncertainty. Accepting uncertainty as a norm has inspired a re-thinking of the role and responsibilities of many agencies involved in various fields of research, planning and management in Africa. In short, an understanding of how to work within this context has emerged. We have drawn on the experience of environmental research and management to illustrate that understanding, in view of the parallels being the threats posed by environmental degradation and HIV/AIDS.

In sum, we note there are relatively clear guidelines for ICRISAT's review of its activities and future course. The organization is to be commended for considering the issue. HIV/AIDS is, for much of Africa, the greatest development challenge.

References

Barnett, T and Blaikie, P. 1992. *AIDS in Africa, its present and future impact.* John Wiley, London.

Barnett, T and Haslwimmer, M. 1993. The impact of *HIV/AIDS on rural livelihoods and farming systems in eastern Africa.* United Nations/Food Aid Organisation, Rome.

Barnett, T and Whiteside, A. 2002. *AIDS in the twenty - first century: Disease and globalization.* Palgrave Macmillan, New York.

Bjorkman, H. 2001. Placing *HIV/AIDS at the center of the human rights development agenda: Implications for national development plans and budgets, poverty reduction strategies and sector plans.* Paper presented at 13 International Conference on HIV/ AIDS and STDS in Africa, Ouagadougou, 5-7th December, United Nations development program.

Bond, V. 1998. *Household capacity and 'coping up' in rural Zambia: Dealing with AIDS, other illness and adversity in Chiawa.* PhD. thesis, University of Hull.

Brummelhuis, H and Herdt, G. eds. 1995. *Culture and sexual risk: Anthropological perspectives on AIDS.* Gordon and Breach, Amsterdam.

Commonwealth. 2001. Regional *HIV/AIDS strategy for East, Central and Southern Africa 2002-2006.* Commonwealth Regional Health Community Secretariat, Arusha.

Douglas, I., Hall, D. and Anderson, J. 2001. *AIDS in Africa: The urban environment in Commonwealth Secretariat. 2001.* Global Health Challenge: Essays on AIDS, Commonwealth Secretariat, London.

Egal, F and Valster, A. 2001 . *HIV/AIDS and Nutrition: Helping families and communities to cope.* Food Aid Organisation, Rome.

Heise, L, Raikes, A, Watts, C and Zwi, A. 1994. *Violence against women: a neglected public health issue in less developed countries.* Social Science and Medicine, 39,9:410-414.

Hickey, A. 2002. *Common challenges in the fight against HIV/AIDS.* Synthesis report drawing from case studies of Botswana, Uganda, Thailand, Brazil and South Africa. Institute for Democracy in South Africa, Cape Town.

International HIV/AIDS Alliance. 2001. *Expanding community action on HIV/AIDS: NGO/CBO strategies for scaling-up.* International HIV/AIDS Alliance, Brighton.

Skordis, J and Nattrass N. 2001. *What is affordable: The political economy of policy on the transmission of HIV/AIDS from mother to child in South Africa.* Paper presented to the AIDS in Context Conference, University of Witwatersrand, April 2001.

Stover, J and Johnson, A. 1999. *The art of policy formulation: Experiences from Africa in developing national HIV/AIDS policies.* Policy Project Occasional Paper No. 3, USAID, Washington.

UNAIDS. 2002. Report on the global HIV/AIDS epidemic 2002. UNAIDS, Geneva.

Whiteside, A and Sunter, C. 2000. AIDS: the challenge for South Africa. Human and Rousseau Tafelberg, Cape Town.

WHO. 2001. *HIV/AIDS strategy in the African region: A framework for implementation.* World Health Organization regional Office for Africa, Harare.

Session 2: Discussion

Kimseyinga Savadogo[1]

- Linkage between food security and household nutrition is important. Examples of related interventions include income-generating activities targeting women and children in Burkina Faso.
- The government in Burkina Faso has recognized that increasing women's income improves household nutrition and is promoting projects on small ruminants.
- Gender issues are location and household specific. How do we deal with intricate intra-familial issues?
- The role of economics in addressing HIV/AIDS is minimal; instead, the pandemic as a human issue could be best addressed by social science.

Lydia Kimenye[2]

Comments made with special reference to the gender issues paper:

- Women are constrained by poor of lack of access to information for adoption of technologies; they are also constrained by a lack of power to amass and command resources necessary for adoption.
- Paper needs to give suggestions on how to deal with
  - i. Structural constraints that men and women farmers face e.g. with reference to micro-enterprises,
  - ii. A lack of access to seed by poor/women farmers.
- Need to include strategies employed by men and women so as to respond to shocks arising from macro-economic policy.
- Need for strategies that will enable men and women farmers exploit market opportunities within the context of globalization.
- How can technology development and exchange be linked so as to satisfy farmer preferences - do we need a basket of options?
- How can social sciences with new tools for gender analysis compliment economics work?
- Should research also focus on value addition for SAT crops so as to increase technology options?

---

1. University of Ouagandougou.
2. University of Nairobi.

Response by the panelists

- Differential resource endowment between men and women and impact of nutrition on women has well been document.
- Will revise paper to address issues raised by discussants.
- Economists often look for cheapest intervention e.g. home-based care versus community-based care of HIV/AIDS patients. What is important is doing research related to the context within which the results will be applied?

Plenary Discussion

Question	Response
Q1. Are SAT farmers producing for the international market?	Yes. There are food exports from the developing world to the western world.
Q2. What is being done to add value to sorghums and millets?	Value addition is necessary although very little value addition is taking place currently.
Q3. Can you say more about the contribution brought by incomers relative to that of existing farmers?	There are a number of websites coordinating trade in domestic and international markets and which in most cases are not mediated. Personal relationships are the norm but need to be backed by good standards.
Q4. Is there a potential for commercialization of SAT agriculture?	The African Growth and Opportunities Act (AGOA) opens opportunities to African products of good quality. Quality standards officers need to be educated more on this.
Q5. Is there a danger of institutionalizing the area of high quality standards?	This affects markets both on the production side and on the consumption side; and both big marketing chains and small groceries. Major drawback is that most farmers do not understand what good quality standards are.
Q6. Agribusiness presentation shows that SAT agriculture needs to go beyond what it is now. But only the few, modernized farmers can commercialize. Is there a way of targeting different types of farmers?	Small farmers need to be organized into cooperatives in order to produce for export. However, the largest market is the domestic market. Need to identify the right opportunities.

Continued

Question	Response
Q7. ***(a)*** Need to address some definitional issues to avoid conceptual problems: off-farm, non-farm, and remittances. ***(b)*** Micro-macro enterprise linkage important in transfer of resources back to the village. How do we ensure that the micro enterprise sector grows? ***(c)*** How can governments deal with actions/impacts of multinational companies?	Regionalization of trade will improve marketing in terms of price, timing and variety. But not all smallholder farmers will take advantage of this due to poor infrastructure and other biophysical/ edaphic factors.
Q8. What counter measures can developing countries take to protect their markets from dumping of sub-standard materials by the western countries?	WTO regulations on dumping are bad. African governments need to screen and /or put a tariff on agricultural products that are subsidized.
Q9. How can small farmers in developing countries benefit from globalization when developed countries are heavily subsidizing their own farmers?	Transnationals doing this are oriented towards big market chains. Important to select the right market because what you produce depends on the market you choose.
Q10. There are a lot of generalizations when discussing gender. Women do not farm equally across Africa.	Gender is location-specific. Hence gender analysis is a must in every area of work.
Q11. Did any specific gender issues that were specific to the SAT emerge from the literature review?	Differences in control of resources and power.
Q12. What new forms of households are emerging due to HIV/AIDS?	Some households are disappearing and new ones - especially those headed by grand parents are emerging. Makes it difficult to analyze households.
Q13. Gender paper has shown that research is embedded in a series of various issues. How best can these be tackled both methodologically and institutionally?	Will revise paper accordingly.
Q14. With reference to the food security paper, has research addressed the issue of how to best to fund research on food security?	Need to know and understand our stakeholders and involve them in defining relevant strategies. A lot of funding available for HIV/AIDS compared to agriculture. Need to link agriculture to HIV/AIDS.
Q15. How can policy research be best carried out in order to attain both food and environmental security?	Need to know and understand our stakeholders and involve them in defining relevant strategies.

Continued

Question	Response
Q16. Food security is multidimensional. The link between household food security and national food security was not clear in the paper. Need to show the most important limiting factors to food security both nationally and at household level.	Need to look at individual households and assess nutritional status and link this to poverty.
Q17. Human health is affected by both HIV/AIDS and malaria and perhaps much more by malaria. Resources need to be shared between HIV/AIDS and malaria.	HIV/AIDS should not be elevated above other research and development issues but be integrated into other issues.
Q18. Prof. Quinlan expressed some doubt on the existence of subsistence farming in Africa today. This needs clarification.	People are subsistence farmers either by choice or because they have been pushed into it by the high production and marketing costs of large scale farming.
Q19. How do researchers practically move forward with results from gender analysis?	Gender analysis helps in understanding the constraints faced by both men and women on the farm. Results should be (1) fed into the next level of research and (2) factored into changes within interdisciplinary teams.

Technology Trends and Prospects

This session addresses two broad questions: Are technologies currently available that can improve incomes and welfare among the rural poor? What new technology issues are emerging in the semi-arid tropics, and how can they be addressed? A range of appropriate technologies for cropping and agroforestry is available - and more breakthroughs can be expected through the judicious application of biotechnology - but adoption has been poor. The solution may be to further broaden partnerships; ensure that research priorities take better account of the target environment, farmers' preferences, market demand, and commercial incentives for technology adoption; and work with policy makers to create an enabling policy environment to stimulate adoption.

Two major constraints - water and soil fertility - are likely to become even more limiting in the future. Better water management will be needed. Institutional innovations are needed for better coordination, cooperation, and management of natural resources. Soil fertility must be improved by combining alternative sources of nutrients, with the emphasis on maximizing the returns from smaller, more affordable quantities of better-targeted nutrients. The growth of the livestock sector offers opportunities to better integrate crops, livestock and agroforestry into a sustainable, productive farming system. Agroforestry provides increased opportunities for income diversification.

Trends and prospects for livestock systems in the semi-arid tropics of sub-Saharan Africa

T Olalekan Williams[1], Philip Thornton[2] and S Fernandez-Rivera[3]

In semi-arid sub-Saharan Africa as in many dryland areas, livestock are an integral part of the farming systems. Livestock offer opportunities for risk coping, farm diversification and intensification and provide significant livelihood benefits to the poor. The ability of livestock systems to continue to provide these functions and services will depend on their future evolution pathways and development priorities which can be determined through a careful analysis of the dynamics, opportunities and challenges confronting these systems. The purpose of this paper is to review the development of livestock production systems in semi-arid tropics of sub-Saharan Africa. The paper examines the ways in which social, economic, institutional and technological factors have influenced the evolution of livestock systems and identifies promising research approaches, technologies, policy and institutional reforms that can improve systems' performance and sustainability and contribute to poverty reduction.

Introduction

Livestock play a critical role in the farming systems of the semi-arid tropics of sub-Saharan Africa. Animals are kept to complement cropping activities through the provision of manure for soil fertility maintenance and draft power for cultivation and transport. Livestock consume and add value to crop by-products that would otherwise be wasted or under utilized and they are often raised on land that has no other sustainable agricultural use. Farmers and pastoralists keep livestock as productive assets to reduce risk and consumption variability. For farmers in particular, livestock serve as a cash generator for seasonal requirements of agricultural activity. In poor crop

1. **International Livestock Research Institute (ILRI),** Ibadan, Nigeria.
2. International Livestock Research Institute (ILRI), Nairobi, Kenya.
3. International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia.

production years animals are sold to buy food for household sustenance, while in good years they provide an important investment opportunity for surplus funds. Livestock also provide highly nutritious food, income, employment and valuable foreign exchange earnings. With the predicted increase in demand for livestock products in developing countries over the next few decades and the importance of livestock for the livelihoods of poor farming households, understanding how livestock systems might change and adapt in the future is critical to the overall development of sub-Saharan Africa. This is particularly true in the semi-arid tropics where approximately 100 million poor livestock keepers live (authors' own estimation based on data reported in Thornton et al. 2002). This paper reviews trends in livestock systems across the semi-arid tropics of sub-Saharan Africa. It considers what the trends tell us about the prospects for the future and highlights the economic, institutional and technical constraints that must be overcome through research. It identifies promising approaches, technologies and policy options that can be used to improve the performance of the livestock sector in a sustainable manner and in ways that can reduce poverty and hunger. In what follows, we start with a classification and delineation of the livestock systems that are of importance in the semi-arid tropics of sub-Saharan Africa.

Classification of livestock production systems

Numerous livestock production systems exist in sub-Saharan Africa. Their diversity necessitates a system of classification to order and group similar systems for the purpose of identifying opportunities and constraints to livestock development. Following Sere and Steinfeld (1996), livestock production systems can be classified on the basis of land use, degree of integration of livestock with crop production and agroecology into eleven categories (Figure 1). Using the first two criteria, four livestock production systems can be identified namely: landless, rangeland (areas with minimal cropping), mixed rainfed (i.e. rainfed cropping combined with livestock) and mixed irrigated systems (cropping under irrigation with livestock). The rangeland and mixed systems can be further broken down by agroecological potential in terms of the average annual length of growing period (LGP) for crops and temperature into three zones viz. the highland/temperate zone defined on the basis of temperature, the arid/semi arid zone defined by LGP of less than 180 days and the humid/sub-humid zone with LGP greater than or equal to 180 days.

This classification scheme provides a useful starting point for our discussion of opportunities and challenges facing livestock development in the semi-arid tropics of sub-Saharan Africa. Although a continuum of livestock production systems ranging from landless (urban and peri-urban), rangeland and mixed rainfed can be found in the semi-arid tropics of sub-Saharan Africa, the main focus of this paper is on the rangeland (LGA) and mixed rainfed crop-livestock systems (MRA)[4] because they are the two most important systems in this zone.

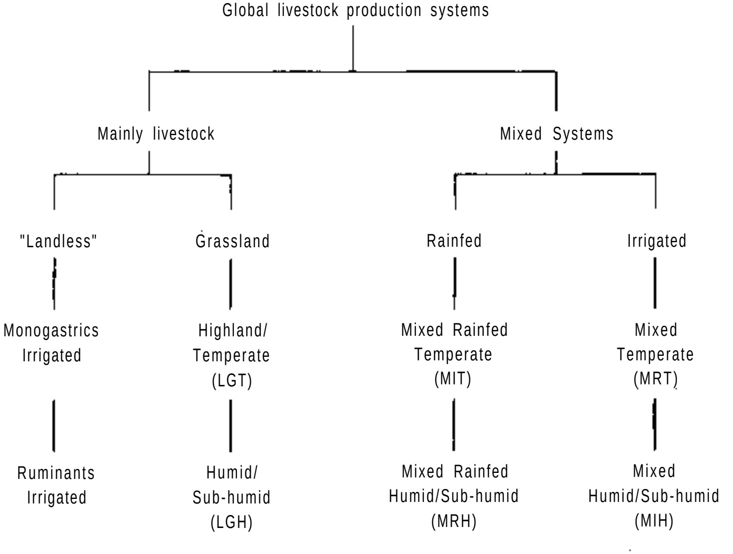


Figure 1. Classification of livestock production systems.

4. These two systems correspond to the pastoral and agropastoral (millet/sorghum) systems in the FAO classification of farming systems in sub-Saharan Africa (see Dixon et al. 2001).

Main features of the dominant livestock systems in the semi-arid tropics of sub-Saharan Africa

The rangeland system covers about 6 million square kilometers or approximately a quarter of the total land area in sub-Saharan Africa (Table 1). Land is the principal resource in this system but its quality and productivity is generally poor. The vast areas of land in the semi-arid zone that are marginal or unsuitable for crop production are well suited to extensive grazing and this serves to explain the prevalence of the rangeland system in this agroecological zone. The mixed rainfed crop-livestock system extends over 3.4 million square kilometers of land and together with the rangeland system occupies about 10 million square kilometers or 40% of the total land area in sub-Saharan Africa (Table 1). Although these systems can be found in all the four

Table 1. Land area by region and dominant livestock production systems in the semi-arid tropics of sub-Saharan Africa.

Region[1]	Total (Million sq. km)	LGA[2] (Million sq. km)	MRA[3] (Million sq. km)	Percent of regional total LGA (%)	Percent of regional total MRA (%)
West	7.3	1.6	1.1	21.7	14.8
Central	4.0	0.05	0.05	1.3	1.2
East	6.8	2.3	0.8	33.7	11.8
South	5.9	2.4	1.5	39.8	25.0
Sub-Saharan Africa (SSA) Total	24.1	6.3	3.4		
% of SSA Total		26	14		

1. The following countries are included in each region:

West Africa

Benin, Burkina Faso, Chad, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo.

Central Africa

Cameroon, Central African Republic, Congo, Democratic Republic of Congo, Equatorial Guinea, Gabon.

East Africa

Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Somalia, Sudan, Tanzania, Uganda.

Southern Africa

Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe.

2. LGA = Livestock only, rangeland arid/semi-arid systems
3. MRA = Mixed rainfed arid/semi-arid systems

Source: Based on data compiled from FAO databases and reported in Thornton et al. 2002.

major regions - west, central, east and south - of the sub-continent, **the** relative area occupied in each region differs. The two systems are of less importance in central Africa where they occupy only 2.5% of the 4 million square kilometers of land in this region, but appear to be the dominant land use systems in southern Africa where they cover 65% of the approximately 6 million square kilometers of land in this region.

In the mixed rainfed system where cropping is feasible, the principal cereals are pearl millet and sorghum grown either in pure stands or intercropped with legumes such as cowpea, groundnut and sesame. Where the land quality permits, maize is also grown. Cereal production is principally geared toward the satisfaction of household needs, although periodic sales occur when money is needed to meet household obligations. The main cash crops are cowpea, groundnut and cotton.

In both the rangeland and rainfed mixed systems, livestock consist mainly of cattle, sheep, goats, donkeys, camels and poultry. The rangeland system carries approximately 33% and mixed rainfed system 23 % of the 233 million Tropical Livestock Units (TLUs) found in sub-Saharan Africa (Table 2). These two systems between them carry over half of the TLUs found in sub-Saharan Africa. East Africa with about 65 million TLUs in both systems has twice as many TLUs as West Africa, which ranks next in order of livestock population.

In the year 2000, the two livestock production systems provide direct livelihood benefits, including food, employment and income, to about 200

Table 2. Tropical Livestock Units (TLUs*) by region and dominant livestock production systems in the semi-arid tropics of sub-Saharan Africa.

Region"	Total (Million TLUs)	LGA (Million TLUs)	MRA (Million TLUs)	Percent of regional total LGA(%)	Percent of regional total MRA(%)
West	55.5	15.5	21.6	27.9	38.9
Central	10.7	0.5	0.9	4.7	8.4
East	131.4	47.4	17.5	36.1	13.3
South	35.6	12.8	12.5	36.0	35.1
Sub-Saharan Africa (SSA) Total	233.2	76.2	52.5		
% of SSA Total		33	23		

*TLU means Tropical Livestock Unit, i.e. an animal of 250 kg live weight.
"The regions and all other terms are as defined under Table 1.

Source: Based on data compiled from FAO databases and reported in Thornton et al. 2002.

million people (Table 3), out of which 97 million were poor people eking out a living on less than 1 US dollar per day (Table 4). By 2050, it is predicted that the same systems will have to cater for the direct needs of 464 million people (Table 3). These statistics underline the importance of these two livestock production systems and demonstrate why they merit considerable attention in the quest to reduce poverty and hunger in the semi-arid tropics of sub-Saharan Africa. In the next section, each system will be briefly examined in order to highlight system-specific opportunities and challenges.

Table 3. Human population by region and dominant livestock production systems in semi-arid tropics of sub-Saharan Africa, 2000 and 2050.

	Year 2000					Year 2050				
				Percent of regional total					Percent of regional total	
Region	Total (million)	LGA (million)	MRA (million)	LGA (%)	MRA (%)	Total (million)	LGA (million)	MRA (million)	LGA (%)	MRA (%)
West	225.2	9.3	77.3	4.1	34.4	536.8	24.6	193.1	4.6	36.0
Central	75.2	0.2	4.0	0.3	5.3	218.4	0.5	10.6	0.3	4.9
East	219.2	21.7	33.9	9.9	15.5	531.5	55.6	78.3	10.5	14.7
South	107.3	10.8	41.9	10.1	39.0	206.9	18.8	82.1	9.1	39.7
Sub-Saharan Africa (SSA) Total	627.0	42.0	157.1			1493.6	99.6	364.2		
% of SSA Total		7	25				7	24		

Source: Based on data compiled from FAO and World Bank databases and reported in Thornton et al. 2002.

Table 4. Number of poor using $1/day poverty threshold by region and dominant livestock production systems in the semi-arid tropics of sub-Saharan Africa, 2000.

	Total	LGA	MRA	Percent of regional total	
Region	(million)	(million)	(million)	LGA (%)	MRA (%)
West	130.3	5.1	48.2	3.9	37.0
Central	36.1	0.1	1.9	0.3	5.2
East	77.0	9.6	12.6	12.5	16.3
South	35.6	3.1	16.0	8.8	45.0
Sub-Saharan Africa (SSA) Total	279.0	18.0	78.7		
% of SSA Total	7	28			

Source: Based on data compiled from FAO and World Bank databases and reported in Thornton et al. 2002.

System-specific issues

Rangeland system

Livestock production under this system relies almost exclusively on natural vegetation in rangeland, with minimum dependence on imported inputs. There is periodic movement of animals in search of natural pastures and water. During the rainy season, the most productive strategy is to move animals to the edge of the arid zone away from cultivated fields to take advantage of the flush of high quality forage produced by annual grasses and to prevent damage to standing crops. During the dry season, pastoralists return with the animals to the villages to access water, crop residues and natural forages growing near the villages to maintain the productive capacity of their herds (Sandford 1982). This migratory system creates opportunities for mutually beneficial exchange relationships between pastoralists and farmers. The exchanges of cereal grain, crop residues and water for manure have linked crop and livestock production for many years in the Sahel (Toulmin, 1983). Within each season, pastoralists take advantage of the patches of pasture that produce more and/or better quality forage either due to higher soil moisture or fertility (Scoones 1989). In terms of output, the rangeland systems in the early 1990s supplied 42 and 75% of the meat and milk produced in sub-Saharan Africa (de Haanetal. 1997).

When properly managed, livestock in rangeland systems can improve soil cover and water infiltration by dispersing seeds and breaking up soil crusts with their hooves, and control shrub growth by removing biomass which otherwise might provide fuel for uncontrolled bush fire. These impacts together with the production of manure stimulate grass tillering and improve seed germination that in turn improves land and vegetation. However, when improperly managed, resource degradation, especially of land and biodiversity, can occur in these systems. Heavy grazing particularly during the initial phase of plant growth, can lead to soil compaction and, in undulating terrain, accelerate erosion thus decreasing soil fertility, organic matter content and water infiltration and storage. Heavy grazing, particularly during the initial phase of plant growth, can also change the composition and plant species mix in a rangeland thereby reducing its productivity and plant diversity. But in many drylands, vegetation yield may be low, not because of livestock grazing, but because of low rainfall and drought. Evidence from the Sahel indicates that vegetation may quickly recover when rainfall improves (Hiernaux 1996).

A breakdown of the rangeland system involving extensive grazing system is occurring in many parts of the semi-arid tropics. Farmers have taken over the best grazing lands and converted them into cropland, overriding and ignoring the traditional use rights of pastoralists to these rangelands. In West Africa, this process has been accompanied by the increasing cultivation of valley bottoms which has restricted pastoralists movement and prevented them from using these areas as migration routes or pastures during the dry season (Turner 1993). The net effect has been a reduction in total pasture area and seasonal inaccessibility to remaining pastures due to fragmentation caused by cropping and expansion of dry season gardening to low-lying areas. This has forced the pastoralists to remain on deteriorating rangelands and has increased conflicts between pastoralists and farmers. Such conflicts over access rights to rangelands have also been reported in East Africa. Nonetheless, it remains true that in the dry parts of the semi-arid zone the rangeland pastoral system represents a rational and profitable system of land use. The challenge to research institutions and development agencies is to devise institutional arrangements that encourage collective action in the joint utilization and management of multi-participant resource systems with fluctuating benefit streams in order to improve livestock production and natural resource use in a sustainable manner in the pastoral zone.

Mixed rainfed crop-livestock system

Mixed farming systems in which crop and livestock production are integrated on the same farm serve as a bridge between the rangeland and 'landless' industrial systems. In the early 1990s, mixed farming systems supplied about 50 and 25% of the total meat and milk produced in sub-Saharan Africa (de Haan et al. 1997). Given the limited access of farmers to external inputs, mixed farming systems represent the main avenue for intensification of food production in sub-Saharan Africa. Mixed farming systems allow the waste products of one enterprise to be used as inputs in the other enterprise (e.g. crop by-products as feed for livestock, animal manure as fertilizer for crops and draft power for land tillage). The provision of manure by livestock is particularly important in those areas where poor soil fertility constitutes a critical constraint to food production. Adding manure to the soil replenishes nutrients removed by crops and creates a better environment for soil micro flora and fauna. Manure also increases the nutrient retention capacity of soil, improves soil structure and physical condition by increasing the water holding capacity. Despite the advantages of mixed crop-livestock systems, the varying degree of integration of crop-livestock production activities seen across the semi-arid tropics indicates that there are still important constraints that inhibit greater integration. For instance, the lack of adoption of forage legumes and the low demand for animal draft power in many parts of the semi-arid tropics have been partly attributed to the absence of price incentives and market conditions under which these technologies have thrived in other parts of sub-Saharan Africa (Mclntire et al. 1992). Competition for land between food and feed production and high labor demands of mixed farming may also limit crop-livestock integration. Integrated crop-livestock systems are labor demanding in terms of crop residue and fodder harvesting, feeding and herding of animals and manure collection and spreading. Although the point at which labor conflicts will appear in land-scarce and land-abundant zones may differ, the potential for conflict between cropping and livestock for labor is nonetheless real (Delgado 1989; Mclntire et al. 1992). It is clear, however, that mixed crop-livestock systems will remain an important part of the agricultural development process in the semi-arid tropics of sub-Saharan Africa both because of the limited growth potential of the extensive grazing systems as a result of population pressure which forces farmers to convert rangeland into cropland and because taking advantage of complementary crop-livestock production interactions represent a least-cost route to agricultural intensification.

Future trends and issues

Livestock production systems evolve in response to increase in human population, income growth, urbanization, and improvements in market access, transport and infrastructure. Recent projections of demand for meat and milk in sub-Saharan Africa indicate that over the next 20 years, total consumption of meat and milk will more than double from about 5.5 and 16.6 million tonnes now to 11.3 and 35.4 million tonnes of meat and milk, respectively. By 2020, total production of meat and milk will also double from about 5.4 and 15.8 million tonnes now to 11.0 and 33.5 million tonnes of meat and milk, respectively (Ehui et al. 2002). These statistics indicate that sub-Saharan Africa will remain a net importer of milk and, to a limited extent, meat and raise a number of issues, which must be addressed in order to improve productivity of livestock production and close the gap between demand and supply. These issues relating to feeds, nutrient management, animal and human health and environmental concerns are discussed here.

Feeds

Inadequate availability of feeds represents an important constraint to animal production in sub-Saharan Africa. For animals raised within rangeland and mixed farming systems, a number of feeds are available most of which have limited alternative value. These include pastures, shrubs, browses, crop residues, agro-industrial by-products and household wastes. Increasing pasture production through area expansion is no longer feasible due to the fact that across Africa, the most productive rangelands are being turned into cropland as the demand for arable land increases (Cleaver and Schrieber 1994; Williams 1998).

In the rangeland system, the scope for increasing range forage production per unit area through the introduction of improved forage species and use of inorganic fertilizer is limited because these technologies are not cost-effective under extensive grazing system. The main options to improve feed availability in this system include controlled grazing to prevent pasture degradation, facilitation of herd mobility and access to different pasture areas to take advantage of the spatial and temporal variability in feed availability and implementation of effective information systems on feed availability in different areas and early warning systems ahead of impending feed shortages caused by drought. These options call for a strengthening of local resource use institutions to promote collective action in the use and management of rangelands or, where these institutions have proved inadequate, the establishment of new ones to negotiate and guarantee the rights of pastoralists to feed resources.

In the mixed crop-livestock system, crop residue production has not increased proportionately with increases in crop yields simply because the emphasis in the past has been on maximizing grain yield. In this system, technologies that increase the quantity and quality of crop residues through the use of improved genotypes of food-feed crops and agronomic practices remain the most promising approach for increasing feed supply. The successful adoption of these technologies, however, will depend on appropriate socio-economic and market conditions (Williams et al. 1997). Similarly, the introduction, adaptation and adoption of herbaceous legumes and multipurpose leguminous trees will enhance future feed supply in mixed systems.

Nutrient management

Depletion of soil nutrients in many parts of the semi-arid tropics is a critical constraint to feed and food production and a very serious cause of soil degradation. It is one factor that causes land extensification. As the discussion under the mixed farming systems indicates, livestock play an important role in soil fertility maintenance in sub-Saharan Africa through the supply of manure. However, village- (Williams et al. 1995) and regional-level (Fernandez-Rivera et al. 1995) studies in the semi-arid zone of West Africa have shown that although manure is a critical resource in this system, its availability is limited and manure alone cannot sustain soil fertility. Beyond the nutrients that can be provided by animals, inorganic soil nutrients and feed supplements from outside the farm or community are needed to maintain the nutrient balance in many systems, particularly in the mixed system. While the negative environmental consequences of fertilizer use must be avoided, in most developing countries the problem is not excessive, but insufficient and inappropriate fertilizer use. To increase total farm productivity in many mixed farming systems, an integrated nutrient management approach that combines organic and inorganic sources of soil nutrients and feed resources is needed in contrast to the component piecemeal methods currently in use in most areas.

Animal and human health concerns

Between the early 1980s and 1990s, many countries in sub-Saharan Africa implemented structural adjustment and economic reform programs that reduced the role of the state in the provision of veterinary services. This reduction in public veterinary services has led to a resurgence of endemic animal diseases and reduced livestock productivity. There is a continuing debate on the appropriate role of the public and private sector in the provision of animal health care and strategic policy research is needed to inform this debate and suggest ways in which the private sector can be encouraged to fill the void created by the withdrawal of the state in the provision of certain services. Beyond this, as the demand for food of animal origin increases and 'landless' industrial livestock production expands, diseases of intensification will become important. Industrial livestock production will also bring about new public health risks. Increased animal concentration in areas of high human population density may facilitate transmission of zoonotic diseases such as tuberculosis, brucellosis, avian flu and salmonellosis between production units and between animals and human beings. Appropriate animal management strategies and regulatory measures are needed to reduce the negative human health impacts while promoting good animal husbandry practices.

Environmental issues

A range of direct and indirect environmental impacts is usually associated with livestock production. Site-specific and production systems related effects include land degradation in grazing and mixed farming systems which can reduce overall systems productivity. These negative environmental impacts often arise as a result of external pressures which turn well managed common property lands into open access areas. In addition to these direct effects, there are other environmental impacts that extend beyond specific production systems and which are becoming topics of global concern. These include issues of climate change and impacts on production systems, carbon sequestration in rangelands, the effects of livestock rearing on wildlife and emission of green house gases such as carbon dioxide, methane and nitrous oxide. A preliminary attempt to assess the possible impacts of rainfall and temperature changes over the next five decades on production systems in sub-Saharan Africa predicted shifts in West Africa from rangeland-based systems to mixed, and in East and southern Africa, the disappearance of mixed highland systems (Thornton et al. 2002). With respect to green house gases, animals emit carbon dioxide as a result of their respiratory activities but methane emission results from the digestion of fibrous materials and is highest when feed quality and level of animal production is low. Nitrous oxide is produced in animal manure. The challenge will be to minimize these emissions through technologies that produce better quality feed and through improved manure collection, storage and utilization.

Research implications

Research is needed to guide the process of change and adaptation that the livestock systems in the semi-arid tropics will undergo in response to increased demand for livestock products and to minimize the environmental and health risks that may be associated with the expansion of production. This research will span the continuum from basic to adaptive research and will involve technical as well as socio-economic and policy work conducted in a participatory manner, with farmers and pastoralists in a central position. They are the ones with the greatest knowledge of local conditions and needs and they must be involved in the research process.

Future research must come up with appropriate technologies to improve animal productivity and boost crop yields. Increases in animal productivity come largely from technological advances in animal breeding, feed production and its efficient utilization by animals and disease control. Crop breeding and agronomic research to improve grain and stover yields and the nutritive value of crop residues will serve to increase feed availability. Improving soil fertility is crucial to increasing overall agricultural productivity in the semi-arid tropics. In addition to manure, which is already commonly used, other organic sources of nutrients and inorganic fertilizers will also be needed as well as research on improved nutrient cycling to reduce nutrient losses. Use of cereal-legume mixtures and introduction of fodder shrubs and trees, for example, agroforestry systems with three strata: grass, leguminous fodder shrubs, and trees, will improve feed availability and soil fertility, provide vegetation cover and reduce soil erosion and pressure on rangelands. Agronomic and ecological studies on the long-term effects of grazing on the vegetation and soil at different spatial scales (e.g. watershed, village and farm levels) will be needed to inform decisions on appropriate grazing regimes.

New scientific knowledge in genomics and biotechnology can be employed to speed up technology development, for example, in marker assisted selection of desirable traits in dual purpose cereals and legumes or in the manipulation of rumen function to maximize ruminants' capacity to digest roughage and reduce fermentation gases (CH_4 and CO_2) that contribute to global warming. Overall, technical research should be geared toward producing a diversified range of technological options to suit the needs of farmers and pastoralists with different resource endowments, management skills and ability to bear risk.

At the same time that research on the technological front is being pursued, socio-economic, institutional and policy research will be needed to identify incentives, policy and institutional strategies to improve technology adoption and utilization and encourage collective action in the management of grazing resources. This is because animal production is strongly influenced by cultural, institutional and socio-economic factors such as ethnicity, differences in access to resources, household and community decision-making and as such livestock rearing needs to be viewed not only from a production perspective, but also from the wider socio-economic and institutional setting. Research on the best institutional arrangements to guarantee pastoralists' access rights to dry-season grazing areas and mechanisms for community-based conflict resolution to deal with problems between pastoralists and sedentary farmers over access to land and water would be useful to improve livestock productivity and reduce land degradation in the rangeland and rainfed crop-livestock systems.

On another front, the projected upsurge in the demand for livestock products and the changes it would bring about in livestock production practices raises a number of questions, which will need to be analyzed through socio-economic and policy research. For instance, will the trends observed and projected for increased livestock production provide employment for the poor in such a way as to narrow the income gap between the poor and wealthier groups or will it accentuate income disparities? What incentives and policies are needed to ensure smallholder participation in market-oriented production? Will the trends towards increased intensification make smallholder producers uncompetitive vis-a-vis large-scale producers, given the large economies of scale that the latter group can derive from huge capital and technology investments? What measures are needed to ensure that small-scale producers will still be able to compete with the large-scale producers as. health and quality standards rise? How should local-level institutions be organized to promote cooperative action, which small-scale producers will need to reduce the high transactions costs of processing livestock products that may act as market entry barriers to them?

Overall, considering the technical, socio-economic and policy research needs, it is clear that only an integrated participatory research approach with an emphasis on the whole production system and value-chain can make a tangible impact in improving livestock productivity and the livelihoods of the poor farmers and livestock keepers in the semi-arid tropics.

Policy and institutional environment

The success of investments in the promising technologies and approaches discussed in the previous section will depend on an enabling environment that promotes technology adoption, innovation, entrepreneurship and devolution of power to local-level institutions. The policy and institutional environment - input and output markets, credit, interest rate and trade policies, rural infrastructure, extension services, and farmers' self help organizations etc - remains considerably weak in sub-Saharan Africa. This weakness inhibits technology adoption in several ways. For instance, poorly developed infrastructure and thin markets delay timely availability and increase the cost of external inputs thereby compromising productivity increase and availability of marketable surplus. Given that an appropriate policy and institutional environment is critical to the successful adoption of new technologies, what incentive policies and support institutions are needed to encourage technology diffusion and adoption?

Initially, the major factors likely to facilitate the adoption of new technologies, particularly those requiring purchased inputs, are: well functioning input and output markets, a good network of roads to ensure access to these markets and credit and remunerative prices for the final products. The catalytic role that credit and a good inputs distribution system can play in promoting sustainable intensification of crop-livestock systems have been demonstrated in many case studies across west, east and southern Africa (Williams, et al. 2000). Although researchers are not in a position to implement these policies directly, they are well placed to highlight them and to point out their significance to policy makers using various media including workshops, seminars and policy briefs. Identifying policy options that are feasible from the policymakers' perspective and are acceptable to farmers is an important research activity in any quest to improve productivity and sustainable management of natural resources.

Further, in most African countries, institutional changes are needed to empower farmers' organizations to fill the vacuum created by the withdrawal of the state from the provision of extension services. Institutional changes might include formation of farmers' associations, cooperatives and decentralization of extension services where they still exist with more local government control. Human capacity building and training in such areas as management and leadership practices, organizational planning and conflict resolution skills will be needed to promote the establishment of local self help organizations to serve the interests and champion the cause of smallholder farmers and pastoralists.

Conclusions

The review of trends and major issues affecting livestock production systems in the semi-arid tropics of sub-Saharan Africa presented in this paper provides a glimpse of the tasks that lie ahead. There are new opportunities to be tapped and challenges to be surmounted. Opportunities arise from the unprecedented growth in demand for food of animal origin, which, if properly managed, can raise incomes and enhance the nutritional status of the poor in sub-Saharan Africa. However, the opportunities created by rapidly increasing demand for livestock products may conflict with the limited potential to expand the conventional resource base given that area expansion is no longer an option in many parts of sub-Saharan Africa. Furthermore, a major productivity gap measured in terms of the difference between the level of output attainable and what is currently attained per animal remains. This gap must be closed without jeopardizing the long-term productive capacity of the natural resource base. The need to link increased livestock productivity with improved management of natural resources calls for an integrated research approach with a greater emphasis on improving whole production systems, in a market-oriented fashion, rather than focusing on specific commodities. The complexity and range of problems to be solved are such that they cannot be adequately addressed through a mono-disciplinary approach. Multi-disciplinary collaboration and participatory approaches are needed to elicit and incorporate stakeholders' perspectives into problem diagnosis, research design and technology development. But apart from developing new technologies, appropriate policies are needed to provide economic incentives for sustainable growth of livestock production in the semi-arid tropics of sub-Saharan Africa in the coming decades.

References

Cleaver, KM and Schreiber, GA. 1994. *Reversing the spiral: The population, agriculture and environment nexus in sub-Saharan Africa.* The World Bank, Washington, DC.

de Haan, C, Steinfeld, H and Blackburn, H. 1997. *Livestock and the environment: Finding a Balance.* European Commission Directorate-General for Development, Brussels.

Delgado, C. 1989. *The changing economic context of mixed farming in savanna West Africa: A conceptual framework applied to Burkina Faso.* Quarterly Journal of International Agriculture 28: 351-364.

Delgado C, Rosegrant, M, Steinfeld, H, Ehui, S and Courbois, C. 1999. *Livestock to 2020: The next food revolution.* IFPRI / FAO / ILRI, International Food Policy Research Institute, Washington, DC.

Dixon, J, Gulliver, A and Gibbon, D. 2001. *Global farming systems study: challenges and Priorities* to 2030. FAO (Food and Agriculture Organization of the United Nations), Rome.

Ehui, S, Benin, T, Williams, TO and Meijer, S. 2002. *Food security in sub-Saharan Africa to 2020.* Socio-economics and Policy Research Working paper 49, ILRI (International Livestock Research Institute), Nairobi, Kenya

Fernández-Rivera S, Williams T O, Hiernaux P and Powell J M. 1995. Faecal excretion by ruminants and manure availability for crop production in semi-arid West Africa. In: Powell J M, Fernández S, Williams T O and Renard C (eds.) *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa. Volume II. Technical Papers.* Proceeedings of an International Conference held in Addis Ababa, 22-26 November 1993. International Livestock Centre for Africa, Addis Ababa, Ethiopia, pp 149-169.

Hiernaux, P. 1996. *The crisis of Sahelian pastoralism: ecological or economic?* Pastoral Development Network Paper 39a, Overseas Development Institute, London.

Mclntire, J, Bourzat, D and Pingali, P. 1992. *Crop-livestock interaction in sub-Saharan Africa.* Washinton, DC. The World Bank.

Sandford, S. 1982. *Pastoral strategies and desertification: opportunism and conservation in drylands.* In Desertification and Development: Dryland Ecology in Social Perspective (Spooner, B and Mann, HS eds.). New York: Academic Press.

Scoones, I. 1989. *Patch use by cattle in a dryland environment: farmer knowledge and ecology theory.* In People, Land and Livestock (Cousins, B ed.). Harare: Centre for Applied Social Sciences, University of Zimbabwe.

Sére, C and Steinfeld, H. 1996. *World livestock production systems: Current status, issues and trends.* Animal Production and Health Paper No. 127. FAO, Rome.

Thornton, PK, Kruska, RL, Henninger, N, Kristjanson, PM, Reid, RS, Atieno F, Odero, AN and Ndegwa, T. 2002. *Mapping poverty and livestock in the developing world.* ILRI (International Livestock Research Institute), Nairobi, Kenya.

Toulmin C. 1983. *Herders and farmers or farmer-herders and herder-farmers?* Pastoral Development Network Paper. 15d. London: Overseas Development Institute.

Turner, MD. 1993. *Life on the edge: Fulbé herding practices and the relationship between economy and ecology in the inland Niger delta of Mali.* PhD Dissertation, University of California-Berkeley, USA.

Williams TO, Powell JM and Fernández-Rivera S. 1995. *Manure availability in relation to sustainable food crop production in semi-arid West Africa: Evidence from Niger.* Quarterly Journal of International Agriculture. 34(3): 248-258.

Williams TO, Fernández-Rivera S and Kelley TG. 1997. *The influence of socioeconomic factors on the availability and utilization of crop residues as animal feeds.* In: Renard C. (ed.), Crop Residues in Sustainable Mixed Crop/Livestock Farming Systems. CAB International, Wallingford, Oxon, UK., pp 25-39.

Williams, TO. 1998. *Multiple uses of common pool resources in semi-arid West Africa: A survey of existing practices and options for sustainable resource management.* Natural Resource Perspectives. No. 38. Overseas Development Institute, London.

Williams, TO, Hiernaux, P and Fernández-Rivera, S. 2000. *Crop-livestock systems in sub-Saharan Africa: Determinants and intensification pathways.* In: Property Rights, Risk, and Livestock Development in Africa (McCarthy, N, Swallow, B, Kirk, M and Hazell, P. eds.). International Food Policy Research Institute, Washington, DC. and International Livestock Research Institute, Nairobi, Kenya, pp. 132-151.

Crop technology: Trends and prospects

Rodomiro Ortiz[1]

Agriculture is still the most important economic activity and source of income in sub-Saharan Africa. Hence, rural sector development through public and private entrepreneurs offers a means for alleviating poverty and enhancing the livelihoods of rural people, who grow somewhat research-neglected crops with minimum inputs in risky environments of the semi-arid tropics that are affected by unpredictable weather, limited and erratic rainfall, drought, nutrient-poor soils, as well as pest and diseases. Crop genetic improvement provides a means for addressing major constraints and prospects in the semi-arid tropics if within the framework or a market-driven research agenda that will consider both input and output traits. Input traits such as resistance to insect pests, diseases (bacteria, fungi, viruses), and weeds such as striga, or acceptable performance in stress-prone environments (e.g. owing to drought, heat or salinity) lead to yield stability, while output traits affecting quality and end-uses provides new options for generating or improving people's incomes.

An international agenda in research-for-development

There are two important pillars in international agricultural research, namely integrated gene management and integrated natural resources management, which includes integrated pest management. Both pillars together with socio-economics and policy analysis constitute the focus of the core of an international research agenda for agriculture in the developing world (Ortiz, in press). By working in these domains, any international center and its research partners in the national agricultural research systems, advanced research institutes, civil society, sister centers of the Consultative Group on International Agricultural Research (CGIAR), and other stakeholders will be able to achieve its mission, i.e. applying science to improve agriculture in areas of the world where "marginal crops are grown on marginal lands with marginal

1. International Institute of Tropical Agriculture (IITA), Oyo State, Nigeria.

resources". Enhanced and sustained crop productivity will, indeed, help to improve human health and rural household food security.

International research centers must move into the new millennium by properly addressing the challenges of sustaining food security, alleviating poverty and protecting the environment, by being proactive in its new triple role as bridges, brokers and catalysts in rural development (Ortiz, in press). Professionals working in international agriculture should become research bridges by fostering the international sharing of knowledge, skills and technology, e.g. by making available online crop and resource information databases or through technology exchange (Mahalakshmi et al. in press). They will be international brokers when helping their partners to negotiate acceptable transaction terms on intellectual, genetic and other proprietary assets, for example through material transfer agreements for international public goods (Dodds et al. 2001). Last but not least, these scientists should be catalysts for launching creative and innovative approaches such as participatory research methods for an enhanced management of natural resources, crop protection or new breeding techniques ensuing from the advances in applied genomics of model crops (Ortiz and Crouch 2001).

Technology ensuing for crop improvement within a development trajectory[2]

The research-for-development agenda to help the most disadvantage rural people living in the semi-arid tropics of Africa should allow the rural poor of today to have a brighter future with the adoption of emerging technology ensuing from genetic enhancement of crops (Ortiz 2000). This research-for-development philosophy considers a "small landholder development trajectory" from subsistence to commercial scale (Figure 1), in which the farmers are not homogeneous and research products should help them to move along the trajectory. Hence, plant breeders need to offer a broad array of products because low input environments require a yield stabilizing technology, whereas matching technology to achieve high yield potential should be developed for high input environments. Such a moving target needs to be addressed by a heterogeneous, but dynamic strategy. Plant breeders along this trajectory must use all available research tools for development. In

2. This section ensues from discussions with MD Winslow (ICRISAT, India) and B Douthwaite (1ITA, Nigeria).

this way farmers in the African semi-arid tropics may move from marginal agriculture to an improved system.

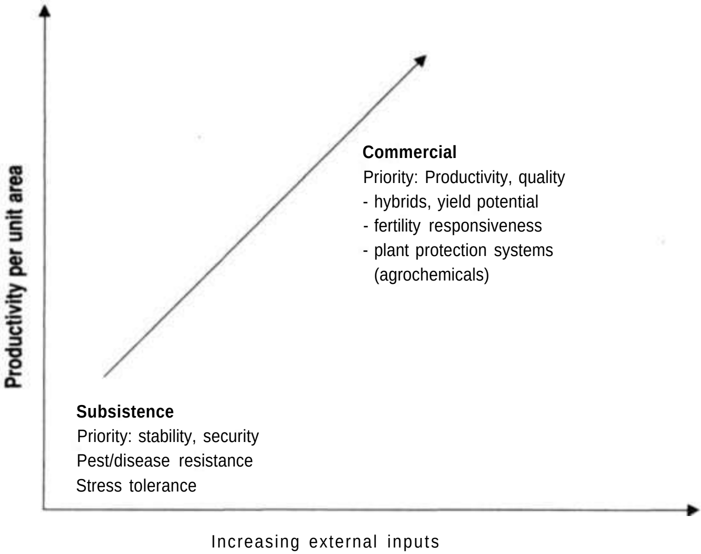


Figure 1. Landholder development trajectory (After Ortiz et al. 2000).

Increasing productivity per unit area leads to more food, extra produce for sale and other crops may be included due to enhanced productivity of the land. Likewise, the higher and more stable yield potential and profitability permit poor farmers to invest in inputs for producing more food and income, whereas high yield may lead to reducing food prices for the urban and rural poor. Furthermore, high yielding crops may provide job employment for poor people throughout the trade chain (from harvest to processing).

The main role of science in agriculture has been to propel this evolutionary process by generating innovations that allow us to produce more with less land and less effort (Douthwaite and Ortiz 2001). However, sometimes people's hopes and fears are centered on the technological changes that it may bring. Some have found it useful to think of technology change as an evolutionary process. People, as a result of the pressures they face and the opportunities they see, learn and then generate new ideas, things, and ways of organizing themselves. If these innovations work well then others adopt them and they spread. Agricultural change is built up of many replications of this innovation generation, selection and diffusion process, just as we have evolved through countless natural selection iterations. Unlike natural selection though, this "learning selection" process is not blind (Douthwaite 2002). Seen in this context biotechnology is a suite of tools that speeds up a guided evolutionary process because it allows plant breeders to introduce a greater array of changes into their cultivars, and select much faster than they could using conventional plant breeding techniques. The tools that allow faster innovation generation and selection include functional genomics and transgenics for overcoming barriers to allele transfer and for appropriate targeted expression in a crop. However, because it is a guided process, who benefits depends on who controls the technology, who innovates, how selection decisions are made, and how innovations are promulgated (Douthwaite and Ortiz 2001).

Priority setting for plant breeding

Crop improvement objectives are many when public plant breeders submit their work plans. An international or regional crop-breeding program needs a clear priority setting for crop improvement whose structure and aims are relevant to the target environments, markets and end-user demands. It should also consider the comparative advantage, owing to its competitive edge, of the breeding programs and the prospects for its impact in both farmers' field and science. An emphasis on crop breeding towards a market-oriented production in the farming system, which may require more external inputs, should lead to an increasing emphasis on product quality, processing and nutritional value. As such, plant breeding faces new challenges that need quantitative indicators to guide priority setting for crop improvement. Then, options for crop genetic enhancement through conventional breeding or biotechnology must ensue from agreed goals and objectives for delivery of innovative germplasm to the end-users, i.e. both farmers and consumers in rural and urban areas.

The plant breeding paradigm

Plant breeding provides a means to close the gap between actual and potential yield in stressed environments (i.e. marginal dry areas) through genetic manipulations (Acevedo and Ferreres 1993). Crops or cultivars within each crop are replaced with others showing better fitness in an environmental gradient arising from the physical limiting uncontrolled factor. Therefore, farmers and breeders search for crop tolerance in these gradients arising from the specific stress. Breeders know well that cultivars with a high yield potential are not able to out yield stress resistant cultivars (i.e. a crossover interaction) in the respective stressful environment. These high yielding cultivars may even perform poorly in stressful environments.

Researchers, farmers and policy markers should also keep in mind the plant breeding paradigm that economic phenotype performances (P) are influenced by many factors and their interactions as indicated in the equation below (Ortiz et al. 2002):

P = Genotype x Environment x Crop Management x Policy (affecting both people and markets) x Institutional Arrangements x Social Demographics

Two approaches are advocated for breeding under stress environments: (a) increasing yield on broadly adapted genotypes (Rajaram et al. 1997) or (b) exploiting genotype adaptation (particularly of landraces as at least one parental source) and fit cultivars to the specific targeted environment (Ceccarelli 1997). The two approaches may stem from a distinct perspective in understanding adaptability and adaptation that could affect the preservation of genetic variation in respective crop breeding pools. Adaptability, which depends on the available genetic diversity within each population, refers to the capacity for genetic response to selection that results in adaptation. However, when cultivars are highly adapted to a specific environment there will be less adaptability for evolutionary change, which appears to be essential for sustained crop improvement by both farmers and professional plant breeders. Decentralized (through networking) and participatory plant breeding with local partners may provide a means for compromising both approaches while breeding in marginal, low input, stressful environments. Decentralization of plant breeding requires refining target areas, targeting local research partners for crop improvement and shifting responsibility from a central breeding station to local undertakings (which may not only include germplasm testing but also new material generation through specific crosses with landraces for further selection). In this way, individual breeding programs (irrespective of their size) will deliberately maintain genetic diversity across locations.

A new philosophy for genetic enhancement in the African cropping systems

DeVries and Toenniessen (2001) argue strongly for the need of biotechnology and end-user participatory methods for crop breeding in Africa, which should be driven by the needs of the rural poor to ensure such work has a positive impact on their livelihoods. Plant breeding, to become cost-effective and efficient in Africa, must follow an agro-ecozone approach with farmers participating with professional plant breeders in developing locally adapted cultivars. This will need to rely on responsive local seed systems for its dissemination to the farming community. An important aim for crop breeding in Africa should be "to assemble a set of traits that reduce yield loss and confer greater yield stability" (DeVries and Toennienssen 2001)

Decentralized country-level breeding programs are mandatory because these teams can only operate efficiently when near the various targeted agro-ecozones for each crop. The CGIAR centers should play a facilitating role to allow these country-level programs to succeed (DeVries and Toennienssen 2001; Douthwaite 2002). Hence, international centers and advanced research organizations should allocate their resources to tackling with innovative crop breeding methods - including biotechnology, the most "intractable" or difficult to-breed-for traits that affect crop productivity in African semi-arid tropics.

The next pages give an overview of advances in integrated gene management showing examples for facilitating access and use by plant breeders, successes in participatory plant breeding, and deploying biotechnology for crop genetic enhancement in the developing world, particularly the semi-arid tropics of Africa.

On-going germplasm enhancement in the CGIAR

The current objectives of the international centers of the CGIAR are to improve breeding populations of major world crops, and release this advance germplasm to meet farmer's needs in the developing world (Ortiz 1999). CGIAR breeders are developing broad-based germplasm populations with potential for local adaptation and stable performance in targeted agro-ecozones. Local adaptation should consider resistance to pest and diseases, tolerance of abiotic stress(es), and end-user demand(s). The end-user demand depends on the cropping system, derived product(s), and quality for fresh market, storage, and processing.

Genetic gains in successful breeding programs result not only from a high heritability for the target trait(s) plus a high selection intensity, but also from combining high mean with broad genetic variance for target trait(s) in the source population, a minimum number of years and sites for testing, and a dynamic selection approach (Ortiz and Golmirzaie 2002). Breeding plans for any crop should rely on information about the target population and data analysis of genetic experiments. In this way the breeding plan will include logical steps such as choosing appropriate parents for crossing schemes, early or late selection in segregating or clonal generations - determined by trait heritability, and adequate environment sampling (i.e. number of locations and years) for testing advanced breeding materials. Of course, these breeding plans depend on objectives, operation costs, cultural practices in targeted environments and even policy affecting cultivar development and marketing. Nonetheless, the major goal of the breeding plan will always be to enhance the efficiency of the selection process.

On-station genetic enhancement (Figure 2). The program starts with the collection of plant genetic resources in farmers' fields and local markets. Gene bank curators define core subsets with passport and characterization descriptors. Geneticists make crosses according to the breeding goals to determine the genetics of target characteristics. Breeders develop improved germplasm through population improvement methods. Parents are selected based on their general combining ability, and elite crosses chosen according to their specific combining ability. The cyclical recurrent scheme begins with the release to national agricultural research systems of elite progenitors, advanced lines, hybrids or clones, and open pollinated populations, composite crosses, synthetics or cultivar mixtures.

Best linear unbiased estimators (BLUE) and best linear unbiased predictors (BLUP) may be included to determine the breeding value of particular individuals in selected populations. They are best because they have a minimum sampling variance and are linear functions of observed genotypes. The conventional selection index should be considered as a special case of BLUP with known fixed effects (Falconer and Mackay 1996). DNA markers may also provide a means for indirect selection of complex characteristics. Also, genome research with molecular markers may "unleash the genetic potential of our wild and cultivated germplasm resources" (Tanksley and

McCouch 1997). For example, DNA marker-aided analysis could identify specific chromosome regions of exotic germplasm to be added to breeding populations.

On station germplasm enhancement

Collection from farmers and markets

↓

Gene-bank (conservation, characterization, core subsets)

↓

Crosses to determine genetics (e.g. mapping QTL) and start breeding

↓

Population improvement of pops, based on GCA (parents), SCA (crosses)

↓

(Cyclical recurrent scheme starts by releasing to NARS elite progenitors, and advanced lines, hybrids, or clones, as well as open pollinated populations, composites, synthetics and cultivar mixtures)

Figure 2. On station genetic enhancement in an international program. GCA and SCA refer to general and specific combining ability, whereas NARS means national agricultural research system (after Ortiz 1999).

Adaptive multi - locational testing in target environments (Figure 3). Germplasm released to national partners by an international breeding program has been often tested in multi-locational experiments. Statistics provide a means to local breeders to select stable high-yielding genotypes. This local selection of material from a broadly based germplasm may result in the development of adapted cultivars resistant to or tolerant of endemic stresses. Some of the locally adapted advanced materials are not only for cultivar release but also they may be incorporated into the breeding populations of the international program for the next cycle of recombination and on-station selection. On-farm selection of locally adapted new cultivars, jointly by plant breeders and farmers, may be needed because in some regions breeders and farmers choices could diverge, especially in environments where farmers have a wide range of preferences. Sperling et al. (1993) suggested that farmer participatory breeding may also enhance genetic diversity and reduce the research costs.

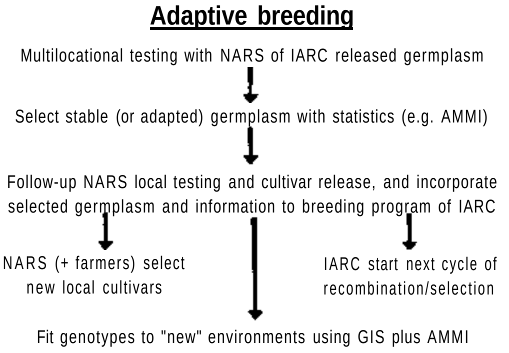


Figure 3. Adaptive breeding of advanced material as a result of cooperative research between national agricultural research systems (NARS) and an international agricultural research center (IARC). In this scheme farmers are also research partners, especially to select new local cultivars. A statistical tool such as the additive main effect multiplicative interaction model (AMMI), and geographic information systems (GIS) provide a means to fit genotypes into specific environments (after Ortiz 1999).

Clustering environments and fitting genotypes into target areas. Mega-environments are broad, not always continuous, often transcontinental areas with similar climatic factors, cropping systems, biotic and abiotic stresses, and consumer preferences (Braun et al. 1996). They were defined by international programs to breed and target adapted genotypes. In this way, plant breeders are dealing with the genotype-by-environment interaction that affects crop performance. Multivariate statistical analysis of geographic information system (GIS) agroclimatic datasets could help determine mega-environments (Pollak and Pham 1989; Pollak and Corbett 1993). However, mega-environmental classification does not always explain all significant associations among locations (De Lacy et al. 1994). Therefore, ordination and clustering of locations based on the discrimination of germplasm should be compared with mega-environmental groupings to identify locations where major stresses affecting performance are yet unidentified.

According to Gauch and Zobel (1997), statistical methods for identifying mega-environments should meet four criteria: "flexibility in handling yield trials with various designs, focus on that fraction of the total variation that is relevant for identifying mega-environments, duality in giving integrated information on both genotypes and environments, and relevance for the primary objective of showing which genotypes are best where". One of such methods is the additive main-effects multiplicative interaction (AMMI) model, which was developed to facilitate the interpretation of the genotype-by-environment interaction as well as to identify genotypes adapted to specific niches. AMMI uses the conventional analysis of variance and the principal component analysis to find any pattern in the data. This procedure, which splits the interaction into pattern and noise, allows making better predictions for suitable genotypes in specific environments. AMMI can be used to define mega-environments in which genotypes are relatively stable.

New tools for "mining" plant genetic resources held in gene banks

The operations of a modern gene bank are not restricted to collection, characterization, regeneration and documentation. A germplasm collection that is not fully exploited is simply a museum of plant accessions or a living herbarium. Conserving and enhancing plant biodiversity is an essential part of sustainable genetic enhancement of crops. Therefore, by promoting the broad utilization of plant genetic resources, gene banks are fulfilling their role in improving human well-being. Improved use of plant genetic resources can help alleviate poverty, increase incomes, and create new income-earning opportunities.

Breeding gains rely on access to useful genetic variation in the respective crop gene pools. If genes available in wild species are to be put into a usable breeding form, it is important that the long-term research agenda includes development of advanced gene pool stocks (Ortiz 2002). In recent years, some gene banks have made significant investments in studies to determine the extent of genetic diversity, because this knowledge enables proper germplasm organization and development of improved parents and new cultivars. In this way, gene bank curators can maximize the utilization of wild and cultivated gene pools in crop breeding.

Genetic resources and human nutrition. Poor public health and shortage of food are distinctive crisis features of highly indebted poor countries (HIPC). One third of all children under the age of five in the HIPC are malnourished and physically stunted, a feature which affects the rest of their lives. Their diets are often deficient in Vitamin A, leading not only to malnutrition, but diseases, and in severe cases, blindness. Interesting to note that a few rare accessions of pearl millet, the cereal of the harsh semi-arid tropics, possesses a yellow endosperm, which contains beta-carotene, the precursor of Vitamin A. Plant breeders should transfer this trait into high-yielding cultivars of this crop following biofortification approaches already showing success in other crops such as yellow-flesh cassava, orange-flesh sweet potato, quality protein-maize, and Golden Rice™, which are good examples of viable and practical methods of improving the health prospects of vulnerable social classes.

Wild species for enhancement of research-neglected crops of the semi-arid tropics. Breeders use genetic resources of wild species particularly for resistance breeding (Lenne and Wood 1991). The levels of resistance to pests and diseases available in primary genes pools are sometimes low or only a limited number of resistance sources seem to be incorporated into elite materials by plant breeders. Furthermore, selection pressure on pathogen populations due to widespread homogeneous host plant resistance may result in more virulent strains that may overcome that resistance. Therefore, discovery and incorporation of new genes for resistance from wild species provides a means for sustaining crop improvement (Ortiz 2002). Although durability of resistance cannot be predicted (Johnson 1992), genetic diversity through pre-emptive breeding may provide buffering against crop losses arising due to changes in the pathogen population (Mcintosh 1992).

A few genes from wild species have been also transferred to the cultivated gene pool by interspecific hybridization followed by embryo culture (Mallikarjuna 1999), which overcomes the cross incompatibility that often occurs after pollination in the so-called "wide-crosses" between species. Some of the barriers to interspecific hybridization are associated to abnormal embryo development, endosperm disintegration, abnormal development of ovular tissue (or somatoplastic sterility due to prolific growth of nucellus or integuments), weak F_1 hybrids owing to genetic disability or disharmony (e.g. nuclear genome-cytoplasm incompatibility), and sterile F_1 hybrids, which may occur due to the lack of pairing arising from non-homology or structural incompatibility between donor genomes. Fertile F_1 hybrids provide a greater versatility for gene introgression or incorporation.

In some interspecific incompatible crosses, fertilization occurs but the embryo aborts a few days later. Hybrid plants may be obtained by preventing pod abscission and saving aborting hybrid embryos with "rescue" techniques. Germplasm enhancement with wild species has seldom resulted in direct cultivar release, but many parents with "wild" genes became available for breeding crops of the semi-arid tropics (Ortiz 2002). In this way, new breeding stocks could be generated to combat more virulent pathotypes when they become important.

Better gene bank and biodiversity management using new molecular tools. Molecular markers (Table 1) are helping to unravel patterns of diversity in crops and their wild relatives. For example, analysis of molecular data reveals genetic similarities among groundnut, chickpea, pigeonpea, cowpea, cassava and sorghum primary gene pools. A new approach involving gene location plus isolation and transfer through transgenics may be needed to access genes from wild species secondary and tertiary gene pools. Furthermore, with the advances in genome sequencing, germplasm collections held in trust in the CGIAR (and other) gene banks and associated genotypes and phenotypic databases are potential sources for allele discovery (or "gene mining"), which in the near term may become an important research area in international genomics initiatives, to gain a better understanding of available genes (and their functions) in key agricultural species (IITA 2001).

Table 1. Major classes of genetic markers (After Ortiz and Crouch 2001).

Morphological traits such as seed or flower color are seriously limited in number and their expression can be differentially affected by the environment.

Proteins, seed storage proteins, structural proteins and isozymes provide very cost-effective markers but their number may be limiting and their expression is not neutral.

Restriction fragment length polymorphism (RFLP) requires hybridization of probe DNA with sampled plant DNA and although provides high quality data has a severely restricted throughput potential.

Random amplified polymorphic DNA (RAPD) was the first of a new generation of markers based on the polymerase chain reaction (PCR). This technique uses arbitrary primers for initiating amplification of random pieces of the sampled plant DNA. This technique requires no knowledge of the genome to be screened but suffers from problems of inconsistency when transferred between populations and laboratories.

Simple sequence repeat length polymorphism (SSR). This technique provides high quality, highly consistent results but the markers are expensive to develop, as they require extensive sequence data from the species of interest. However, once developed this type of marker is easily transferred between populations/laboratories and is amenable to high throughput screening.

Amplified fragment length polymorphism (AFLP). In this approach the sample DNA is enzymatically cut up into small fragments (as with RFLP analysis) but only a fraction of fragments are

Continued

Table 1. *Continued*

studied following selective PCR amplification. Although this assay provides a great quantity of marker information, it is not particularly well suited to high throughput marker-assisted selection.
Expressed sequence tag (EST). The development of EST markers is dependent on extensive sequence data of regions of the genome that are expressed. However, once developed they provide high quality, highly consistent results and because they are limited to expressed regions of the genome, markers themselves are directly associated with functional genes. As with SSR markers, EST markers are amenable to high throughput screening.
Single nucleotide polymorphism (SNP). The majority of differences between individuals are point mutations due to single nucleotide polymorphisms. As such, there are a vast number of potential SNP markers in all species. Massive amounts of sequence data are required to develop SNP markers, particularly as many may be population specific. However, their great advantage lies in the potential to screen them through simple yes/no tests, which can be readily automated to facilitate mega* throughput screening through the use of technologies such as micro-arrays.

Sorghum as a model for a core collection.[3] The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) holds the largest collection of sorghum landraces, which today represents a challenge for the maintenance of both the accessions and the information documented for this germplasm. Accessibility and knowledge of this collection are essential factors for an efficient use of sorghum genetic resources by both breeders and farmers. This large size of the sorghum landrace collection maintained by ICRISAT led to the establishment of a core collection (Grenier et al. 2000a; Grenier et al. 2000b; Grenier et al. 2000c; Grenier et al. 2001a; Grenier et al. 2001b).

Core collections are subsets of large germplasm collections, containing chosen accessions that capture most of the genetic variability in the entire collection. Thus, developing a core collection improves the management and utilization of a germplasm collection. Core collections are assembled considering a hierarchical structure of the gene pool. The entire collection can be stratified into groups sharing common characteristics according to taxonomy, geographic or ecological origin, and neutral or non-neutral descriptors, followed by sampling within these groups. By using this process core subsets can be identified. Genetic studies in selected crops have shown that common widespread and localized alleles occurring in the entire collection are contained in the core subset. Only rare localized alleles may be excluded during the sampling process. The core subset often provides an entry point to the entire collection for further investigation of biodiversity or for the utilization of these resources.

3. The author thanks Dr Paula Bramel for sharing and discussing some of the information provided in this section.

Morpho-agronomic and molecular research were undertaken to define sorghum core collections and to compare each of their sampling procedures (Grenier et al. 2000a, Grenier et al. 2000b, Grenier et al. 2001a, Grenier et al. 2001b). During this research, an assessment was also made, according to geographic and taxonomic classification, to determine the diversity pattern maintained in the landrace collection and its adequacy. This assessment indicates that the sorghum collection held in trust at ICRISAT was underrepresented for the race *bicolor* and for accessions from China. Furthermore, this assessment highlighted redundancies especially in races *caudatum* and *durra,* and in the germplasm acquired from East Africa and South Asia. Different sampling strategies, either random or non-random, were proposed to obtain core subsets of reduced size. Three subsets were established following a random sampling within a stratified collection (logarithmic strategy: L), a sample based upon morpho-agronomic diversity (principal component score strategy: PCS), and a sample based upon an empirical knowledge of sorghum (taxonomic strategy: T). Comparisons of these samples for morpho-agronomic characterization and passport information were assessed to determine their impact on phenotypic diversity (Grenier et al. 2000a). For their overall diversity, the three subsets did not differ, as shown with the two-dimensional representation of the morpho-agronomic diversity and the Shannon-Weaver diversity indices. When comparisons for morpho-agronomic and passport data were considered, the PCS subset looked similar to the entire landrace collection. The L subset showed differences for characters associated with the photoperiod reaction that was considered in the stratification of the collection. The T subset was the most distinct from the entire landrace collection as it over-represented the landraces selected by farmers for specific uses and covered the widest range of geographical adaptation and morpho-agronomic traits.

Microsatellite markers (SSR) are used in crops to differentiate among genotypes and as tools in marker-aided selection and gene introgression. Early research with the sorghum world collection showed significant variation in the five microsatellite markers examined: 2.4 was the average number of alleles per locus within accessions and 19.2. in the whole sample of 25 accessions (Dje et al. 2000). This sorghum collection seems to be highly structured genetically with about 70% of genetic diversity accounted for among accessions. In contrast, morphologically defined races of sorghum, or the geographic origins accounted for less than 15% of the total genetic diversity. This result shows that microsatellites are useful in the identification of individual accessions with a high relative contribution to the overall allelic diversity of the collection. Hence, microsatellite markers were used to quantify genetic diversity in each of the sampling procedures (PCS, L, T) using polymorphism at 15 microsatellite loci (Grenier et al. 2000b). The landraces of each subset were genotyped with three multiplex polymerase chain reactions of five fluorescent primer-pairs each with semi-automated allele sizing. The average allelic richness for each subset was equivalent (16.1, 16.3 and 15.4 alleles per locus for the subsets PCS, L, and T, respectively). The average genetic diversity was also comparable for the three subsets (0.81, 0.77 and 0.80 for the subsets PCS, L, and T, respectively). Allelic frequency distribution for each subset was compared with a chi-square test but a few significant differences were observed. High percentages of rare alleles (71-76% of 206 total rare alleles) were maintained in the three subsets. The global molecular diversity retained in each subset was not affected by the phenotypic sampling.

Agrohiodiversity and pest management. Partial assessment of host response to five sorghum diseases in the entire and core collections provided a means to quantify the importance of agro-biodiversity in disease management (Lenne and Ortiz, in press). Frequency distributions were the same between the entire collection and core subsets for all diseases, except between the entire collection and the L core subset for grain mold, which was not surprising because the sampling strategy for this core subset and the material included in the screening for this disease did not match. Furthermore, the entire collection and core subset included the same range and distribution of variation with only the above stated exception for grain mold in the L core subset. New accessions with high resistance to specific diseases are likely to be identified by completing the screening of the core subsets. This rational, targeted approach may also be cost-effective and more precise than long-term screening of the entire collection.

Core selection to enhance germplasm utilization and meet specific users needs. Large landrace collections are a challenge for the maintenance of both the accessions and the information documented for this germplasm. Accessibility and knowledge of this collection are essential factors for efficient use of the genetic resources. These collections are often the result of collecting missions and specific research programs that may be an over representation of certain materials. Core collections improve the sampling while selecting accessions from a germplasm collection. However, static core collections, which are a *priori* selected by the curator, are often of limited use to users of the gene bank who are interested in a specific trait or accessions of a specific type. In traditional core collections, the domain definition, division of the domain into distinct groups, determination of the number of accession from each group and the choice of accessions from each group are all done *a priori* by the curator. A core selector program allows the user to choose the domain of interest (van Hintum 1999). Mahalakshmi et al. (in press) following the ongoing revolution in information technology provide gene bank users with software to select accessions through the World Wide Web from germplasm data containing both qualitative (non-parametric traits such as glume color) and quantitative (parametric traits such as plant height) descriptors. For the parametric trait the user can choose the number of groups (between 5 and 20). The size of core selection is to be given between 1% and 10% of the total collection size. The allocation over groups is based on either proportional or logarithmic sampling strategy, with a minimum of one for the small groups. This approach provides the users with a tool to create more focused selection of the germplasm than the traditional core collections, but with broad representation of diversity within the selection.

Farmers in the "driving seat"

A woman farmer was the first to domesticate a plant species for human cultivation, and for many hundred years, farmers have been able to keep dynamic and productive agro-biodiversity in their fields, which was driven by the need of ensuring sustainable food supply (Ortiz, in press). However, during domestication and evolution of plant species in the farming systems, the original agro-biodiversity was replaced if it did not meet the farmers' needs. Furthermore, agro-biodiversity *per se* does not seem to be an insurance to control diseases (Lenne and Ortiz, in press). Useful genetic variation could be acquired from a few germplasm sources only. Hence, farmers change agro-biodiversity by introducing new forms of the crop (i.e. migration) or other plants species or by selecting mutants arising *de novo* or hybrid genotypes derived from natural outcrossing.

Farmers have also accumulated for many generations, native or traditional knowledge for crop management, which includes selecting promising materials or introducing pest control in their specific geographical areas. The CGIAR acknowledges, therefore, the important role of farmers in not only influencing but also involving them for assessing and developing together with its researchers a wide range of new, improved and locally adapted crop technology in the developing world.

Okashana-1 - the impact of farmer participatory research in Namibia.[4] Okashana-1 is an early-maturing, high-yielding pearl millet cultivar developed by ICRISAT and partners through the Sorghum and Millet Improvement Program (SMIP). The parent material for this cultivar originated in Togo and was collected jointly by ICRISAT and national partners. ICRISAT breeders in India crossed this raw material with several lines of African origin. Teams in Zimbabwe and Namibia improved it further through selection and regional adaptation trials. A non-government organization initiative in Namibia involved smallholder farmers in participatory cultivar selection. Farmers expressed a strong preference for Okashana-1 (or ICTP 8203), insisting on a "fast - track" release. Therefore, Okashana-1 was released in 1989, and is now grown on 49% of Namibia's pearl millet area. The benefits generated have a net present value (in 1998) of US$ 11 million (Rohrbach et al. 1999). This widespread adoption was essentially due to partnerships. National research and extension staff worked with farmers to promote the new cultivar and distribute seed. The national program developed a farmer-based seed production system with technical support from SMIP, funding from development investors, and advisory assistance from national policy makers and other development agents. This system has now grown into a financially self-sustaining farmers' cooperative that produces over 200 t of certified pearl millet seed each year.

The success of Okashana-1 in Namibia results from the introduction of genetic material improved by ICRISAT breeders, early involvement of farmers in participatory selection, rapid cultivar release responding to farmers' preferences, and the commitment of the national government for high-quality seed multiplication and dissemination (Bidinger 1998). The success of the pearl millet improvement program for Namibia has increased the confidence of the public research and extension services in their capacities to promote technological change.

Owing to its early maturity and large grains, Okashana-1 became popular but its weak stalks made this cultivar very susceptible to lodging especially

4. The author acknowledges Drs Emmanuel S Monyo (ICRISAT, Zimbabwe), Fran Bidinger (ICRISAT, India), and Eva Weltzien-Rattunde (ICRISAT, Mali) for sharing information that allowed thee writing of this section.

after maturity. Because of its large bold grain, Okashana-1 was also more susceptible to storage pests than smaller seeded local landraces. Adoption of improved cultivars depends on whether or not the cultivars meet farmers' needs, and possess the quality that farmers prefer. Hence, plant breeders should keep in mind farmers needs for specific plant characteristics and grain traits. As a result small-scale farmers demand better cultivars and are in the lead in the pursuit of this through their active involvement with researchers in new cultivar development.

The Maria Kaherero Composite (MKC). The MKC population was initially based on a set of half-sib progenies obtained from a field in Ruacana that belonged to a woman farmer called Maria Kaherero. Namibian farmers were seen to deliberately plant Okashana-1 alongside local cultivars, aiming to exploit natural cross-pollination to introgress traits such as grain hardness and stalk strength from local landraces into Okashana-1. The resultant outcrosses were more vigorous than Okashana-1, with larger heads and stronger stalks, and farmers deliberately selected these outcrosses to provide seed for the following season. Maria Kaherero used this approach for four cropping seasons (1989 through 1992). When ICRISAT was requested to assist in the initiation of a breeding program for Namibia it was natural to recommend that the program continue to be guided by farmer's needs through farmer participation in all stages of cultivar development. Many of the farmers who participated were also hosting on-farm trials. The selected farmers could visit the research station at least once a week for participatory selection from the breeding nurseries, monitoring and evaluation, including processing and taste tests. In 1992, ICRISAT and national breeders selected half-sib progenies from Maria's field for further improvement at the research station. These were random mated with other 30 farmer selected materials from 150 that were under national testing on station and in the on farm testing program during the 1992/93 season for three more seasons to constitute the Maria Kaherero Composite (MKC). The constituent varieties in MKC were therefore jointly identified by farmers for preferred traits and by the breeders for their suitability to improve yield and agronomic characters.

A detailed analysis on traits most preferred by farmers, was performed comparing accessions from MKC with those from the two other composite populations, the Farmers' Germplasm Composite Population (FGC) and NC90, which were developed using conventional methods. The majority of the genotypes selected by farmers for constitution of the new participatory breeding population were earlier than the local landrace, had excellent seed set with large bold grains, and medium to tall height with thick strong stalks that do not lodge. The joint selection by breeder and farmer was stricter on earliness without sacrificing yield. Up to 14.5% of the material in NC90 required more than 70 days to reach half bloom, compared with only 2.16% in MKC. The frequency of high-yielding accessions (i.e. yield >3.30 t ha^{-1}) in MKC was higher than in NC90, 21.61% of the accessions versus 18.21%. The highest-yielding accession in FGC yielded only 1.26 t ha^{-1}. Mean kernel sizes for the FGC and NC90 populations were medium (1.227 g and 1.300 g / 100 kernels), while MKC had large kernels (1.441 g). From this participatory breeding endeavor it became clear that the pearl millet ideotype for Namibia would have the following characteristics: early maturity without sacrifice on yield, drought tolerance, large grains and good threshability. It should be preferably taller than Okashana-1, but with strong stalks that does not lodge (Ipinge et al. 1996). In fact the Namibian farmer prefers an Okashana-type cultivar with improved storage pests resistance and improved lodging resistance (Monyo et al. 1996).

The major contribution of farmers' participatory research to Namibia's pearl millet breeding program has been provision of early maturity cultivars (Okashana-1, Okashana-2 and Kangara), which are also constituent elements in the MKC composite. These cultivars also provide higher average grain yields, and improve the probability of harvest when rainfall is poor. Farmers who plant with the first rains can obtain a grain harvest up to one month earlier than would be possible with traditional landraces. The new cultivars have enabled farmers to distribute their labor through multiple plantings and timely performance of different crop management practices because they could obtain some harvest even by planting late in the season. Ongoing monitoring of investment returns will ensure that this foundation laid down through researcher farmer partnerships remains productive.

Factors for success. Participatory plant breeding depends on (i) farmers' knowledge, (ii) a dialogue between farmers and breeders, which enriches both groups knowledge in crop improvement, (iii) an agreement between the new research partners regarding goals and priority setting for both on-farm conservation and genetic enhancement, (iv) an enhanced cooperation ensuing from previously determined comparative advantages and roles among these new partners, (v) a flexible process in which research procedures and interventions must be adjusted to suit specific physical and socio-economic environments. Owing to the above, participatory plant breeding is situation specific. ICRISAT researchers and their partners benefited from this participatory farmer approach by re-targeting pearl millet breeding, and changing the source breeding material as well as the selection methods to better suit harsh arid environments, e.g. in Rajasthan (India), which suffers from low rainfall and poor soils (Ortiz 2002).

Landrace-based topcross hybrids in participatory pearl millet breeding. High yielding adapted topcross hybrids have been obtained by crossing a uniform inbred line as the female seed parent with a genetically heterogeneous landrace as the male parent (Bidinger et al. 1994; Yadav et al. 2000a). Furthermore, topcross hybrids were either as stable, or more so than their pollinators (Mahalakshmi et al. 1992) or more responsive to improved environmental conditions than their pollinators (Bidinger et al. 1994). Recent results indicate that environment affects the combining ability of landrace pollinators (Yadav et al. 2000b), thus specific pollinators should be selected for a particular zone. These topcross hybrids provide a unique prospect to exploit and preserve indigenous agro-biodiversity in an enhanced genotype, and should be given to farmers for their further testing and selection, especially in arid or semi-arid environments.

Evolutionary crop breeding[5]

Among the most important vegetatively propagated food crops for dryland agriculture are cassava and some fruits grown in drought-prone areas. Cassava is regarded as a crop adapted to drought-prone environments and grows well in poor soil (Cock 1985; Nassar 2001a), because under stress it reduces water loss through stomatal closure and leaf area reduction. After the stress, the cassava leaf area recovers (Connor and Cock 1981; Connor and Palta 1981; Connor et al. 1981), which, of course, influences root yield in cassava depending on the developmental stage of the crop and the environment where it grows (Baker et al. 1989).

Genetic bottlenecks may happen during the evolution of vegetatively propagated crops because breeders of these crops (farmers in the early days or nowadays mostly trained professionals) may select a few sports (or mutants) with the desired characteristic, which could replace old cultivars in

5. The concepts and approaches discussed in this section result from interactions with Emer. Campbell-Bascom, Prof Dr SJ Peloquin (University of Wisconsin-Madison), Dr Masaru Iwanaga (CIMMYT, Mexico) and the late Dr Dirk R Vuylsteke (IITA, Uganda), who kindly shared their knowledge in manipulating chromosome sets for the genetic betterment of vegetatively propagated crops.

a large area (Ortiz 2001). In some vegetatively propagated crops (e.g. banana, plantain, potato, sweet potato, yam) genetic manipulations of complete chromosome sets are included in the plant breeder's kit, particularly ploidy manipulations, i.e. scaling up and down chromosome numbers of a species within a polyploid series.

Such a germplasm enhancement approach allows for widening the genetic base of breeding materials, in specific genome regions (introgression) or more broadly (incorporation). Any successful evolutionary breeding scheme for gene introgression (or incorporation) from exotic or wild gene pools to cultigen breeding pool(s) requires: (i) viable (and better fertile) F_1 hybrids arising from interspecific crosses, and (ii) "integration" of chromosome segment(s) or set(s) from a donor species into the cultigen pool, to accomplish the incorporation of unadapted genetic resources into cultivar development. In this breeding strategy wild species and diploid landraces are the source of genetic diversity. Furthermore, the diploid germplasm provides allelic variation that may enhance yield because non-additive intra- and inter-locus interactions are important for most vegetatively propagated crops (Ortiz 2002). Sometimes haploids are derived from adapted polyploid cultivars to "capture" this genetic diversity in crosses with the diploid germplasm. These haploid-species hybrids or the original diploid stocks transmit this genetic diversity to the adapted polyploid breeding pool via 2n gametes (or gametes with the sporophytic chromosome number). CGIAR breeders improving potato and plantain transferred important characteristics such as pest and disease resistance, tolerance of abiotic stresses, and produce quality using this method (Ortiz 1998a; Vuylsteke et al. 1997).

Hybrid clones may result from artificial hand-pollination or through poly-crosses among parents that are selected owing to their specific combining ability. Poly-cross refers to a pollination system based on natural random mating among selected genotypes grown together in isolated plots. The seeds from the multiple hybrid mixtures may be also regarded as synthetic cultivars because they are derived from selected genotypes that combine well among them (Ortiz 1997a; Ortiz 1997b). Hybrid seed from poly-crosses are obtained from isolated plots to avoid contamination with pollen from other non-selected clones.

Synthetic populations derived from these poly-crosses should be tested in other locations to identify promising offspring for selection and cultivar development. Local selections follow a dynamic conservation approach of genetic resources because target farmers preserve distinct, locally adapted and improved genotypes across locations. Ploidy manipulations coupled with this breeding approach broadens the genetic base of vegetatively propagated crops, thereby enhancing crop adaptation, and sustaining genetic gains in respective breeding pools. Early locally adapted germplasm with enhanced adaptation to stress-prone environments or resistance to pests and diseases will allow the sustainable and environment-friendly production of vegetatively propagated crops, which often are affected by many biotic or abiotic stresses (Ortiz, in press).

There are about 100 wild Manihot species, which provide an important genetic endowment for cassava breeding (Nassar 2000a; Nassar 2001a), though some wild cassava is under threat of extinction in natural habitats in South and Central America (Nassar 2000b). Polyploidy and apoximis could participate in the evolution of cassava within the genus Manihot. Polyploidy enhances genetic variation, whereas the apomictic mechanism, which appears to be favored by natural selection, offers an escape from lethality and provides a means for perpetuating the genotype (Nassar 2001b). Sexual polyploidization occurs in cassava because of 2n gametes, and some polyploid cassava genotypes show high plant vigor during growth and root yield (Hahn et al. 1990). Polyploids arising from sexual polyploidization from intermating diploid stocks may assist to incorporating desirable traits from wild species to the cultigen gene pool of cassava (Peloquin and Ortiz 1992). Such breeding methods for cassava, and for other vegetatively propagated crops should be regarded as part of an evolutionary improvement approach because conventional breeding will be enhanced by innovative knowledge-led methods for introducing additional genetic variation, as described above (Ortiz 2003), which will accelerate the process of recurrent selection in the crop.

New science to improve the food crops of the poor

The last century saw the rise of genetics with findings that DNA was the source of hereditary material. From the 1950s to the early 1980s scientists elucidated the double helix structure of the DNA molecule, "cracked" the genetic code, developed methods for isolating genes, and started using DNA recombinant techniques. These advances shaped animal and plant breeding and have allowed for major advances in crop and livestock improvement (Doddsetal. 2001).

The full impact of these discoveries is yet to be realized, but applications in current use are:

- Cell and tissue culture of plant cells produces uniform individuals on a large scale. Micro-propagation techniques have led to dramatic production increases in cassava, yams, bananas and plantains, among other crops. Anther or microspore culture shortens time required to develop new cultivars by producing doubled-haploids.

- Genetic transformation provides a means for incorporating new genes for pest and disease resistance in many crops. Many millions of hectares of genetically engineered crops are grown throughout the world, principally for crops needing large amounts of pesticides in highly intensive production systems, such as maize and soybeans.

- DNA fingerprinting of pest and disease agents or vectors provides better understanding of pathogen diversity and helps pre-empt breakdown of host plant resistance to pests and diseases.

- Molecular-aided analyses of genetic diversity assist characterization of breeding materials, management of ex situ germplasm collections and planning for conservation of biodiversity or for in situ/on-farm management of plant genetic resources for food and agriculture.

- DNA markers allow scientists to locate genes on a chromosome and develop plants and animals with specific disease and pest tolerance. Such DNA markers will assist breeders in the selection process to monitor introgression of exotic germplasm in their populations, e.g. introgressing striga resistance from teosinte to maize. More recently, the first plant genome - Arabidopsis was sequenced and crops, such as rice, are nearing completion. What the human genome-sequencing program is starting to achieve may soon be seen in agriculture.

- New testing tools and techniques allow searching for pests, diseases and dangerous food contaminants, which will help to ensure safe food supplies.

Biotechnology in sub-Saharan Africa. The staple foods of dryland agriculture (cassava, sorghum, millets, groundnut, chickpea, cowpea, pigeonpea) feed tens of millions of poor people daily yet receive relatively little attention from the biotechnology industry (Table 2), because they are not major cash crop commodities (they are mostly consumed in the home or village). The CGIAR centers should bridge this gap by linking advanced research institutions around the world to developing countries to help them share the benefits of biotechnology (Dodds et al. 2001). Molecular markers are being used to tag specific chromosome segments bearing the desired gene(s) to be transferred (or incorporated) into the breeding lines (or populations) (Table 3) while transgenic plants offer new genes to the breeding pool.

Table 2. Number of nucleotide sequences of selected organisms deposited in the GenBank database as of April 2002 (Source: P Keese, IITA, and V Mahalakshmi, ICRISAT, personal communications).

Organism	Number of sequences
Flowering plants (all species)	2,306,855
Arabidopsis thaliana	311,271
Soybean	252,326
Maize	247,747
Asian rice (Oryza sativa)	211,010
Medicago truncatula	180,000
Tomato	162,023
Barley	157,560
Wheat	75,481
Potato	69,580
Cotton	12,113
Pea	1,378
Alfalfa	1,123
Onion	1,115
Cassava	946
Sweet potato	473
Petunia	404
Carrot	340
Musa spp. (all species of banana and plantain)	241
Cowpea	203
Yam (all species of Dioscorea)	191
Parsley	171
Cacao	150
Oil palm	83
Groundnut	82
African rice (Oryza glaberrima)	39
Coconut	13
Dioscorea rotundata (African white yam)	3
Human	5,658,006
Domestic rabbit	5,690
Goldfish	503

Table 3. DNA markers applications in plant breeding (After Ortiz and Crouch 2001).

Improved access and utilization of germplasm resources - DNA marker analysis for defining the genetic structure of plant populations, species, genera and families to optimize the acquisition, management and utilization of germplasm collections.

Genetic analysis of breeding populations - For many crops, particularly tropical vegetatively propagated crops; the current genetic and cytogenetic knowledge restricts crop improvement efforts. Molecular markers are contributing to a substantial resurgence of progress in these areas.

Parental selection and predicting progeny performance - based on genetic diversity estimated by DNA marker analysis.

Marker-assisted selection - indirect selection of traits, which are difficult to score, expressed late in the growth season and/or traits which are a primary selection criterion but occur infrequently in breeding populations.

Marker enhanced backcross breeding - when introgressing traits from exotic germplasm, DNA markers can be used for indirect selection of that trait plus simultaneous selection of offspring with the least amount of other genomic material from the exotic parent.

Pyramiding genes from diverse sources - it may not be possible to identify different sources of resistance to the same disease through field evaluation. However, it is useful to combine different sources of resistance in the same cultivar to reduce the chance that the pathogen will evolve mechanisms to breakdown this resistance. Similarly, many genes may contribute to important agronomic characters such as yield but it may not be easy to identify the presence of individual genes through field evaluation.

Fingerprinting for impact assessment and protection of plant breeders' rights - by identifying unique DNA marker fingerprints, elite lines can be identified in farmers' fields and in the pedigree of new cultivars.

Comparative mapping - Recent studies on cereal crops have shown a high level of similarity of certain genes and the position of those genes in the genome across members of this diverse group. These developments will allow the considerable progress in model systems to be increasingly utilized in related and unrelated species and genera.

Gene isolation, function and manipulation - Based on dense DNA marker maps, scientists can move onto the isolation and characterization of single genes and whole genomic regions. From this point, rapid progress can be made in determining gene function or transferring important genes across species barriers.

Fingerprinting pests - DNA marker analysis for phytosanitation screening or monitoring changes in pest populations to predict the breakdown of current sources of resistance to viruses, bacteria, fungi, nematodes, arthropods and insects).

Crop biotechnology seems to be in its infancy in Africa, some national researchers are well trained in this area but lack of funding from their national governments does not allow them take advantage of their knowledge and professional skills. Among the agro-biotechnology tools, tissue culture ranks first in the micro-propagation of asexual crops such as cassava and tree crops. DNA marker-aided breeding (Table 4) for a range of traits (particularly to overcome diseases and pests or low input environments) should become the second most important application of agro-biotechnology in the mid-term (DeVries and Toenninssen 2001). When biosafety laws are enacted by African governments, and appropriate regulatory frameworks and systems to ensure food safety and human health, and minimize environmental risks are in place, then transgenic crops may be added to the tool-kit of plant breeders working in Africa.

Table 4. Future prospect in the breeding of tropical food crops with DNA markers in sub-Saharan Africa (After Ortiz and Crouch 2001).

Vegetatively propagated crops

Plantain and banana: Current priorities for the molecular breeding of *Musa* crops focus on the development of appropriate marker-assisted selection schemes for parthenocarpy, apical dominance/regulated suckering and short cropping cycle. Thereafter, the focus will turn to markers for post-harvest characters and for favorable alleles contributing to heterosis in components of yield.

Cassava: The development of markers for post-harvest characters and virus resistance appears to warrant the greatest emphasis for cassava breeders. In the longer-term, it is proposed that attention should focus on the development of DNA markers for tolerance of abiotic stresses and for storage characteristics.

Yam: Many of the important agronomic characters in yam breeding are difficult or expensive to score. On this basis, marker-assisted selection could be warranted in this crop for resistance to nematodes and viruses, tuber dormancy, and post-harvest characters (texture, taste and oxidation). Progress in the molecular breeding of potato might provide good orientation but cannot promise any direct benefits.

Legumes

Cowpea: As in most legumes grown in the semi-arid tropics, insect pests present the most overwhelming constraint. Thus, in cowpea, the development of markers for resistance to thrips, bruchids, *Maruca* and pod borer is of greatest priority. In the longer term, markers for resistance to the parasitic weed *Striga* and markers for genes contributing to drought resistance are a high priority intervention.

Groundnut: Drought, fungi, viruses, bacteria and insect pests are among the major constraints in groundnut (also known as peanut) production. The identification of genome regions bearing the

Continued

Table 4. *Continued*

genes controlling tolerance of or resistance to these constraints may be the main target, as a first step, for marker aided selection aiming to pyramid resistance within the cultivated gene pool or for germplasm enhancement with wild species, which possess the resistance genes for most biotic constraints. In addition, DNA markers should be used to identify diverse germplasm, which can be used to broaden the genetic base in groundnut breeding.

Chickpea: Ascochyta blight, Fusarium wilt, root rots, Botrytis gray mold and pod borer are among the most important diseases and pests of chickpeas. A preliminary genetic map has been developed in this species but considerable work remains to identify markers, particularly for tolerance of and resistance to biotic stresses.

Soybean: Tremendous advances in all aspects of the molecular breeding of soybean are being made in advanced laboratories, particularly in the USA. Although, these may provide substantial background understanding and perspective, many of the constraints to soybean cropping in sub-Saharan Africa are very different. A high priority, for example, could be the use of marker-assisted breeding for selecting lines with the ability to cause germination of Striga hermonthica, a parasitic weed affecting maize but not soybean. In the longer term, increased nodulation and resistance to pod shattering would be highly important candidates for marker-assisted selection systems.

Pigeon pea: Fusarium wilt, sterility mosaic virus, Phytophthora blight and pod borer substantially reduce crop productivity of pigeon peas. Resistance breeding to achieve both stability and productivity are top priority in the genetic enhancement of this pulse. Thus, DNA markers for pest and disease resistance will also be of utmost importance. The development of F_1 hybrid cultivars of pigeonpea was the first amongst the legume crops. For this reason, the development of marker-assisted selection for new sources of male sterility will also have high priority in this crop.

Cereals

Sorghum: The major stresses affecting sorghum are drought, striga, grain mould fungal diseases, anthracnose, foliar fungal diseases and insect pests such as stem borer, shoot fly, midge and head bugs. The use of microsatellite markers to assess genetic diversity has been helpful in defining new breeding strategies in this crop. Now the development of DNA markers for resistance to pests and diseases is receiving greatest priority.

Pearl millet: The most important constraints are drought, high soil temperature, downy mildew, panicle diseases and insect pests. Markers for downy mildew resistance have already been developed and successfully used to aid the backcross breeding of a parental inbred line for an F_1 hybrid cultivar which is now grown on more than one million hectares across India. However, in the long-term marker-assisted selection should be used to generate new cultivars combining this source of resistance with horizontal polygenic background resistance to lengthen the probable life span of new cultivars.

Maize: The development of biometrical techniques and their association with DNA marker data is probably more advanced in maize than in any other crop. Based on comparative mapping, it is

Continued

Table 4. *Continued*

likely that sorghum in particular will greatly benefit from general advances in the molecular breeding of maize. However, in common with soybean, many of the specific constraints to maize production in sub-Saharan Africa are very different from those in the USA. Again of greatest importance is the identification of markers for resistance to the parasitic weeds striga and *Sesamia.* The development of striga resistant maize cultivars is crucial to the future success of maize production in sub-Saharan Africa, but it is sometimes extremely difficult and expensive to screen for this trait.

Rice: Due to the great importance of this crop combined with its relatively small genome size, rice is probably the most intensively studied crop in terms of traditional and molecular genetics. In addition, when the genomes of the various cereal crops are aligned, rice can be placed at the very core, and thus rice has become known as the nodal species for the cereal crops. This finding has intensified molecular genetic research on rice, as progress in sequence-based research can be made most quickly in the crop with the smallest genome and then findings can be extrapolated to other cereal crops.

An international, public agro-biotechnology strategy in research-for-development.[6] This strategy for agro-biotechnology should rely on applying appropriate biotechnological theory and tools to its research and to assess and demonstrate their effectiveness and efficiency in contributing to achieving improved agricultural productivity and food security, reduced poverty and the effective management and conservation of natural resources for sustainable agriculture in sub-Saharan Africa. This strategy can be implemented through strengthened collaborative alliances with advanced research institutes in both the public and private sectors worldwide. These alliances will have the objectives of developing and assessing the effectiveness of a range of biotechnological tools and demonstrating how they can be utilized and deployed in research for development programs to serve national interests within sub-Saharan Africa. As its contribution to these alliances a regional (or continental) research facility and capacity will be necessary as an effective resource for enhancing the research-for-development agenda, This facility can develop, foster and support biotechnology capacity building in Africa through research collaboration, training and public awareness programs, and can assist in the transfer of biotechnology tools and products to the marketplace in the continent.

6. This section ensues from discussions with Drs P Hartmann, I Ingelbrecht and other IITA colleagues.

In summary, this agro-biotechnology strategy must energize and strengthen appropriate aspects of relevant molecular life science research to meet African food and income needs by:

- Conducting applied biotechnology research addressing priority areas in the development agenda for agriculture;
- Transferring, when and where appropriate and in collaboration with partners overseas and on the continent, biotechnology products from the laboratory to the marketplace;
- Serving as a platform for technology transfer between overseas advanced research institutes and Africa; and
- Enhancing capacity of selected partners in sub-Saharan Africa to apply and monitor biotechnology via comprehensive interactions and training-through-research programs.

Owing to limited funding, strategic biotechnology research had to be centralized at this regional (or continental) facility. However, the routine applications of biotechnology should be in the mid- to long-term decentralized and close to the end-user, i.e. laboratory and equipment for micro-propagation, minimum equipment for molecular marker technology to support diagnostics of pathogens (particularly, viruses) and fingerprinting of plant breeding materials should be available in experimental stations across the continent.

Biotechnology and genetic enhancement. Plant breeders determine their genetic response to selection (R) by the following equation:

$$R = ih^2s_p$$

where *i* is the selection intensity, expressed in standardized units, h^2 is the narrow-sense heritability in the reference population, and s_p is the phenotypic standard deviation of the selected characteristic. For example, *in vitro* techniques may provide a means for achieving a higher intensity of selection, whereas molecular markers are being used to tag specific chromosome segments bearing the desired gene(s) to be transferred (or incorporated) into the breeding lines (or populations). In this way, indirect selection with co-dominant molecular markers tightly linked to the gene(s) controlling the characteristic(s) of interest improves R, because co-dominant markers have an h^2 equal to 1 Transgenic plants offer new genes to the breeding pool, thus, enhancing the phenotypic standard deviation of the population.

7. Thanks to Dr N Seetharama (ICRISAT, India), who provided interesting information for this section.

Accelerating progress by shortening the breeding cycle.[7] Techniques to develop homozygous plants in a single generation, known as dihaploids, are becoming routine in cereal breeding. Cultured spikelets generate double haploids from female gametes. The plants derived by using this method can set seed normally, survive and reproduce outside the laboratory, thus shortening the breeding cycle to produce uniform lines, and accelerating the development of new cultivars. Likewise, geneticists possess new tools for identifying and isolating genes that govern specific characteristics, thereby enhancing their ability to manipulate genes and develop new cultivars with high yield, enhanced resistance to pests and diseases, and improved adaptation to targeted agro-ecozones. In pearl millet, a cross-pollinated cereal, homozygosity was achieved in a single generation using the double haploid technique on female gametes. Ploidy was confirmed using root cells from a gynogenic plant (i.e. a maternal haploid) that showed seven chromosomes.

Genetic transformation to overcome pest and disease constraints. About 5.5 million farmers grew 52.6 million hectares of transgenic crops in 2001 (James 2001). The characteristics most commonly incorporated into new cultivars or breeding lines through genetic engineering include resistance to herbicides, insects and viruses. Phipps and Park (2001) provided recent ex post and ex ante assessments of the environmental benefits of genetically modified crops (with global and European perspectives, respectively) for reducing pesticides. Available transgenic crops reduced pesticide use by a total of 22.3 million kilograms of formulated product in the year 2000. Ex ante analysis, assuming if 50% of transgenic maize, oil seed rape, sugar beet and cotton are grown in the EU, indicates that pesticide use in this region would decrease by 14.5 million kg of formulated project (4.4 million kilograms active ingredient). In addition there would be a reduction of 7.5 million hectares sprayed which would save 20.5 million liters of diesel and result in a reduction of approximately 73,000 t of carbon dioxide being released into the atmosphere.

Transgenic crops and integrated pest management (IPM).[8] The deployment of transgenic crops with insecticidal genes for pest control will lead to the reduction in insecticide sprays, an increased activity of natural enemies, and IPM of secondary pests. However, as with any other technology, there are some problems associated with the utilization of transgenic pest resistant crops (Sharma et al. 2000). For example, secondary pests are not controlled in

8. Dr HC Sharma (ICRISAT, India) kindly shared his views on this subject with the author of this article.

the absence of sprays for the major pests, and control of secondary pests requires chemical sprays that will kill the natural enemies, thus offsetting one of the advantages of transgenic crops. Furthermore, transgenic crops may have very high costs, and the proximity to sprayed fields will reduce the benefits of transgenic crops. Insect migration may also reduce the effectiveness of transgenic crops, and last but not least, insects and other crop pathogens may develop resistance to the transgenes because of persistent exposure. Therefore, deployment of transgenic crops with pest resistance must be integrated into an IPM strategy, because the management of pests needs to be seen as an integral aspect of farming systems. Indeed, transgenic crops can further interact positively with bio-control interventions as shown by cotton IPM in Australia (Mensah 2002a; Mensah 2002b). Entomologists, breeders and molecular biologists need to determine how to deploy this technology for pest management, and at the same time reduce possible environmental hazards. An appropriate understanding will be needed about the insect biology and behavior, its response to the insecticidal proteins, and temporal and spatial expression of insecticidal proteins in plants. Such knowledge will help deploy an environmentally sound strategy for resistance management, and perhaps to determine the impact of insecticidal proteins on natural enemies and non-target organisms. Likewise, an adequate mechanism to deliver the technology to the resource poor farmers should be developed.

Trangenic crops for the semi-arid tropics.[9] Genetic transformation provides a complementary means to crop breeding, especially for traits that are rare or not available in the investigated gene pool (Sharma and Ortiz 2000; Sharma et al. 2001). Various steps in the production of transgenic plants include isolation and multiplication of desired genes, and incorporation of these genes into plants by adopting suitable regeneration and transformation technologies. Regeneration, using somatic embryogenesis, plus transformation protocols (with biolistics - or Agrobacterium tumefaciens - mediated gene transfer) appear promising for transferring resistance against viruses and insects into leguminous crops such as groundnut (Sharma and Anjaiah 2000), cowpea (Anand et al. 2001) and pigeonpea (Sharma and Ortiz 2000), as well as in sorghum (N Seetharama, ICRISAT, personal communication). Hopefully transgenic plants of these crops with resistance to major biotic constraints will be available soon for testing in the semi-arid tropics of the world.

---

9. Drs KK Sharma and N Seetharama were the main sources of information for this section.

With the availability of a suitable stem borer rearing facility, ICRISAT researchers tested the efficacy of several Bt toxins to control Chilo borer. They also successfully devised a protocol for genetic transformation of sorghum using particle bombardment method and a marker gene conferring resistance to herbicide phosphinothricin. Work is also in progress to generate transgenics with a Cry 1Ac gene construct along with the herbicide resistance gene used as a selectable marker.

More than 100 putative transformants of groundnut expressed the coat protein gene of peanut clump virus (PCV-cp) (Sharma and Anjaiah 2000). Polymerase chain reaction (PCR) and Southern blot hybridization revealed the integration of PCV-cp in over 50% of the putative transformants. While 70% of the transformants carry a single gene, the rest carry two to in excess of eight copies of the gene when analyzed in the first generation of transformed plants (or T_1). Work on their further characterization, including resistance to PCV, is ongoing. This appears to be one of the first reports where such large numbers of transgenic groundnut plants were recovered. Similarly, resistance to the groundnut rosette assister luteovirus may be available soon by introducing coat protein gene and putative polymerase gene of the luteovirus.

Biosafety.[10] With the above advances in genetic transformation of crops from the semi-arid tropics, soon transgenic plants (now in glasshouses) will be selected for field-testing following international biosafety standards for transgenic trials (Sharma et al. 2002). After thoroughly monitoring transgenic plants for the presence of desired gene(s), they should be evaluated in a containment facility, which conforms to a P2 level of biosafety and include:

- **Insect proof conditions.** Even small insects, such as thrips, cannot enter the glasshouse.
- **Pollen proof.** Special filters prevent pollen escapes from transgenic crops.
- **Shatterproof** polycarbonate sheet covering the glasshouse stops the pollen escaping.
- **Negative pressure** is maintained to avoid airborne dispersal.
- **An effluent treatment plant** stops soil-borne and water-borne dispersal.
- **Preventing contamination** from personnel by decontaminating clothing, tools, pots, and equipment.
- **Excess water after watering** the plants and from other operations is

10. This section benefits from interactions with Dr DVR Reddy (ICRISAT, India).

collected into a sump housed within the facility, and then pumped using level sensors into another sump located outside the facility. Water is allowed to stay for one day before it is discharged into the drainage system. The entire operation is automated.

- **Sterilizing by autoclaving** all material entering into the facility. All transgenic plants will be disposed by incineration.
- **Constant monitoring** of host plants grown in the vicinity of the facility.

New diagnostic tools warn of dangerous food contaminants.[11] The rural poor and their livestock often consume cheap, mold-infected nuts, cereals and spices containing carcinogenic and immunosuppressive aflatoxins, which are produced by the fungi Aspergillus flavus and A. parasiticus. Besides endangering human health, aflatoxin contamination effectively blocks groundnut exports, a lost income opportunity for farmers of the semi-arid tropics. One of the major problems has been the lack of tools for cost effective estimation of aflatoxins in food and feed because analytical protocols are expensive. Immunochemical methods offer cost effective ways to estimate aflatoxins. Indirect competitive penicillanase-based ELISA tests developed at ICRISAT (Devi et al. 2000) can detect carcinogenic aflatoxins for a mere US$ 1 per sample versus US$ 12 for imported test kits. Similarly, ELISA for the detection and resistance screening of sterility mosaic virus in pigeonpea has been developed.

Understanding the enemy: pre-empting breakdowns of plant resistance to diseases.[11] DNA fingerprinting and banding patterns of DNA markers reveal genetic variability in fungal pathogens so that appropriate resistances can be deployed in advance. For example, a microsatellite marker detects variability in host-specific pathotypes of Sclerospora graminicola, the downy mildew pathogen in pearl millet (Sastry et al. 1995; Thakur et al. 1999). Furthermore, DNA fingerprinting shows variability among sexual and asexual progenies of Sclerospora graminicola. Also DNA marker patterns were able to discriminate among Indian, Australian and American strains of Colletotrichum graminicola, the sorghum anthracnose pathogen.

Finding genes with DNA markers and magnifying the power of selection in plant breeding.[12] Molecular markers are descriptors that offer reproducible results for

---

11. Drs DE Hess (ICRISAT, Mali) and RP Thakur (ICRISAT, India) share their knowledge with the author on this section.
12. Information provided by Drs JH Crouch, CT Hash and N Seetharama (ICRISAT, India).

characterizing genotypes (Ortiz 2002). Similarly, applied plant genomics also improves the understanding of crop gene pools, which are being enlarged by including transgenes and "native" gene pools. Furthermore, finding new genes adds value to traditional agricultural products. There are many ongoing applications of DNA markers in research-for-development and crop improvement for the semi-arid tropics (Ortiz and Crouch 2001). Marker-assisted selection and -aided introgression are being used to locate and select genes for controlling important quality and disease or pest resistant traits.

A pearl millet linkage map using a diverse array of molecular markers (RFLP, STS, AFLP, SSR and some isozymes) was successfully used to detect quantitative trait loci (QTL) contributing to resistance to African and Asian downy mildew populations (Jones et al. 1995). The QTL analysis for resistance to downy mildew isolates in pearl millet, collected at three sites in Africa and one in India, suggest that a major QTL for resistance exists in linkage group IV for the isolates collected from Sadore (Niger), Patancheru (India) and Bamako (Mali). However, this QTL does not provide resistance to the isolate of downy mildew from Nguru (Nigeria). Not only have QTL been mapped, but this has been followed up with marker-assisted selection programs that are now beginning to bear fruit. Researchers are field testing hybrids from new versions of an elite pollinator possessing new downy mildew resistance gene complements and a QTL for increased plant height and biomass, which is not associated with delayed maturity, from a single plant selection of another elite pollinator. With more recent advances in DNA marker-assisted breeding, a new gene resistance deployment approach was suggested and it consists of gene pyramiding in three-way hybrids and synthetic parent populations of pearl millet (Witcombe and Hash 2000).

Sorghum production in Africa is severely constrained by the lack of resistance to striga, which is a complex quantitative trait. Transfer of resistance to striga into adapted sorghum cultivars has been limited due to inadequate information on the genetics of resistance (Haussmann et al. 2000a), and the difficulty of evaluating resistance in the field (Haussmann et al. 2000b). Two mapping populations (RIPs), each consisting of 226 F3-derived F5 lines (F3 families), were developed from the crosses IS 9830 (a low producer of stimulant for striga germination) x E 36-1 (striga susceptible, but terminal drought tolerant) (RIP 1) and N 13 (impedes parasite attachment to its roots by "mechanical" barriers) x E 36-1 (RIP 2). Marker analyses were performed with bulked DNA from 20 plants per F3 family. RIP 1 was genotyped for 177 marker loci (151 AFLP, 16 RFLP, 4 SSR, 6 RAPD). RIP 2 was scored for 243 marker loci (197 AFLP, 20 RFLP, 9 SSR, 17 RAPD). For RIP 1, the genomic map had a total length of 872 cM, and contained 147 markers distributed over 10 meaningful linkage groups (at LOD[13] 5.1). For RIP 2, the map comprised a total length of 939 cM, and contained 191 markers distributed over 11 meaningful linkage groups (at LOD 4.5). A high goodness-of-fit indicated high reliability of the linkage maps for both RIPs. However, the total lengths of the genomic maps are lower than expected. Field reaction to striga of both RIPs was evaluated for two years in Kenya, Mali and Burkina Faso. In addition, germination distance, a measure of the proportion of striga seeds germination by a host genotype, was determined for RIP 1 in an agar-gel assay (laboratory). Two to eight QTL were identified for germination distance with the individual striga populations. The moderate percentage of genetic variance explained by the QTL indicates that no marker was close to the (major) gene for low stimulant production. For area under the striga number progress curve (a measure of infestation severity) in the individual environments, the number of QTL ranged from zero to six in RIP 1 and from three to eight in RIP 2. No QTL seemed to be common to all environments in either RIP, which may be at least partly due to the variation in striga populations. Work is continuing to refine the QTL analyses and determine precise positions and effects of the QTL. Further, additional markers are being added to the genomic maps of both mapping populations to better cover the sorghum genome.

DNA markers are also playing an important role in the genetic manipulation to improve digestibility and feed quality of sorghum and millet crop residues. *Ex ante* impact assessment shows that a mere increase of 1% in stover digestibility results in US$ 42 to 208 million, depending on adoption rates increasing from 10% upwards (Kristjanson and Zerbini 1999). Predicted rates of return to research investment vary from 28% to 43%, with corresponding benefitxost ratios of 15:1 to 69:1, respectively. Researchers from the CGIAR together with other research partners worldwide are making significant progress to map QTL controlling the characteristics for stover and fodder quality in pearl millet and cowpea. After these QTL are mapped, pearl millet and cowpea breeders will apply marker-assisted selection to develop new populations with the desired stover and fodder characteristics.

13. The LOD score refers to the log likelihood ratio of a particular association due to chance alone. Significant LOD scores generally are above 3.

Learning the language of resistance and putting it to use. The candidate gene approach was developed considering the gene-for-gene hypothesis for disease resistance. In this hypothesis the defense response of the host-plant occurs if this plant has a resistance gene and the pathogen possesses an avirulence gene. The similarity of resistance gene sequences among species (e.g. in the nucleotide binding domain) also allows the identification of resistance gene candidates that may eventually be transferable among crops. The polymerase chain reaction has proven to be an important tool in the identification and isolation of these resistance gene candidates.

The promise of gene synteny together with bioinformatics[14]

Positions of useful genes in target crops can be inferred by cross-referencing to the maps of other most popular crops that allows the eventual intergeneric transfer of genes. Recent advances in sequencing of plant genomes (e.g. Arabidopsis or rice) coupled with developments in functional genomics and information technology (which led to the new field of bio-informatics) demonstrate that indeed "biotechnology based on molecular biology is generating revolutionary advances in genetic knowledge and the capacity to change the genetic makeup of crops and livestock." Today, we have the unique opportunity to share and link information from other resources around the world on the World Wide Web. Tools and resources are being developed to interpret the sequence in terms genes and their functions (Mahalakshmi et al., submitted). The Institute for Genomic Research (TIGR) (http://www.tigr.org) has assembled the gene annotation or indices for various crops.

Gene synteny research in legume species of the genus Vigna provides a means to detect orthologous genes by using common sets of chromosomes to probe their genomes (Fatokun et al. 1992). Cowpea and mungbean have QTL for seed weight in the same conserved region, which are arranged in identical order (Menancio-Hautea et al. 1992). This result was not surprising because it reflects the selection of chromosome regions controlling the most important character selected by farmers in these crop species: seed size. In cereal crops such as maize and sorghum similar findings for plant height were reported (Lin et al. 1995; Pereira and Lee 1995), which reveals the same domestication evolution pattern among crop species (Paterson et al. 1995). Hence, we

14. Interactions with V Mahalakshmi (ICRISAT, India) help to write this section.

envisage the successful integration of data mining, gene discovery, marker development and tactful gene deployment to become routine practice in crop improvement programs in the next decades.

Researchers expect in the mid-term to identify and characterize useful genomic regions conferring a specific trait in crops. The common regions relevant to this trait will be further saturated and annotated. Additionally appropriate test materials will be chosen to assess the relevance of these genomic regions in each of the targeted crops in relevant environments. In the long-term this approach should lead to the isolation and characterization of candidate genes for traits of interest if the ordering of DNA loci between chromosomes of two (or more) crops within the same family corresponds well. This gene order conservation between genomes permits that genes in an X crop are isolated by map-based cloning at the homologue in the Y crop, and then by homology in the X crop. Perhaps, one day the genes providing extreme drought tolerance of pearl millet can be introgressed into other cereals, to achieve more water-efficient crops.

Cereals. Researchers worldwide have developed DNA marker-based sorghum maps. Information gathered by these research teams on sorghum maps has been included on the Internet (Mahalakshmi and Ortiz 2001). Information on all linkage groups from a specific source or on a particular linkage group is displayed with details at http://www.icrisat.org/text/research/grep/homepage/rflp/sorghum_maps.htm. Comparative genome mapping of related plant species has shown that the organization of genes is highly conserved during the evolution of members of taxonomic families. This has lead to the identification of genome co-linearity between the well-sequenced model crops and their related species (e.g. Arabidopsis for dicots and rice for monocots). Co-linearity overrides the differences in chromosome number and genome size. The rice genome project has constructed a RFLP linkage map with 2275 DNA markers (Harushima et al. 1998). By studying the synteny between the rice and sorghum genomes a consensus linkage map consisting of 607 DNA markers covering 1285 cM was developed. A high degree of co-linearity exists between the 10 sorghum linkage groups and the 12 rice linkage groups (Nagamura et al. 1998). An interactive representation of available data from this rice-sorghum genome synteny project (http://www.icrisat.org/text/research/grep/homepage/synteny/intro.htm) was developed (Mahalakshmi and Ortiz 2001). Likewise, all sequences in GenBank were screened for the presence of SSR. These sequences have been collated in a database with direct linkage to primer design software. There were 110,000 available sequences for sorghum, and 9232 SSR were detected (as of June 2002). Information on publicly available micro-satellite markers was included in a separate database to be used for removing overlap with GenBank sequences before selection of sequences for design primers.

Legumes. The molecular maps for legume crops of the African semi-arid tropics (cowpea, groundnut and pigeon pea) are not very dense compared with the other related legume crops such as soybean. However, data from related species could be mined to develop maps and markers. Hence, nucleotide sequences of the legume model species Medicago truncatula, available at the National Center for Biotechnology Information (http://www.ncbi.nlm.nih.gov) were downloaded in FASTA format and the repeat patterns in the sequence were located using the tandem repeat finder program at http://c3.biomath.mssm.edu/trf.html. The sequences with potential repeat motifs were then analyzed to determine possible potential flanking regions around the repeat motifs, which might yield product sizes of about 200 bp using PRIMER 3 program (http://www-genome.wi.mit.edu/cgi-bin/primer/primer 3_www.cgi). The gene indices database from TIGR (http://www.tigr.org/tdb/tgi/mtgi/) was also downloaded, and a local database containing the entire sequences in FASTA format, the repeat motif and the potential primer and the gene indices was created in a relational database (SQL7.0™). The resultant database of the repeat motifs was analyzed to classify the patterns, their occurrence and abundance (Mahalakshmi et al. submitted). Of the total of about 156,000 sequences which were searched, 7325 sequences were found to contain repeat motif and may yield SSRs which will yield product sizes of around 200 bp. Of these the most abundantly found repeats were the tri-nucleotide (5210) group. Except for a very small proportion (436), these link to the gene annotation database at TIGR. To facilitate further exploration of this resource, a dynamic database with options to search and link to other resources are becoming available. Such an approach may lead to development of micro-satellite markers for the same species or closely associated species within the same genus.

Crop genetic enhancement using biotechnology -- cowpea as an example

Cowpea is the most important food legume in the dry savannas of tropical Africa covering globally over 12.5 million hectares with annual production exceeding 3 million metric tons. About 64% of the area under cowpea is in West and Central Africa where it is normally grown in a mixture with millet and sorghum in the Sudan savanna and Sahelian regions. Pearl millet or sorghum provide staple food, fodder, fuel and thatching materials and cowpea provides cash income and protein supplement in the daily diets of people. The protein rich grains, which are commonly eaten in different forms, constitute the main product of the crop. Cowpea leaves, green pods, green peas and dry grains are consumed as food and both the green and dry haulms are fed to livestock particularly in the dry season when animal feed is scarce. In addition, because of its tolerance of drought and soil acidity and its ability to fix atmospheric nitrogen coupled with its fast growth habit in warm climates, cowpea grows extremely well and contributes to improving the soil in the desert margin areas of the tropics characterized by low rainfall, high temperature, sandy soils and low fertility. Thus, cowpea forms an essential and integral component of sustainable and integrated crop-livestock farming systems in the semi-arid and arid regions of sub-Saharan Africa. However, the overall productivity of the existing traditional cowpea-cereals intercropping systems is very low. To meet the extra demand for food for the increasing population, there is a need to increase productivity by increasing yields per unit area through improved cultivars and intensive, more productive cropping systems. The share of cowpea production among various grain legumes in Nigeria has increased since the late 1980s, making Nigeria the largest cowpea-producing country in the world (Ortiz 1998b). Most of the cowpea produced is used for direct consumption in both urban and rural areas.

The International Institute of Tropical Agriculture (IITA) has the global mandate for improving cowpea cultivars within the CGIAR. IITA develops and distributes a range of improved cowpea breeding lines, combining multiple disease and insect resistance with early maturity and preferred seed types to 65 countries. From 1970 to 1988, the research concentrated on developing cowpea cultivars for sole crop only. However, from 1989, cowpea breeding was diversified to include systematic improvement of local landraces as well as development of a range of new improved cowpea cultivars, which would produce higher grain as well as fodder yields under sole cropping as well as in the traditional intercropping systems. The major focus of cowpea research at IITA has been to study traditional cropping systems, identify cowpea production constraints and, in collaboration with national programs and other international centers, develop improved cowpea cultivars combining disease and insect resistance with better adaptation and high yield potential under intercropping systems of the savanna ecologies, where soils are poor and moisture is limited. Since the mid-1990s, IITA has further broadened the objectives by including improvement of cowpea-cereal systems on a holistic basis, involving crop-livestock integration rather than cultivar improvement alone. It is envisaged that through the dissemination of improved cultivars, improved cropping systems, integrated pest management and integrated crop-livestock systems, farmers in the marginal lands of the dry savannas and the Sahel will improve their food security, livestock feed security, income generation opportunities, and the sustainability of enhanced food production and their cropping systems, without requiring substantial inputs, pesticides and inorganic fertilizers.

Grain yield of cowpea in the African farmers' fields is much lower than potentially could be obtained and this low yield is attributable to a number of biotic and abiotic factors (Ortiz 1998b). The adverse effects of some of these yield-limiting factors could be ameliorated through cultural practices while others require genetic manipulation through breeding. For example, the post flowering insect pests of cowpea are particularly devastating in their effects on grain yield. The major insects are the legume pod borer *(Maruca vitrata)* and a complex of pod sucking bugs *(Clavigralla tomentosicollis, Anoplocnemis curvipes, Riptortus dentipes).* Although efforts are being undertaken to introduce IPM for cowpea, most farmers are still spraying insecticides, very often unsuitable ones (e.g. cotton pesticides) because the recommended ones for cowpea are either unavailable or unaffordable. Neem extracts are being tested by IITA to control cowpea pests in West Africa. Preliminary results indicate a range of 50% to 70% performance as compared to a synthetic pesticide, but at less cost for farmers, their health and the environment (M Tamo, IITA, personal communication).

Most of the efforts devoted to develop cowpea cultivars with resistance to these pests using conventional breeding methods have been so far unsuccessful. Some wild *Vigna* species have been identified as possessing good levels of resistance to some of these pests but due to strong cross incompatibility between cowpea and these other Vigna species it has not been possible to transfer the desirable genes to cowpea. The lack of progress in the use of conventional methods to effectively contain the pest problem of cowpea makes the application of biotechnological procedures for overcoming the constraints to cowpea production attractive. This is particularly the case for the legume pod borer (M. vitrata), a lepidopteran whose larvae attack and destroy cowpea flowers, seeds and pods. If transgenic cowpea can be obtained which expresses the Bt gene in the flowers and pods the productivity of cowpea would be improved immensely. The Bt protoxin is known to have adverse effects on lepidopteran larvae.

IITA works in partnership with the University of California at Davis, Purdue University, University of Virginia, Bean/Cowpea CRSP, University of Zimbabwe and CSIRO (Australia) to obtain transgenic cowpea lines. The ultimate goal of this partnership in research-for-development is to make available to farmers, particularly in sub-Saharan Africa, new cowpea cultivars that are resistant to several of the post flowering insect pests that presently cause extensive grain yield losses. Such improved varieties should allow a reduction in the cost of cowpea production. Farmers will be more attracted to cowpea production. In addition, the reduced use of insecticides will have significant health and environmental benefits.

These collaborative research efforts are becoming very productive because scientists representing various institutions involved identify and carry out activities in those areas where they have a comparative advantage. The expected outputs from this collaborative work are as follows:

- Protocol for routine transformation of cowpea lines developed;
- Cowpea with an appropriate Bt gene transformed;
- Candidate genes with insecticidal properties identified;
- Bt gene constructs for expression in cowpea flowers and pod walls as well as of other gene constructs with multiple insect resistance developed;
- Transgenic cowpea available for testing for reaction to Maruca attack;
- Transgenic cowpea lines tested for allergenicity and food quality;
- Effects of Bt gene on biodiversity (e.g. gene flow) quantified;
- Best ways for managing Bt resistance in cowpea in farmers' fields established;
- BAC library available;

15.Drs J Machuka, P Keese and I Ingelbrecht (IITA, Ibadan) provided information for this section.

- DNA markers associated with desirable traits in cowpea identified;
- DNA markers converted to sequence characterized amplified regions (SCARs) for use in marker-assisted selection; and
- Effective freedom-to-operate procedures ensured, and any potential intellectual property or material transfer agreement issues solved.

Transgenic cowpea.[15] Over the last two decades, sporadic efforts have been made to develop regeneration and transformation systems in cowpea using tissue culture dependent and de novo approaches. Among the target tissues investigated to date, cotyledons and their nodes appear to be the most promising tissues for Agrobacterium tumefaciens-mediated transformation. A protocol using immature cotyledon-derived callus was suggested recently for transformation with low chance of chimeras (Anand et al. 2001). Initial studies suggest that hygromycin and possibly geneticin may be the preferred agents for selection of transformed tissues.

The recent development of a simple and routine de novo dipping transformation procedure in Arabidopsis has sparked new optimism to develop similar techniques for other crops. Since electroporation of cowpea nodal tissue has already been reported, work was initiated at IITA Biotechnology Laboratory to maximize the number of buds produced at every node or at the shot apex by spraying potted cowpea plants with various concentrations of benzyl aminopurine (BAP, at 0-10 mg/1). This procedure has potential for coupling to in planta transformation techniques, notably electroporation and dipping or hormone-induced organs in Agrobacterium suspensions.

Selection of transformed tissue is likely to be the key obstacle for reliable adoption and exploitation of a de novo cowpea regeneration-based transformation system. Progress has been made in the optimization of parameters for cowpea transformation through (a) transient GUS gene expression following Agrobacterium-mediated transformation, (b) establishment of antibiotic thresholds (geneticin at 10 mg/1 and hygromycin at 20 mg/1) for selection of transformed cowpea tissues, and (c) development of shoot elongation (2 mg/1 GA3) and rooting (0.05 mg/1 NAA) media. By having well rooted cowpea plantlets in tissue culture, it is now possible to avoid loss of these plantlets when they are transferred to soil for hardening. Initially, about 50% of plantlets died during this transfer, compared with about 100% survival of well-rooted plantlets.

DNA marker-aided breeding.[16] A linkage map of cowpea is being developed using a set of recombinant inbreds that were derived from a cross between an

16. Most information provided by Dr C Fatokun (IITA, Nigeria) for this section.

improved cowpea cultivar and one of its cross compatible wild relatives. The map presently has 171 RAPD; SSR and AFLP markers in 12 linkage groups (2269 cM). This implies that on average map distance between two adjacent loci is about 13 cM. The markers on the map are made up of RAPD, AFLP, SSRs (microsatellites), and some morphological attributes for which the population is segregating. Additional markers, especially AFLP and microsatellites are being generated for placement on the linkage map. The SSRs presently on the map were derived from cowpea genomic DNA. Some cDNA derived microsatellites from common bean (Phaseolus vulgaris) have been tested on cowpea and most of these were found to amplify cowpea DNA and detected polymorphism among the parents used to generate the mapping population. The ability of common bean microsatellites to amplify with cowpea DNA will enable comparative genome analysis between both crops belonging to the subtribe Phaseolinaea.

This genetic linkage map will become very useful for the detection of DNA markers that are closely associated with traits of agronomic importance - for example, to detect quantitative trait loci (QTL) for 100 seed-weight (in chromosomes I and II); resistance to a virus (CMeV) in chromosome III of V vexillata. Such DNA markers could facilitate marker-assisted selection in breeding for desirable traits. Also IITA researchers determine genetic diversity and phylogenetic relationships in Vigna with DNA markers.

An appropriate population must be available from where DNA markers associated with desirable traits can be identified. To this end, a number of cowpea lines were selected and crossed with one another on the basis that they contrast in some traits of interest. The progeny derived from these crosses have been advanced to F_8 generation and are now available for use as recombinant inbred lines.

The cowpea mapping population has as parents two lines that contrast for bruchid (Callosobruchus maculatus) resistance. The cowpea wild relative, TVNu110-3A is susceptible to this insect while the improved cultivar IT84S-2246-4 is resistant. Bruchid is the major storage insect pest of cowpea. Resistance to this pest is measured by non-emergence or delay in emergence of adults from eggs laid on the seeds. Seeds of the recombinant inbred lines were infested with eggs of bruchid and the number of days to emergence was measured. The values obtained were compared with DNA data for the recombinant inbred lines. A microsatellite marker VM50 was closely associated with delay in emergence of adult insects. This microsatellite could explain up to 20% of the variation observed for this trait among 81 RILs. This microsatellite marker is bound on one side by another microsatellite (VM56) and an AFLP marker (AACCTC306) on the other. The two flanking markers are located about 10 cM on either side of this locus. The microsatellite marker VM50 will be useful in getting to the locus with effect on bruchid resistance in cowpea. This region is to be saturated with additional markers that will be more closely associated.

Recently, researchers were able to identify many of the strain-specific resistance genes to striga in cowpea (Ouedraogo et al. 2001). However, legume breeders still need to test whether marker-assisted selection will assist more efficiently in pyramiding this striga resistance into single cowpea genotypes. Generally speaking until now DNA markers are not routinely used in selecting for highly quantitative traits in other crop species. Perhaps some of the shortcomings of marker-aided introgression relate to the genetics of the trait itself.

Approach for cowpea IPM.[17] The use of modified plants (resistant cultivars), beneficial organisms (biological control) and a modified environment (cultural practices) or bio-intensive IPM, continues to be the thrust of IITA's work in the management of pests and diseases on cowpeas. In an ecosystem such as that of cowpea, where the pest spectrum is complex and not likely to be kept under control (except with the use of sometimes unaffordable pesticides) this approach is without doubt the most appropriate. After a wide range of consultations with stakeholders, it appeared that a concerted effort focusing on a participatory approach to assemble the technologies for farmer testing, validation and adaptation in a location specific manner would be required to improve the adoption chances for cowpea IPM technologies. Through participatory processes and technologies IITA promotes collaborative cowpea IPM research, and learning between the Institute and national partners, attracts non-governmental organizations for participatory research and training, reorients training and extension methods towards the farmer field school model, and enhances technology dissemination and adoption. While implementing this work IITA and its partners follow a multi-disciplinary approach and encourage joint activities by scientists and extension agents to diagnose cowpea pests and diseases, test, validate and implement technology options to overcome these constraints, and evaluate the technology itself and its impact.

17. Information kindly provided by M Tamo (IITA, Benin Republic).

Innovative germplasm development - an important component for a global challenge program dealing with climate change

Abiotic stresses (including drought) account for significant yield reduction (up to 71%) in crops. In developed world agriculture (e.g. USA, where data are available) insurance indemnities are paid more for crop losses due to drought than for any other kind of loss. Examples from the developing world speak by themselves, For example, drought stress coinciding with flowering and grain filling reduces maize yields by 50% and 12% respectively, thereby becoming one of the major abiotic constraints for this crop in the Guinea savanna belt of West and Central Africa, or in the drought-prone environments of eastern and southern Africa (Ortiz et al. 2002). An annual economic loss of US$ 520 million may be due to drought in groundnut, and genetic enhancement for this trait may reduce this by US$ 208 million, i.e. 5.2 benefit : cost ratio. Hence, farmers in dryland agriculture in environments prone to long and unpredictable dry-spells will be the main beneficiaries on this research-for-development undertaking.

There are distinct options for managing water resources and improving water productivity (WP). Irrigation (or modifying the environment) was the traditional approach for dealing with water shortages but now that water resources are scarce other solutions are sought. For example, plant breeders are working on the development of crops better adapted to drought-prone environments or for plants with high water-use efficiency. Research suggests that relatively high productivity may be accomplished even in unfavorable environments if selection for adaptation to these environments occurs in targeted crops. Furthermore, recent advances in cell and molecular biology offer a new means (either through genetic transformation or applied genomics) for improving crops tolerant of water stress. All CGLAR centers working on crop breeding invest resources to improve crops for water-scarce environments and are introducing biotechnology methods for enhancing their breeding protocols. Genome sequencing and functional genomics in model plant or crop species are providing not only new knowledge but also new genes to tackle some important abiotic stresses in the plant kingdom. Inputs from crop physiologists and water/irrigation managers/engineers are included in defining new plant types (or ideotypes), which may enhance the adaptation of crops to drought-prone environments or improve the water-use efficiency. Indeed, germplasm improvement and crop-water management are complementary approaches for managing water more efficiently in water-scarce environments.

Table 5. Plant mechanisms for drought tolerance or water-use efficiency in crops.

Crop	Plant characteristic or mechanism
Cereals	
Barley	Earliness, harvest index, low transpiration efficiency, proline accumulation, short grain filling period, tillering
Maize	Anthesis-silk interval, fertile ear number, grain number per fertile ear, great partitioning of biomass to the ear (or high harvest index)
Pearl millet	Panicle harvest index or ratio of grain mass to total panicle mass
Rice	High harvest index, intermediate plant height, leaf rolling, high leaf water potential, osmotic adjustment, root length density, root penetration ability, root pulling resistance, small total dry matter
Sorghum	High water extraction efficiency, few nodal roots per plant, few higher late metaxylem, small leaf area, stay-green owing to delayed senescence
Wheat	Abscisic acid (ABA) accumulation, leaf water potential, proline content, transpiration efficiency
Legumes	
Bean	Ability to avoid flower abscission and sustain pod formation
Chickpea	Deep roots, earliness, rapid root development and water extraction, rapid rate of large seed development, small leaf area due to few pinnules
Cowpea	Delayed-leaf senescence and slow growth or stop growth for conserving plant tissue moisture, thereby staying alive
Groundnut	Harvest index, specific leaf area, total amount of water transpired and transpiration efficiency
Lentil	Early flowering, osmotic adjustment, pod set, transpiration efficiency
Lupin	High number and large seeds per pod owing to fast seed growth
Pigeonpea	Osmotic adjustment, seedling establishment and early growth vigor
Soybean	Root size, ability to degrade ureides, leaf Mn^{+2} concentration, transpiration efficiency
Starchy crops	
Cassava	Growth index, leaf retention, photosynthetic rate, root length density, stomatal conductance
Musa	Leaf stomatal conductance, photosynthetic rate, stomatal morphology, transpiration
Potato	Low water potential, root pulling resistance, stomatal conductance
Sweet potato	Leaf water potential, root pulling resistance, root systems

Plant mechanisms to become better adapted to water-scarce environments are widely reported but most of them are not yet well understood (Ortiz et al. 2002). Among the most important are root architecture, leaf morphology, physiological characters such as osmotic adjustment or proline accumulation, partitioning of total biomass (as determined by dry matter or harvest index), timing for plant development (e.g. earliness), or others associated with the plant reproductive biology. Some of these characteristics are specific while others are common to many species (Table 5). Some reports indicate a significant association between crop tolerance of heat and respective adaptation to drought-prone environments in the warm tropics. Germplasm screening for tolerance to drought under naturally occurring drought stress does not seem to be reliable. Lack of uniform drought stress in the field will render screening for drought tolerance ineffective and thus limit progress from selection. Selection must occur under controlled environments, where drought will be reliably induced to distinguish between tolerant and susceptible genotypes, particularly at flowering or grain filling stages in seed crops.

A multidisciplinary approach and capitalizing on new science will be the means for making rapid progress in developing new crops that will help increase water productivity in farming systems worldwide. Integrated crop-soil-water management suggests that genetic solutions may be the one of the answers for enhancing crop adaptation to water stressful environments, e.g. drought-tolerant or short-season crops. Ideotype breeding and new recombinant-DNA tools appear to be complementary to ongoing cross-breeding approaches being undertaken by the CGIAR and its research partners in the dry agro-ecozones of the world. However, breeders need to include in their trait assessment not only plant characteristics but also water parameters, such as water productivity and water savings. Also, suggested characteristics among new plant types must be tested to determine their potential not only in the targeted crop but also related species and where it fits in the agricultural system. Model plant species (Arabidopsis, Medicago truncatula, rice or soybean) are available tools for assessing whole-genome transcriptional response and new sources of alleles for (a)biotic stresses, e.g. drought. Characteristics of interest may be included in a plant ideotype and genetic control points associated to them may be determined. Further, comparative mapping will allow determining gene synteny of drought tolerance loci between crops within the same family (or tribe therein). Forward and reverse genetics may identify key regulators of drought tolerant genotypes. These tolerant genes may be candidates for genetic transformation

Table 6. Selected examples of genetic systems (some linked to molecular markers) enhancing adaptation to drought-prone environments in some dicotyledonous crops.

Crop	Trait	Genetic marker system	Putative genes
Bean	Yield response to drought	RAPD	4-5 QTL
Cowpea	Genotype stops growth and keeps moisture to stay alive	Mendelian	1 major
	Slow trifoliate growth but senescent unifoliate drops; growing tips remained turgid and alive for long time	Mendelian	1 major
Groundnut	DNA transcripts regulated after water stress	PTRD	3 promising for MASc
Soybean	Water-use efficiency	From the available nmap	1 major QTL
Tomato	Water-use efficiency	RFLP	3 QTL

RAPD = random amplified polymorphic DNA; MASc = marker-aided screening; PTRD = peanut transcripts responsive to drought; RFLP = restriction fragment length polymorphism; QTL = quantitative trait loci.

or cross-breeding manipulations to develop new crops that may enhance water productivity in drought-prone environments.

Genetic analysis in some crops suggests that a few genes may control each of the independent plant mechanisms of drought tolerance (Table 6). Further marker-aided genetic analysis reveals that most of the variation for responses to drought may be accounted for by one or few QTL. Cross-breeding assisted by selection with DNA markers could become a means for a fast and objective selection of new cultivars with enhanced adaptation to water-scarce environments. For example, recent analysis of molecular responses to abiotic stresses suggest that using regulation of gene expression and signal transduction in transgenic crops could enhance their adaptation to stressful environments, e.g. to drought, frost, salinity (Shinozaki et al. 1999). The following actions are needed in a holistic approach:

- Crop physiologists and irrigation/water engineers/managers define traits of interest for new plant types with enhanced adaptation to water-scarce environments;
- Gene bank managers and crop breeders search for the suggested attributes in the germplasm available in their collections;
- Geneticists map genes controlling these traits in respective crop pools;
- Crop breeders use mapped DNA markers as landmarks for gene introgression for selection;

- Molecular biologists using functional genomics and gene sequencing dissect candidate genes for specific attributes enhancing water productivity in crops;
- Biotechnologists transform plants with candidate genes across species; and
- Crop physiologists and breeders test new plant types to **determine their** agronomic potential in targeted agro-ecozones.

Research in model crops (e.g. Medicago truncatula) will add new tools to the breeder's kits for associated crop species or even for research-neglected crops. Cowpea (Mai-Kodomi et al. 1999a ; Mai-Kodomi et al. 1999b; Singh et al. 1999a, Singh et al. 1999b) seems to be the best suitable species to determine the genetic potential of legume crops for drought using QTL analysis and germplasm characterization. The characteristics of interest in a drought tolerant "consensus legume" species are root architecture, transcriptional pathways, physiological parameters (e.g. osmotic adjustment), plant development (e.g. earliness) and genetic control points. Comparative mapping will be the means to determine gene synteny of drought tolerance loci between crop legume genomes. The outputs of this legume genomic research are genetically defined loci controlling this trait, candidate genes (as defined by mapping, mutation and transcriptional investigations) for drought tolerance and DNA markers for assisted-selection or aided-introgression and germplasm management regarding the improvement of drought adaptation in legume crops. We should expect that new plant types for crops that will enhance water productivity will be developed and experimental legume genotypes with new plant architecture or physiological trait(s) may be, therefore, added to the testing tool kit of crop physiologists.

Cost and benefits on cultivar development[18]

This discussion assumes that investments already provide for infrastructure, equipment and access to any technology, including that in the proprietary domain. Likewise, staff members possess the "know-how" on plant breeding methods and relevant genetic resources that are available for breeding work. These genetic resources could be accessions from a gene bank, introductions of exotic germplasm, other cultivars, clones or breeding lines or genes. The costs depend on crop under improvement, breeding objectives being pursued, breeder's skills,

18. Notes (after reading references), particularly Morris et al. (2001).

capacity of the organization, location where work being undertaken and costs of key inputs throughout the process from selecting the parents for crossing to marketing the cultivar, among the most important factors.

Economic function for investment outputs. The amount of research investment on cultivar development can be conceived by using a research production function relating research inputs to research outputs (Morris et al. 2001). From a breeding company perspective, this could comprise many small functions, each representing a different level of research capacity distinguished by complexity and scope (Brennan 1989); i.e. the breeding research production function becomes a meta-function obtained by adding discrete sub-programs and changes along the meta-function, which are associated to changes in focus and increases in the breeding company research capability. Such movement across one to another level requires "lump" investments that are not easy to divide: investments in lab equipment plus appropriate professional staff with skills to manage the new equipment or to apply new protocols. The decision on investing lumpy resides on whether the extra resources will provide a means to additional (and significant) benefits to the breeding company. And benefits for most breeding programs consist of adding value to crop production enterprises, so the incentives for further investments in adding research capacity to their programs will generate an increase in the area planted with new cultivars ensuing from the extra resources given to research, as well as better investment returns because of the value associated to the new cultivar.

Potential savings for cultivar development process. Savings, in time and costs, are associated to costs during phenotypic screening (Koo and Wright 2000), which range from cheap eye scoring to expensive equipment-led testing at central site (Moreau et al. 2000), or in multi-environment testing. The quicker (and cheaper) the new cultivar reaches farmers the rapid return to investment; i.e. accelerating new cultivar releases, through reducing breeding cycle, may bring significant benefits UNCLEAR (Pandey and Rajatasereekul 1999). The plant breeding method to be included in cultivar development is an investment decision, and conventional investment criteria can facilitate its selection (Sanders and Lynam 1982).

Morris et al. (2001) determined the net present value (NPV) by summing the stream of benefits over the life of a cultivar (n years):

$$NPV = S^{n}_{t=1} (GB_t - VR_t - RC_t)$$

where GB is gross benefits (calculated as area planted to the cultivar x incremental benefits associated with adoption), VR is cultivar release expenses (cost of evaluation trials, registration procedures, seed multiplication, advertising and promotion, and other non-research investments), and RC is research investment costs. The internal rate of return (IRR) to the investment can be conventionally calculated by solving the discount rate at which the NPV equals zero.

There are three stages associated with the streams of costs and benefits linked to cultivar development by the breeding company and release to the farmers, who will be replacing their planting materials by adopting (all or partially) the new cultivar propagules (Morris et al. 2001):

1. Research for developing improved germplasm, including the potential new cultivars, e.g. 5 or 6 years from a cross to advanced testing;
2. Release stage after advanced testing of improved germplasm, in which specific genotypes, (with potential to become new cultivars) are included in multi-site and on-farm testing before registering for release. Commercial seed of new cultivars are also produced at this stage; e.g. 2 or 3 years starting from advanced testing; and
3. Adoption stage when farmers grow the new cultivar, 9 to 12 years after cultivar release.

In stages 1 and 2 net benefits are negative since only costs are incurred and no benefits are yet realized. In stage 3 net benefits will depend on the rate of farmers' adopting the new cultivar. This benefit increases until the peak of adoption (about 5 to 7 years after the new cultivar reaches farmers) and then decline when the cultivars become "old" and newer releases, with novel traits, "hit" the farming community markets.

The rule of thumb to decide on breeding method suggests that if abundant capital exists then it make sense to consider those methods (e.g. DNA marker-aided breeding) that generates the largest NPV (i.e. quick profits or early return to investments). Otherwise, the method that maximizes IRR (e.g. conventional cross-breeding) could be better when capital is constrained in the breeding program.

Private seed sector, crop breeding and plant biotechnology

The search for profit, as in any other business, attracts the interest of the private sector for investing in the seed industry. They also look for new ways of protecting these investments through intellectual property rights, patents or the like, especially if biotechnology applications are used for accelerating the genetic enhancement of crops. The private seed sector considers that plant variety protection encourages and ensures return of research investments, and serves as an economic incentive for private and public sector investments in research and development. Likewise plant variety protection, as indicated by agri-business managers, helps to facilitate the transfer of technology and knowledge, and provides encouragement and assurance for plant breeders to introduce their best varieties for production and propagation. In short, the private seed sector considers that any kind of plant variety protection would attract new and improved genetic material and technology, thereby enhancing the quality and yield of breeding materials. As a consequence of the introduction of intellectual property protection, a material transfer agreement (MTA) has become a routine document for exchange of genetic material.

The MTA has been adopted not only by the private seed sector but also by public research organizations. For example, the CGIAR centers are using MTAs to exchange breeding materials, which are recognized by these centers and their development investors as international public goods. Likewise, MTAs are needed for the "designated" germplasm accessions held by the CGIAR gene banks in trust for the international community, as per the agreement with the Food and Agriculture Organization of the United Nations. The CGIAR's commitment to fairness gives emphasis to the needs of the rural poor and to disadvantage member of the society. Therefore, CGIAR centers recognize the contribution of many different communities and individuals, especially of women, to the conservation and enhancement of genetic diversity of potential use for food and agriculture, and will strive to ensure they benefit from such contributions.

The main objectives of these MTAs of the CGIAR are to protect the germplasm or breeding lines and associated information from ownership or intellectual property claims by the recipients of this material. Hence, MTAs ensure continued and free availability of the genetic materials from the CGIAR centers. The MTA may evolve and become part of a multilateral system that facilitates access, exchange and use of genetic resources, and it ensures a fair and equitable share of the benefits ensuing from the commercialization or further utilization of these genetic materials in the development of improved cultivars. As a part of the policy of maximizing the utilization of genetic materials for any agricultural research or breeding purposes, the centers of the CGIAR have facilitated in the last four decades the development of both public and private seed sector in many parts of the developing world. Sorghum provides a good example of such support for the seed sector in India. In 1986, 89% of the demand for sorghum breeding materials developed at ICRISAT was from the public sector; this demand shifted to 64% for the emerging private seed sector in 1997. Nowadays, about 60% of the proprietary sorghum hybrids in India are derived from lines or segregating material that were provided by ICRISAT.

It has been argued that the private sector plays a key role and therefore has been investing in the development of hybrid seeds for cereal crops. However, research for development in the public sector may promote the utilization of so-called "orphan" or neglected crops. ICRISAT research on pigeonpea provides an example of this situation. Innovative research at ICRISAT challenged the assumption that hybrid seeds in farmers' fields were not achievable for food legumes, in which cross-pollination systems are difficult to develop (Saxena et al. 1996). Leguminous species exhibit low natural out-crossing and seed multiplication rates, thereby the resulting costs of hybrid seed are not economical. Nonetheless, the first pigeonpea hybrid ICPH 8 reached Indian farmers in 1991 as a result of a research partnership between ICRISAT and the Indian Council of Agricultural Research (ICRISAT 1998). An Indian private seed company became involved in 1992 and started marketing hybrid pigeonpea seeds. The pigeonpea hybrids show a yield advantage of 25% to 35% over open-pollinated cultivars, which partially explains the high demand by farmers for hybrid seed; the demand has so far been exceeding the supply. After this initial success a new wave of research was launched by a public research consortium led by ICRISAT that won the funding support from a private seed company to identify and incorporate cytoplasmic male sterility, which facilitates the production of hybrid seeds.

In recent years investment by the private sector in agribusiness have substantially increased in the developing world with the aim of providing quality seed, food and feed. Therefore partnership with these companies is crucial in research for development, and not only to transfer technology but also to attract research funding. The establishment of public-public or private-public partnerships will enhance the potential for agricultural production enhancement through ongoing developments in plant biotechnology. However, all outputs of research and development with grants provided by the private sector should remain in the international public domain. Public plant breeders should see the private sector investment as supplementary and not as a replacement of the funds provided by the government, international development investors, foundations or other non-government organizations. These new and evolving partnerships needs to be carefully assessed, especially with regard to intellectual property rights.

Outlook

Some of the successes of plant breeders in the past depended on somewhat "empirical" approaches. Further plant breeding gains would increasingly become reliant on science-led strategies using genetic knowledge and integrating transgenics, molecular marker technology and genomics into breeding programs. More advances in functional genomics, proteomics and metabolomics will enhance the knowledge and provide new resources for developing new breeding methods for the somewhat research-neglected crops of the semi-arid tropics.

Regional approaches on seed and biosafety laws will facilitate trade of biotechnology products and tools within a region. Policy options to enhance the adoption of plant breeding products and tools requires not only harmonizing laws within the region but also approaches for helping business start-ups, e.g. tax-relief, interest-free loans and other similar schemes that encourage private investments for entrepreneur development. This policy should stimulate self-sustaining commercial operations. Rich-poor cooperation, institutional alliances, information and knowledge sharing, and intellectual property rights management are also influencing the success of crop genetic enhancement.

Plant genetic resources and crop breeding alone are only part of the solution but they do not provide all answers to eradication of poverty, food security and environmental safety. Sustainable crop and natural resource management coupled with new, resilient, improved cultivars and their healthy propagules, which may possess traits for agro-processing and commerce, are critical for enhancing the livelihoods of the rural poor in Africa through access to local, regional and international markets. In this regard, long-term financing for producing international public goods, which aim at the enhancement of the livelihood and prosperity of today's poor, should be a top priority in the agenda of development investors in the African semi-arid tropics.

References

Acevedo, E and Ferreres E. 1993. *Resistance to abiotic stresses.* In: Plant Breeding: Principles and Prospects (Hayward, MD, Bosemark, NO, and Romagosa, I. eds.). Chapman and Hall, London, pp. 406-421.

Anand, RP, Ganapathi, A, Vengadesan, G, Selvaraj, N, Anbazhagan VR and Kulothungan S. 2001. *Plant regeneration from immature cotyledon-derived callus of Vigna unguiculata (L.)* Walp (cowpea). Current Science 80: 671-674.

Baker, GR, Fukai, S and Wilson GL. 1989. *The responses of cassava to water deficits at various stages of growth in the subtropics.* Australian Journal of Agricultural Research 40:517-528

Bidinger, FR. 1998. *Farmer participation in pearl millet research in Namibia. In Participatory Plant Improvement.* Proceedings Workshop, Chennai India, 27-28 October 1998. M.S. Swaminathan Research Foundation - ICRISAT, Chennai, India, pp. 21-30.

Bidinger, FR, E Weltzien R, Mahalakshmi, V, Singh SD and Rao KP. 1994. *Evaluation of topcross hybrids of pearl millet for arid zone environments.* Euphytica 76:215-226.

Brennan, JP. 1989. *An analysis of economic potential of some innovations in a wheat breeding programme.* Australian Journal of Agricultural Economics 33:48-55

Ceccarelli, S. 1997. *Adaptation to low/high input cultivation.* In Tigerstedt, P.M.A. (ed.) Adaptation in Plant Breeding. Kluwer Academic Publishers, Dordrecht, pp.

Cock, JH. 1985. Cassava. *New potential for a neglected crop.* Westview Press, Boulder and London.

Connor, DJ and Cock JH. 1981. *Response of cassava to water shortage. II. Canopy dynamics.* Field Crops Research 4:285-296.

Connor, DJ, Cock JH and Parra GH. 1981. *Response of cassava to water shortage. I. Growth and yield.* Field Crops Research 4:181-200.

Connor, DJ and Palta J. 1981. *Response of cassava to water shortage. llI. Stomatal control of plant water stress.* Field Crops Research 4:297-311.

De Lacy, IH, Fox, PN, Corbett, JD, Crossa, J, Ranjaram, S, Fischer RA and van Ginkel, M. 1994. *Long-term association of locations for testing spring bread wheat.* Euphytica 72:95-106.

DeVries, J and Toenniessen G. 2001. *Securing the harvest - biotechnology, breeding, and seed systems for African crops.* CABI Publishing, CAB International, Wallingford, Oxon.

Dje, Y, Heuertz, M, Lefebvre C and Vekemans X. 2000. *Assessment of genetic diversity within and among germplasm accessions in cultivated sorghum using microsatellite markers.* Theoretical and Applied Genetics 100:918-925.

Dodds, J, Ortiz, R, Crouch, JH, Mahalakshmi, V and Sharma KK. 2001. *Biotechnology, the gene revolution, and proprietary technology in agriculture: A strategic note for the World Bank.* IP Strategy Today 2 http:// www. biodevelopments. org/ip/index. htm

Douthwaite, B. 2001. *Enabling innovation: A practical guide to understanding and fostering technological change.* Zed Books, London.

Douthwaite, B and Ortiz R. 2001. *Technology exchange.* Electronic Journal of Biotechnology 4(2) http://ejb.ucv.cl/content/issues/02/index.html

Falconer, DS and Mackay, TFC. 1996. *Introduction to quantitative genetics.* 4 th ed. Longman, Harlow, UK.

Fatokun, CA, Menancio-Hautea, DI, Danesh, D and Young, ND. 1992. *Evidence for orthologous seed weight genes in cowpea and mung bean based on RFLP mapping.* Genetics 132:841-846.

Grenier, C, Bramel-Cox, PJ, Noirot, M, Prasada Rao, KE and Hamon P 2000a. *Assessment of genetic diversity in three subsets constituted from the ICRISAT sorghum collection using random vs. non-random sampling procedures A. Using morpho-agronomical and passport data.* Theoretical and Applied Genetics 101: 190-196.

Grenier, C, Deu, M, Kresovich, S, Bramel-Cox, PJ and Hamon P. 2000b. *Assessment of genetic diversity in three subsets constituted from the ICRISAT sorghum collection using random vs non-random sampling procedures B. Using molecular markers.* Theoretical and Applied Genetics 101: 197-202.

Grenier, C, Bramel, PJ, Hamon, P, Chantereau, J, Deu, M, Noirot, M, Reddy, VG, Kresovich, S, Prasada Rao, KE, Mahalakshmi, *V,* Crouch, JH and Ortiz, R. 2000c. *Core collections, DNA markers and bio-informatics: new tools for "mining" plant genetic resources held in gene banks - Sorghum as an example.* In Proceedings of the International Workshop on Integration of Biodiversity and Genome Technology for Crop Improvement. Tsukuba, Japan, 28 November - 1 December 2000. pp.

Grenier, C, Bramel Cox, PJ and Hamon, P. 2001a. *Core collection of sorghum. I. Stratification based on eco-geographical data.* Crop Science 41:234-240.

Grenier, C, Bramel Cox, PJ and Hamon, P. 2001b. *Core collection of sorghum. II. Comparison of three random sampling strategies.* Crop Science 41:234-240.

Hahn, SK, Bai, KV and Asiedu R. 1990. *Tetraploids, triploids and 2n pollen from diploid interspecific crosses with cassava.* Theoretical and Applied Genetics 79:433-439.

Haussmann, BIG, Hess, DE, Reddy, BVS, Welz HG and Geiger HH. 2000a. *Analysis of resistance to Striga hermonthica in diallel crosses of sorghum.* Euphytica 116:33-40.

Haussmann, BIG, Hess, DE, Reddy, BVS, Welz HG and Geiger HH. 2000b. *Improved methodologies for breeding striga-resistant sorghums.* Field Crops Research 66:195-211.

ICRISAT. 1998. *From orphan crop to pacesetter: Pigeonpea improvement at ICRISAT - Winner of the 1998 CGIAR King Baudouin Award.* International Crops Research Institute for the Semi-Arid Tropics, Pathancheru, Andhra Pradesh, India.

IITA. 2001. *UTA Strategic Plan 2001-2010: supporting document.* International Institute of Tropical Agriculture, Ibadan, Nigeria.

Ipinge, SA, Lechner, WR and Monyo, ES. 1996. *Farmer participation in the evaluation of priority plant and grain traits on station: The case of pearl millet in Namibia.* In Leuschner, K., and C.S. Manthe (eds.). Drought tolerant crops of southern Africa. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, pp. 35 - 42.

James, C. 2001. *Preview - Global review of commercialised transgenic crops: 2001.* ISAAA Briefs 24. ISAAA, Ithaca, N.Y.

Jones, ES, Liu, CJ, Gale, MD, Hash CT and Witcombe JR. 1995. *Mapping quantitative trait loci for doumy mildew resistance in pearl millet.* Theoretical and Applied Genetics 91:448-456.

Johnson, R. 1992. *Past, present and future opportunities in breeding for disease resistance, with examples from wheat.* Euphytica 63:3-22.

Kristjanson, PM and Zerbini, E. 1999. *Genetic enhancement of sorghum and millet residues fed to ruminants - an ex ante assessment of returns to research.* International Livestock Research Institute Impact Assessment Series Vol. 3.

Koo, B. and Wright, B. 2000. *Optimal timing of evaluation of genebank accessions and the effects of biotechnology.* American Journal of Agricultutal Economics 82:797-811.

Lenné, JM and Ortiz R. In press. *Agrobiodiversity in pest management.* In Leslie JF (ed.) Sorghum and Millet Diseases III. Iowa State University Press, Ames.

Lenné JM and Wood D. 1991. *Plant diseases and the use of wild germplasm.* Annual Review Phytopathology 29:35-61.

Lin, Y-R, Schertz, KF and Paterson, AH. 1995. *Comparative analysis of QTLs afftecting plant height and maturity across the poaceae, in reference to an interspecific sorghum population.* Genetics 141:391-411.

Mahalakshmi, V and Ortiz, R. 2001. *Plant genomics and agriculture: from model crops to other crops, the role of data mining for gene discovery.* Electronic Journal of Biotechnology 4(3) http://ejb.ucv.cl/content/vol4/issue3/full/5/index.html

Mahalakshmi, V, Bidinger, FR, Rao, KP and Raju, DS. 1992. *Performance and stability of pearl millet topcross hybrids and their variety pollinators.* Crop Sci. 32:928-932.

Mahalakshmi, V, Reddy, BSV, Bandyopadhyay, R, Sharma, HC, Rao, NK and Ortiz, R. In press. *Sorghum on line crop information.* In Leslie J.F. (ed.) Sorghum and Millet Diseases III. Iowa State University Press, Ames.

Mahalakshmi, V, van Hintum, TJL and Ortiz R. In press. *Enhancing germplasm utilization to meet specific user needs through interactive core selections.* Plant Genetic Resources Newsletter.

Mahalakshmi,V, Aparana, P, Ramadevi, S, and Ortiz, R. Submitted. Genomic sequence *derived simple sequence repeat* markers - Case study with Medicago spp. Electronic Journal of Biotechnology.

Mallikarjuna, N. 1999. Ovule and embryo culture to *obtain hybrids from interspecific incompatible pollinations in chickpea.* Euphytica 110:1-6.

Mai-Kodomi, Y, Singh, BB, Myers Jr., O, Yopp, JH, Gibson, PJ and Terao T. 1999a. Two *mechanisms of drought tolerance in cowpea.* Indian Journal of Genetics 59:309-316.

Mai-Kodomi, Y, Singh, BB, Terao T, Myers Jr., O, Yopp, JH and Gibson, PJ. 1999b. *Inheritance of drought tolerance in cowpea.* Indian Journal of Genetics 59:317-323.

Mcintosh, RA. 1992. Pre-emptive breeding to control wheat rusts. Euphytica 63:103-113.

Menancio-Hautea, DI, Fatokun, CA, Kumar, L, Danesh, D and Young ND. 1992. *Comparative genome analysis of mung bean (Vigna radiata)* and cowpea (V. unguiculata) using RFLP mapping data. Theoretical and Applied Genetics 86:797-810.

Mensah, RK. 2002a. Development of integrated pest management for cotton. 1: *Establishing and utilizing natural enemies.* International Journal of Pest Management 48:87-94.

Mensah. RK. 2002b. Development of integrated pest management for cotton. 2: *Integration of a Lucerne/cotton interplant system, food supplement sprays with biological and synthetic insecticides.* International Journal of Pest Management 48:95-105.

Monyo, ES, Ipinge, SA, Mndolwa, SI, Mangombe N and Chintu, EM. 1996. The *potential of local landraces in pearl millet improvement.* In Leuschner, K., and C.S. Manthe (eds.). Drought tolerant crops of southern Africa. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, pp. 153 162.

Moreau, L, Lemarie, S, Charcosset A and Gallais A. 2000. Economic efficiency on one *cycle of marker-assisted breeding.* Crop Science 40:329-337.

Morris, ML, Ribaut, J-M, Khairallah, M and Dreher, KA. 2001. Potential impacts of *biotechnology-assisted selection on plant breeding programs in developing countries.* In Pardey, P.G. (ed.) The Future of Food: Biotechnology Markets and Policies in an

International Setting. International Food Policy Research Institute (IFPRI) - The John Hopkins University Press, Washington DC. pp. 197-218.

Nassar, NMA. 2000a. *Cassava, Manihot esculenta Crantz, genetic resources: their collection, evaluation and manipulation.* Advances in Agronomy 69:179-230.

Nassar, NMA. 2000b. *Keeping options alive: a case for averting the extinction of wild cassava in South and Central America.* Diversity 16(4):21-23.

Nassar, NMA. 2001a. *Cassava, Manihot esculenta Crantz and wild relatives: their relationships and evolution.* Genetic Resources and Crop Evolution 48:429-436.

Nassar, NMA. 2001 b. *The nature of apomixis in cassava (Manihot esculenta Crantz).* Hereditas 134:185-187.

Nagamura, Y, Tanaka, T, Nozawa, H, Kaidai, H, Kasuga, S and Sasaki, T. 1998. *Syntenic regions between rice and sorghum genomes.* In Proceedings of the International Workshop on Utilization of Transgenic Plants and Genome Analysis in Forage Crops. National Grassland Research Institute (Nishinasuno, Tochigi, Japan) Report 9:97-103.

Ortiz, R. 1997a. *Secondary polyploids, heterosis, and evolutionary crop breeding for further improvement of the plantain and banana (Musa spp. L.) genome.* Theoretical and Applied Genetics 94:1113-1120.

Ortiz, R. 1997b. *Breeding for potato production from true seed.* Plant Breeding Abstracts 67:1355-1360.

Ortiz, R. 1998a. *Potato breeding via ploidy manipulations.* Plant Breeding Reviews 16:15-86.

Ortiz, R. 1998b. *Cowpeas from Nigeria: A silent food revolution.* Outlook on Agriculture 27:125-128.

Ortiz, R. 1999. *Genetic enhancement and base broadening efforts.* In Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture-Implementation of the Global Plan of Action in Europe. (Gass, T, Frese, L, Begemann, F & Lipman, E. eds.) International Plant Genetic Resources Institute, Rome, Italy, pp. 191-203.

Ortiz, R. 2000. *ICRlSAT research strategy in the medium-term.* In Technical and Institutional Options for Sorghum Grain Mold Management (Chandrashekar A, Bandyopadhyayay, R and Hall, A. eds.). ICRlSAT, Patancheru, India, pp. 1-6. http://www.icrisat.org/text/research/grep/homepage/sgmm/chapter 1 .htm

Ortiz, R., 2001. *The state of use of potato genetic diversity.* In Broadening the Genetic Base of Crop Production (Cooper, HD, Spillane, C and Hodgkin, T (eds.). Food and Agriculture Organization of the United Nations (FAO) - IPGRI, Rome, Italy - CAB International, Wallingford. pp. 181-200.

Ortiz, R. 2002. *Germplasm enhancement to sustain genetic gains in crop improvement.* In Managing Plant Genetic Diversity (Engels, JMM, Ramanatha Rao, V, Brown, AHD and Jackson, M eds.). IPGRI, Rome, Italy - CAB International, Wallingford. pp. 275-290.

Ortiz, R. 2003. *Breeding clones.* In Encyclopedia of Plant & Crop Science (Goodman, RM ed.). Marcel Dekker, Inc., New York.

Ortiz, R. In press. *ICRISAT bridge-broker-catalyst role for building partnerships for agricultural research-for-development in the semi-arid tropics: A holistic approach for sorghum and millet improvement as a potential opportunity for such collaborative programs.* In Sorghum and Millet Diseases III (Leslie, JF. ed.). Iowa State University Press, Ames.

Ortiz, R. In press. *Analytical breeding.* Acta Horticultural.

Ortiz, R and Crouch, JH. 2001. *Applied biotechnology in the improvement of the tropical food species.* In e-Proceedings REDBIO IV, Goiana, Brazil, 3-8 June 2001.

Ortiz, R and Golmirzaie, AM. 2002. *Hierarchical and factorial mating designs in quantitative genetics of tetrasomic potato.* Theoretical and Applied Genetics 104:675-679.

Ortiz, R, Bramel-Cox, PJ, Hash, CT, Mallikarjuna, N, Reddy, DVR, Seetharama, N, Sharma, HC, Sharma, KK, Sivaramakrishnan, S, Thakur RP and Winslow, MD, 2000. *Potential for Improving Agricultural Production through Biotechnology in the Semi-Arid Tropics.* Water Commission on Dams Thematic Reviews IV 2 - Assessment of Irrigation Options. 29 pp. http://www.dams.org/thematic/contrib_papers.php7rec=ENV092

Ortiz, R, Ekanayake, I, Mahalakshmi, V, Menkir, A, Nigam, SN, Saxena, NP, and Singh, BB. 2002. *Development of drought resistant and water stress tolerant crops through traditional breeding.* In Water for Sustainable Agriculture in Developing Regions, Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Japan. In press.

Ouedrago, JT, Maheshwari, V, Berner, DK, St-Pierre, CA, Belzile F and Timko, MP. 2001. *Identification of AFLP markers linked to resistance of cowpea (Vigna unguiculata L..) to parasitism by Striga gesnerioides.* Theoretical and Applied Genetics 102:1029-1036.

Pandey, S and Rajatasereekul, S. 1999. *Economics of plant breeding: The value of shorter breeding cycles for rice in Northeast Thailand.* Field Crops Research 64:187-197.

Paterson, AH, Lin, YR, Li, Z, Schertz, KF, Doebley, JF, Pinson, SRM, Liu, S-C, Stansel, JW and Irvine, JE. 1995. *Convergent domestication of cereal crops by independent mutations at corresponding loci.* Science 269:1714-1718.

Peloquin, SJ and Ortiz, R. 1992. *Techniques for introgressing unadapted germplasm to breeding populations.* In Plant Breeding in the 1990s (Stalker, HT and Murphy, JP eds.). CAB International, Wallingford. pp. 485-507.

Pereira, MG and Lee, M. 1995. *Identification of genomic regions affecting plant height in sorghum and maize.* Theoretical and Applied Genetics 90:380-388

Phipps, RH and Park, R. 2002. *Environmental benefits of genetically modified crops: global and European perspectives on their ability to reduce pesticide use.* Journal of Animal and Feed Sciences 11:1-18.

Pollak, LM and Corbett, JD. 1993. *Using GIS datasets to classify maize-growing regions in Mexico and Central America.* Agronomy Journal 85:1133-1139.

Pollak, LM and Pham, HN. 1989. *Classification of maize testing locations in sub-Saharan Africa by using agroclimatic data.* Maydica 34:43-52.

Rajaram, S, Braun, H-J and van Ginkel, M. 1997. *CIMMYT's approach to breed for drought tolerance.* In Adaptation in Plant Breeding (Tigerstedt, PMA. ed.). Kluwer Academic Publishers, Dordrecht, pp. 161-168.

Rohrbach, DD, Lechner, WR, Ipinge, WR and Monyo, ES. 1999. *Impact from investments in crop breeding: the case of Okashana I in Namibia.* ICR1SAT Impact Series Vol. 4, Patancheru, Andhra Pradesh, India.

Sanders, JH and Lynam, JK. 1982. *Definition and relevant constraints to research resource allocation in crop breeding programs.* Agricultural Administration 9 (4): 273-284.

Sastry, JG, Ramakrishna, W, Sivaramakrishnan, S, Thakur, RP, Gupta, VS and Ranjekar, PK. 1995. *DNA fingerprinting detects genetic variability in the pearl millet downy mildew pathogen (Sclerospora graminicola).* Theoretical and Applied Genetics 91:856-861.

Saxena, KB, Chauhan, YS, Laxman Singh, RV, Kumar and Johansen C. 1996. *Research and development of hybrid pigeonpea.* International Crops Research Institute for the Semi-Arid Tropics Research Bulletin Vol. 19.

Sharma, HC and Ortiz, R. 2000. *Transgenics, pest management and the environment.* Current Science 79: 421-437.

Sharma, HC, Sharma, KK, Seetharama, N and Ortiz, R. 2000. *Prospects for using transgenic resistance to insects in crop improvement.* Electronic Journal of Biotechnology 3(2) http://www.ejb.Org/content/vol3/issue2/full/3/

Sharma, HC, Sharma, KK, Seetharama, N and Ortiz R. 2001. *Genetic transformation of crop plants: risks and opportunities for the poor.* Current Science 80:1495-1508.

Sharma, KK and Anjaiah, V 2000. *An efficient method for the production of transgenic plants of peanut (Arachis hypogaea L.) through Agrobacterium tumefasciens-mediated genetic transformation.* Plant Science 59:117-119.

Sharma, KK and Ortiz, R. 2000. *Program for the application of genetic transformation for crop improvement in the semi-arid tropics.* In Vitro Cellular and Development Biology - Plant 36:83-92.

Sharma, KK, Sharma, HC, Seetharama, N and Ortiz, R. In press. *Development and deployment of transgenic plants: biosafety considerations.* In vitro Cellular and Development Biology - Plant.

Shinozaki, K, Yamaguchi-Shinozaki, K, Li, Q, Kasuga, M, Ichimura, K, Mizoguchi, T, Urao, T, Miyata, S, Nakashima, K, Shinwari, ZK, Abe, H, Sakuma, Y, Ito, T and Seki, M. 1999. *Molecular responses to drought stress in plants: regulation of gene expression and signal transduction.* In Plant responses to environmental stress (Smallwood, MF, Calvert, CM and Bowles, DJ. eds.). BIOS Scientific Publishers, Oxford, pp. 133-143.

Singh, BB, Mai-Kodomi, Y and Terao, T. 1999a. *A simple screening method for drought tolerance in cowpea.* Indian Journal of Genetics 59:211-220.

Singh, BB, Mai-Kodomi, Y and Terao, T. 1999b. *Relative drought tolerance of major rainfed crops of the semi-arid tropics.* Indian Journal of Genetics 59:437-444.

Sperling, L, Loevinsohn, ME and Ntabomvura B. 1993. *Rethinking the farmer's role in plant breeding: local bean experts and on-station selection in Rwanda.* Experimental Agriculture 29:509-519.

Tanksley, SD and McCouch, SR.1997. *Seed banks and molecular maps: unlocking genetic potential from the wild.* Science 277:1063-1066.

Thakur, RP, Rao, VP, Sastry, JG, Sivaramakrishnan, S, Amruthesh, KN and Barbind, LD. 1999. *Evidence for a new virulent pathotype of Sclerospora graminicola on pearl millet.* Journal of Mycology and Plant Pathology 29:61-69.

Thirumala Devi, K, Mayo, MA, Delfosse, P, Gopal Reddy, Reddy, SV and Reddy, DVR. 2000. *Production of polyclonal antibodies for ochratoxin A and its detection in chillies by ELISA.* Journal of Agricultural and Food Chemistry 48:5079-5082.

van Hinthum, TJL. 1999. *The core selector, a system to generate representative selections of germplasm collections.* Plant Genetic Resources Newsletter 118:64-67.

Vuylsteke, D, Ortiz, R, Ferris, RSB and Crouch, JH. 1997. Plantain improvement. Plant Breeding Reviews 14:267-320.

Witcombe, JR and Hash, CT. 2000. *Resistance gene deployment strategies in cereal hybrids using marker-assisted selection: gene pyramiding, three-way hybrids, and synthetic parent populations.* Euphytica 112:175-186.

Yadav, Weltzien, RE, Bidinger, FR and Mahalakshmi, V 2000a. *Heterosis in landrace-based topcross hybrids of pearl millet across arid environments.* Euphytica 112:285-295

Yadav, Weltzien, RE, Bidinger, FR and Mahalakshmi, V. 2000b. *Combining ability of pearl millet landraces originating from arid areas of Rajasthan.* Indian Journal of Genetics 60:45-53.

Agricultural water management in the semi-arid tropics of Africa: Challenges, opportunities and the way forward

Francis N Gichuki[1] and Doug Merrey[2]

This paper presents challenges and opportunities for agricultural water management in semi-arid areas of Africa, illustrates the complexity of these challenges and provides background information on the issues to those concerned with the emerging water crisis to scrutinize how water for agriculture is being managed and reflect what the future would be if these constraints are not alleviated.

The main challenges are identified as scarce and unpredictable water supplies, overcoming wasteful practices, sharing water resources, increasing level of investment, and socio-economic, policy and institutional constraints. Opportunities for improving water management discussed include increase through development of additional sources, reducing storage, transmission and application losses, improving water productivity, increasing economic return per unit volume of water and reducing resource degradation.

Finally, the paper presents suggestions on the way forward consisting of a system approach involving addressing implement issues related to creating an enabling environment, facilitating and supporting framework and resource use and management programs. Research needs are identified.

Introduction

The most common features of semi-arid land are (a) erratic and unpredictable rainfall with high seasonal, annual and spatial variability; (b) mean annual potential evaporation much higher than the mean annual rainfall; (c) low infiltration of rainwater due to high rainfall intensities over short a period of time and relatively low soil permeability - a combination that gives rise to low soil moisture availability for plant growth and low rates of groundwater recharge; (d) soil constraints such as low inherent soil fertility, low organic

1. International Water Management Institute (IWMI), Nairobi, Kenya
2. IWM1, Silverton, South Africa

matter content, high soil salinity and/or alkalinity and high soil erodibility; and (e) low plant productivity limited mainly by water and nutrient availability and consequently poor vegetative cover, limited grazing resources, low crop production and low human carrying capacity.

Despite these limitations, the population in semi-arid areas is increasing. The growth in human, livestock and wildlife population, increased economic activities and improved standards of living leads to increased demand for water resources and competition for and conflict over the limited water, land and grazing resources. Under such conditions, a major challenge is how to secure food security for the poor and vulnerable communities in semi-arid areas, through more efficient use and equitable allocation of water resources in a sustainable manner.

This paper contributes to the debate on this issue by highlighting the main challenges in agricultural water management, the opportunities for addressing the challenges and finally proposes the way forward. The paper illustrates the complexity of these challenges and provides background information on the issues to those concerned with the emerging water crisis to scrutinize how water for agriculture is being managed and reflect what the future would be if these constraints are not alleviated.

Challenges of agricultural water management

Scarce and unpredictable water supplies

Limited and unreliable rainfall

The mean annual rainfall over the African continent is 724 mm with a standard deviation of 664. The rainfall is poorly distributed with approximately 67% of the area receiving less than 1000 mm per annum (see Figure 1). Twenty five percent, 50% and 75% of the land area receives less than 134, 564 and 1178 mm per annum, respectively. Approximately 10% of the area receives more that 1650 mm and only 3% receives more than 2100 mm per annum (see Figure 2). Hence the internally renewable water resources in the semi-arid areas of Africa is low and the potential contribution of the more humid areas to water resources in the semi-arid areas is limited due to the low percentage of the areas receiving more than 1000 mm of rainfall and their spatial distribution.

Other characteristics of rainfall in SAT that create additional management challenges are its high intensity, short duration, temporal

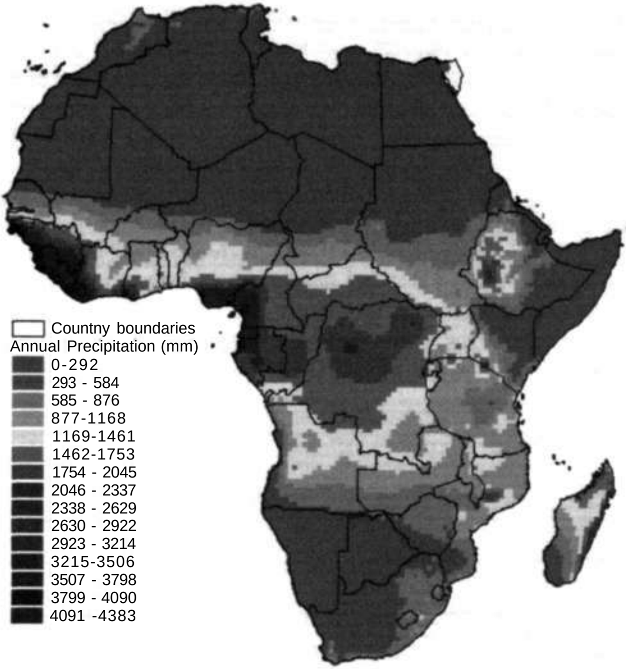


Figure 1. Spatial variability of annual precipitation.

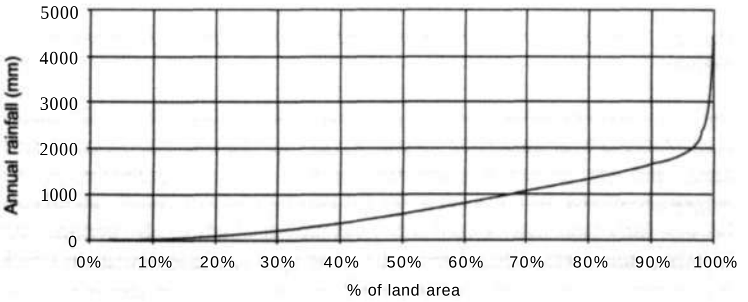
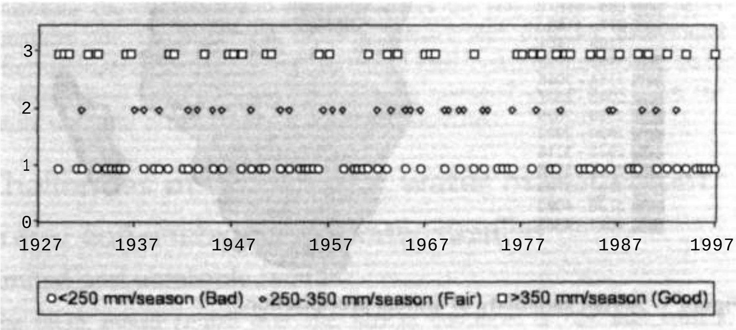


Figure 2. Rainfall as a function of % of the land area.

variability, and unpredictability. High rainfall intensities lead to high runoff and soil loss potential, short duration limits the length of the growing season, while temporal variability and unpredictability of rainfall are the main causes of smallholder farmers reluctance to invest in high input crop production. There is also a high variability in the rainfall onset date (30-50 days onset window) and the seasonal rainfall decreases with the delay in the onset of the rains. Trends analysis of seasonal rainfall for Dwa-Kibwezi rainfall station in a semi-arid area of Kenya, which has bimodal rainfall, showed that seasonal rainfall (120 days) ranged from 0-850 mm. A chronology of bad, fair and good rainfall seasons[3] showed that bad seasons occur characteristically in runs of 2-5 seasons rather than singly (see Figure 3) (Gichuki, 2000).

Experiences in the semi-arid areas of Ewaso Ngiro North river basin have shown that due to the high rainfall variability, there are risks associated with



Source: Gichuki, 2000

Figure 3. Chronology of bad, fair and good rainfall seasons (Dwa-Kibwezi, Kenya).

the water sources. Water sources with quantifiable risks include (a) sources with adequate hydrological data available; (b) large dams with large catchment areas; and (c) proven groundwater aquifers. Realistic estimates of the magnitude of risk is not possible for (a) small dams with small catchments because such dams have periods with good rainfall which are also periods with low irrigation water requirements; (b) dams with catchment areas in which

3. Defined in terms of seasonal rainfall threshold value of 250 mm needed to produce a Makueni Composite maize crop.

land use is changing and affecting runoff rates and silt loads; and (c) surface water sources in which upstream water abstraction may increase due to ineffective systems of water rights and their enforcements.

Groundwater

The challenges of groundwater resources management are associated with groundwater recharge, development, pollution and over- or under-exploitation. In the semi-arid areas, evaporation is higher than rainfall and infiltration rates are low and hence the potential contribution of rainwater to groundwater recharge is low and mainly takes place in areas with sandy soils and/or where runoff accumulates. Hence most of the groundwater resources in semi-arid areas originate from the surrounding semi-humid and humid areas. Development of groundwater in semi-arid areas is constrained by the limited aquifer capacity and water yield, lack of data on water availability and quality and the high cost of exploring, developing and lifting groundwater resources. Pollution and over-exploitation of groundwater is a serious problem in some localized areas. In other areas the groundwater resources are relatively under-utilized and can serve as a buffer against seasonal shortfalls in rainfall and surface water resources (Gichuki et al. 1998).

Mismatch between water availability and demand

Water scarcity situations exist where users are in competition for access to water brought about mainly by drought, population growth, overuse and misuse (pollution) and the mismatch between supply and demand. Temporal and spatial mismatch between water availability and demand occurs naturally. The temporal mismatch is associated with the rainfall and natural river flow regime and the water demand for human, plant and animal use. Rainfall in semi-arid areas is concentrated over a short period when there is a surplus while the dry season experiences water deficits. Storage is therefore required to meet the water demands of the dry season. The spatial mismatch of water availability and demand is associated with the spatial distribution of human population and the suitability of land for irrigation, which determines the demand point and the water availability, which determines the supply points. Water is in most cases concentrated in areas that are spatially distant from the demand points and hence the need for hydraulic structures to capture the water from the supply point and deliver and distribute it to the various demands points. This places an enormous demand on the financial resources to construct the hydraulic structures, the development of human and institutional capacities to manage these facilities in ways that promote equity and are dependable. Development of water infrastructure shifts access or distribution patterns to people's advantage but may also concentrate water resources in a certain region and subject another region to extreme scarcity.

Overcoming wasteful water management practices

Agriculture has been accused of operating at low water use efficiencies. Evaporation, runoff and deep percolation losses in rainfed agriculture range between 30% and 80%. In irrigated agriculture conveyance, distribution and application losses range between 10% and 90% with overall irrigation efficiencies of 30-95%. Hence there is a high potential for reducing these wasteful practices. However, Keller et al. (1996) noted that water wasted in the upper regions sometimes ends up being reused downstream. They argued that while analysis at irrigation project may indicate low water use efficiency (20-60%), from a basin perspective the efficiency may be high (60-90%) if the water is reused. Hence increasing efficiency at the project level may have negative impacts on the systems reusing the water perceived to be lost by the upstream irrigation project. However, it is important to note that this reuse water is availed at a later time, at a low quality and may involve additional costs of capturing and transporting it.

Reversing trends in water and land degradation

Inappropriate land use and management

The main natural ecosystems undergoing major land use changes in Africa are forestland, grassland and wetlands. Intensification is taking place in most land uses particularly where high population pressure and market forces are driving intensification. Inappropriate land use and management in both semi-arid areas and the more humid upland watersheds has been identified as a major threat to water availability for downstream agriculture, domestic, livestock and wildlife use (Gichuki et al., 1998).

Deforestation of upper watersheds has been identified as a major threat in Africa, which lost 55 million hectares to deforestation in the period 1980-1995 with Cameroon accounting for nearly 2 million hectares (FAO

1997). In just 100 years, Ethiopia's forests have declined from 40% to only 3% of the land. These land use changes have adversely affected ground and surface water availability and seasonality of surface water in the semi-arid areas, as the upper watersheds are the main sources of water in semi-arid areas.

Wetlands are a habitat of great ecological importance (e.g. as habitats for water fowl, fish, and other wildlife, as regulators of water quantity and quality in receiving waters, areas of high biodiversity etc.) and support human existence as sources of fish (for food), drinking water, building materials, medicines and dry seasonal grazing. Conversion of wetlands (mainly swamps and marshlands) to cropland and urban-industrial establishments is threatening their integrity and ability to perform ecological functions (Day 1998, Bugenyi and Balirwa, 1998). Also increased water use, mainly for agriculture, in the upper reaches of rivers is in some cases resulting in drying up of the wetlands in semi-arid areas with adverse social, economic and environmental impacts.

Land use and management influence water yield and quality in a grassland landscape in semi-arid areas, Where grasslands have been converted to croplands without adequate conservation measures or are over-grazed, the water quality is negatively affected. As a consequence of inappropriate land use and management, wildlife ecosystems and habitats are threatened by the decline in dry season flows, flood flow regulation resulting in destruction of habitats created by seasonal flooding, encroachment and conversion of savannahs, wetlands and forest land (Gichuki et al. 1998; SMUC 2001).

Water pollution

Poor agricultural water management practices are the major source of water pollution. Gichuki et al. (1998) reported that the Upper Ewaso Ngiro North basin experiences a high soil loss with suspended sediment load of the 15,200 km^2 basin area ranging from 350-1538 Parts per million (ppm) mainly attributed to runoff from overgrazed land. Kihara (1998) reported that sediment discharge for different sub-catchments of the Ewaso Ngiro North basin varied from 12-281 t km^{-2} per year. Thomas (1995) studied the sediment discharge of an ephemeral catchment (2.21 km^2) and reported suspended sediment discharge as high as 200 kg s^{-1} during peak flow period. Soil loss at plot level for a single storm as found to range from 1-5.6 t ha^{-1} (Mutunga 1994) and the average seasonal soil loss for a gentle slope (5%) in the semi-arid Laikipia Plateau of the Ewaso Ngiro North basin was 24.8 t ha"^{1} and 19.7 t ha^{-1} for crop land and grazing land, respectively (Liniger, 1991).

Okwach (2000) investigated the effect of tillage and crop cover on runoff and soil loss on Chromic Luvisols on 8-10% slopes in Katumani, Kenya, and reported that the control plot ploughed and left bare had the highest runoff and soil loss, 26% and 32 t ha"^{1}. The plot that was conventionally plowed, mulched with 50% of previous season maize stover and a maize plant population of 22,000 plants per hectare had runoff loss of 15% and soil loss of 10 t ha^{-1}. Conventionally plowed plots, mulched with 100% stover from previous season and a maize plant population of 53,000 plants per hectare had runoff loss of 7% and soil loss of 2 t ha^{-1}. Doubling the maize plant population doubled the maize yield and reduced soil and runoff loss.

Poor agricultural land use and management is blamed for eutrophication[4] that is taking place in some places at an alarming rate (Bugenyi and Balirwa 1998). The increased deposition rates of nitrogen and phosphorous into water bodies is associated with agricultural activities and modification of the riverine ecosystem, particularly wetlands which perform some natural purification function. Degradation of these aquatic ecosystems is threatening the sustainability of fishery resources.

Groundwater contamination is a growing problem as biological and chemical pollutants from agriculture, industry and urban areas penetrate into the groundwater aquifers and contaminate the fresh water stored in them. The challenge is even more daunting when you consider the difficulties associated with restoring a contaminated aquifer to safe conditions.

Water logging and salinization

Continental level analysis shows that approximately 40-60% of irrigation water is lost through seepage and evaporation. This seepage loss contributes to serious soil salinization and waterlogging problems. For example, in Mozambique, the lower Limpopo basin is experiencing serious salt problems partly due to the salinity brought down stream from the poorly drained Chokwe Irrigation scheme and also by salt coming from the Changane River tributary which passes through saline soils in the Changane basin (UNEP 2000b).

4. Eutrophication is an aquatic environmental degradation process whereby water bodies become progressively enriched with nutrients (mainly nitrogen and phosphorous), with a resulting excess production of plant (usually algae) biomass, which grossly disturbs the ecological functioning, and floral and faunal balances of the water body.

In the Nile Delta, water logging and salinity problems are very extensive partly due to the hot arid climate, the high level of irrigation water use and the fine-grained alluvial soils with poor internal drainage (Murakami 1995). In 1982 almost all the irrigated area in Egypt was potentially affected by salt and about 400 km^2 of irrigated area were being equipped with drainage systems each year at a cost of US$ 200 per hectare to partially address the salinization problem (Murakami 1995). Solutions to the water logging and salinization are constrained by the inability of farmers to make the required level of investment and the inability of irrigation authorities inability to effectively operate the drainage system.

Achieving fair sharing of water resources

The temporal and spatial variability in the availability of water resources and the fact that it is a moving resource adds to the socio-economic, policy, legislative and institutional complexities of sharing water resources making achieving fair water allocation a daunting task. Consequently, water allocation remains a contentious issue with claims and counter-claims among competing uses and users leading to conflicts. As competition for water increases, agriculture is expected to receive a decreasing share of the water resources.

While the law gives priority to domestic use, this is an inadequate mechanism for fair sharing of water resources especially for the semi-arid communities. This is mainly attributed to over-abstraction and pollution in the upper reaches. In the semi-arid areas, irrigated agriculture is in competition for limited supplies with domestic and industrial uses which can afford to pay more per unit volume of water and with use for maintaining ecosystem services such as sustaining wetlands and meeting minimum stream flow requirements. As water scarcity increases, the poor become increasingly disadvantaged as the rich can afford to construct reservoirs, increase the depth of their boreholes or even invest in inter-basin water transfers.

The examples below illustrate the trends towards unfair water sharing. Overuse of water by upstream users is significantly reducing dry season river flows in many rivers in Africa. For example the analysis of the Ewaso Ngiro North River at Archer's Post, Kenya, for the number of days with mean flow less than 1 $m^3 s^{-1}$ from 1960 shows a clear trend of decreasing dry-season flow (see Figure 4). The flow is lowest in February and the mean for this month dropped from 9 $m^3 s^{-1}$ in the 1960s, to 4.59 $m^3 s^{-1}$ in the 1970s, to 1.29 $m^3 s^{-1}$ in the 1980s, and to 0.99 $m^3 s^{-1}$ in the 1990s (Liniger 1995). The river dried up for a stretch of up to 60 km upstream of Buffalo Springs in 1984, 1986, 1991, 1994, 1997 and 2000. For the period April 1998 to December 2000, the daily mean flow peaked at 354 $m^3 s^{-1}$ in May 1998 and dropped to zero in February 1999 illustrating the rapid response to climatic drought (Gichuki et al. 1999). This reduction in flow is attributed mainly to increasing water abstraction upstream and drought cycles, as there is no corresponding decline in rainfall amounts over the same period.

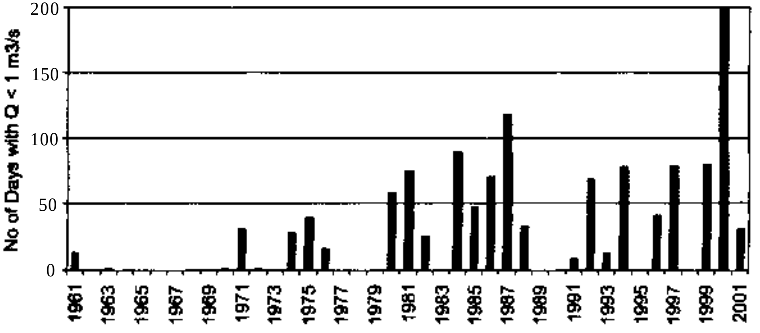


Figure 4. Declining trends of increasing period of very low flow of Ewaso Ngiro North River, Kenya.

Similar experiences are reported for the Great Ruaha river where dry season flows have been reported to have declined since the early 1970s, with the complete cessation of flow during the drought years (SMUC 2001). The situation is predicted to get worse in the future. For example in the Lower Limpopo Basin the predictions are that there will be a decrease of 20% in the present inflows of the Limpopo at Pafuri in the medium term and a decrease of 20% in the inflows in the Elefantes and 40% in the Limpopo at Pafuri in the long term (UNEP 2000b).

Over-use of the water in the upper more humid watersheds results in reductions in surface water flows into the semi-arid areas. This has major implications on the future surface and ground water availability, cost of development and management responses in the semi-arid areas.

Investment challenges

Concerns for the environment

Agricultural water management activities particularly irrigation and drainage projects, despite having received large investments and subsidies have not always fulfilled expectations for yield increases and efficiency of water use. Improved understanding of the environmental impacts has highlighted the negative aspects of such development. Critics have been calling upon governments and donors to rethink their investment strategies in irrigation and drainage, which has resulted in a decline in funding new irrigation and drainage projects in the last decade.

Inadequate maintenance of existing works

Irrigation and drainage projects in semi-arid areas are at risk from poor operation and maintenance. The high sediment load in most rivers chokes up the intake works and silt is deposited in canals and reservoirs reducing their capacity and making water control structures inoperable. As a consequence, the systems operate below capacity with unreliable supplies which result in reduced cultivated area, yield decline, farmers shifting to lower value crops and lower level of inputs to reduce risks and reduced level of investment in maintenance (IPTRID 1999). As a result, smallholder farmers and some government irrigation projects undergo cycles of build-neglect-rehabilitate-neglect and some of them are ultimately abandoned.

A study on the effect of different levels of maintenance on incremental net benefits showed that with satisfactory maintenance, there was a positive incremental benefit even under adverse conditions such as discount rate increased to 12%, crop prices reduced by 20%, maintenance cost increase by 20% and rehabilitation delayed by two years (IPTRID 1999). Despite such encouraging returns on investments in satisfactory system maintenance, such investments are not being made to safeguard the existing investments in order to sustain the system, its outputs and associated livelihoods. IPTRID (1999) argues that to improve effectiveness of maintenance, irrigation planners, managers and policy makers must recognize the impact of neglect and act by providing a conducive policy and institutional framework, providing incentives and improving on design, planning and operation procedures.

Increasing cost of water development

The cost of agricultural water management interventions, particularly large-scale irrigation and drainage projects, has increased considerably. The average cost of water supply has risen from US$ 0.6 to 1.4 m^{-3} between 1975 and 1995 (World Bank 1996). Olivares (1990) reported that the weighted average irrigation cost were US$ 2000, 2850, 5600, 5900 and 9500 ha^{1} in Zambia, Sudan, Kenya, Botswana and Zimbabwe, respectively. In 1992, the average investment cost for medium- and large-scale irrigation projects in sub-Saharan Africa was estimated as US$ 8300 ha^{1} (FAO 1992). Jones (1995) reported that the average cost of irrigation systems in sub-Saharan Africa increases to US$ 18,300 ha^{-1} if the indirect costs of social infrastructure, such as roads, houses, electricity grid, and public service facilities were included.

Such high costs and low returns on investments have discouraged governments and donors as evidenced by data on trends in irrigated areas in Africa (see Figure 5). However, private investments in irrigation have increased, particularly in areas where development costs are low and there is good access to the market. For example, in the upper Ewaso Ngiro North river basin, private irrigation development (both smallholder and large scale) has increased from 280 ha in 1982 to 890 ha in 2000 (NRM3 database).

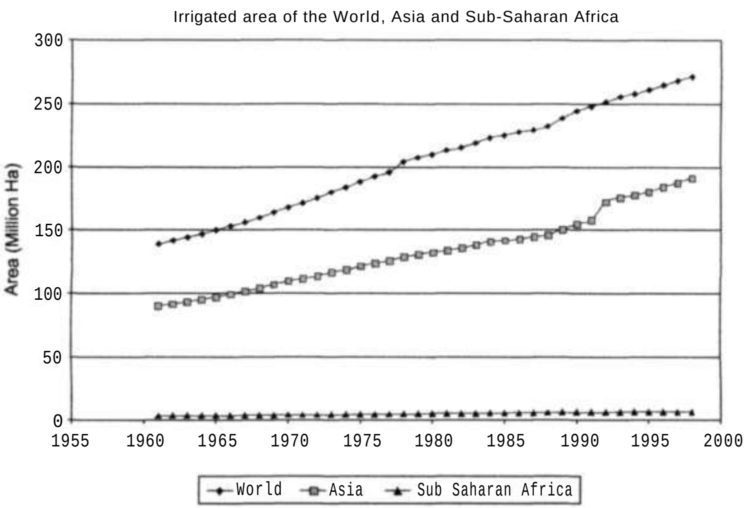


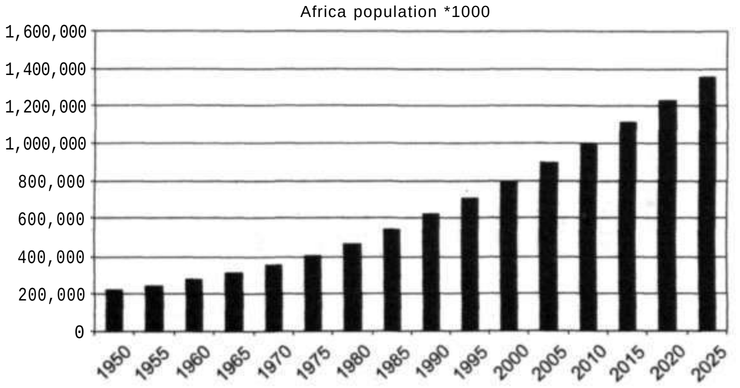
Figure 5. Irrigation development in the World, Asia and Sub-Saharan Africa.

Alleviating socio-economic constraints

Increasing population and poverty

Africa has the world's highest population growth rate (2.36%), and although this rate is expected to drop the population is projected to reach 1,358,120 by 2025 and 1.8 billion by 2050. A large percentage of this population derives its livelihood from land and water resources in semi-arid areas and the people living in upper watersheds have an influence on the water availability for the semi-arid inhabitants and those in the arid lands depend on the water resources generated in the humid and semi-arid watershed that is allowed to reach them.

Analysis of the geographic distribution of the population in Africa (UNEP 1999) showed that it is unevenly distributed with major population concentrations in the northern coast between Tunisia and Morocco and in the Nile Delta, around Lake Victoria, in Ethiopian highlands and in and around Nigeria. Some localized areas in the semi-arid regions are also experiencing high population growth rates particularly where government policies have encouraged settlement in previously under-utilized areas. For example, in the upper Ewaso Ngiro semi-arid areas, the human population increase at 2-8% per annum in different parts between 1979 and 1995 as the population pressure in the humid and sub-humid areas drove people into the semi-arid areas (Karekia 1995).

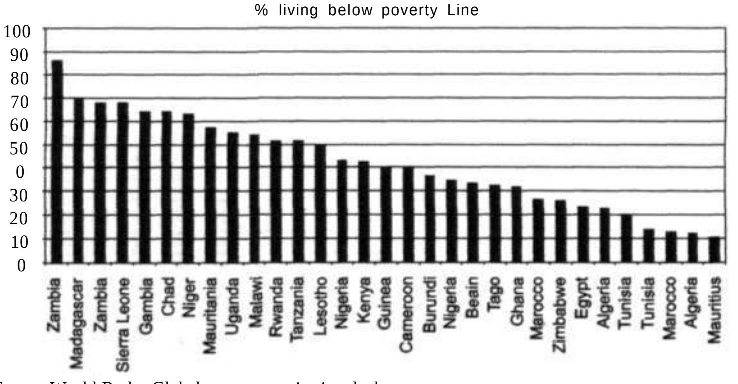


Source: FAOSTAT database

Figure 6. Africa population (actual and projected).

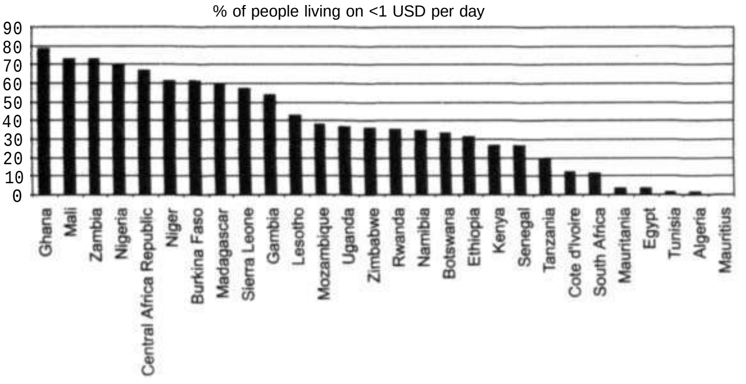
The average gross domestic product (GDP) of Africa countries for the year 2000 was US$ 9540 (World Bank 2001). The countries with the highest GDP were South Africa (US$ 125,887), Egypt (US$ 98,333), Nigeria (US$ 41,248), Tunisia (US$ 19,463), Sudan (US$ 11,169) and Kenya (US$ 10,410). The countries with the lowest GDP were Cape Verde (US$ 556), Djibouti (US$ 554), The Gambia (US$ 396), Guinea Bissau (US$ 225) and Comoros (US$ 202).

Global poverty monitoring data (1988-1998) from the World Bank help to illustrate the high poverty levels in Africa. Twelve countries had more than 50% of the population living below the poverty line and 10 countries had more that 50% of the population living on less than one dollar per day (see Figure 7 and Figure 8). Thus the lives of many people are characterized by a "poverty spiral" of poor nutrition, poor education, disease, inability to compete successfully in the workforce and high rates of population increase (Day 1998). The semi-arid areas are home to a large percentage of the continent's poor. The economies of most of the countries have experienced negative growth rates and high inflation. Agricultural producer prices are declining making it more and more difficult to make a decent living from agriculture. The persistent poverty tends to accelerate environmental degradation as farmers and pastoralists have limited capital to invest in sustainable agricultural development practices.



Source: World Bank - Global poverty monitoring database
http://www.worldbank.org/research/povmonitor/

Figure 7. Percentage of people living below poverty line in selected countries.



Source: World Bank - Global poverty monitoring database
http://wvvrw.worldbank.org/research/povrnonitor/

Figure 8. Percentage of people living on < 1 USD per day in selected African countries.

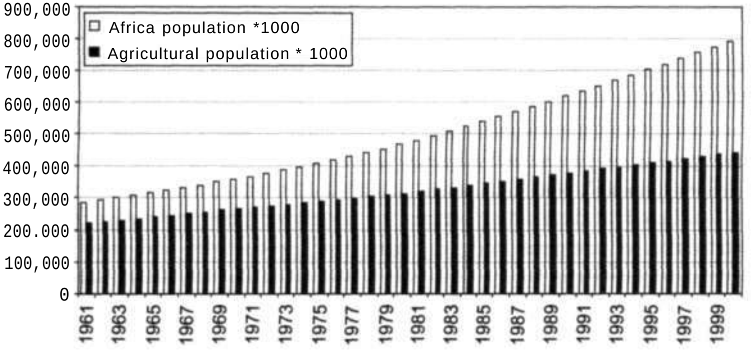
Population growth can be a driving force for disaster or recovery. Those who link population growth with disaster take the view that increases in population density ultimately lead to increased poverty and environmental degradation. This is attributed to diminishing returns to capital and labor and to land scarcity, cultivation of marginal lands, declining land productivity and growing food demands resulting in famine. This is how Machakos District, Kenya, was viewed in the 1930s. However, the disaster predicted by Maher did not take place. Instead, without further environmental deterioration, productivity increased and living standards improved. Population growth has been accompanied by increasing productivity and living standards. How has this happened?

Population pressure in this case certainly led to agricultural intensification. However, in other areas, land productivity has declined due to erosion and soil nutrient depletion. Simpson et al (1996) argue that there has been a substantial decline in soil fertility and that soil fertility improvements have been slow, uneven and hampered by availability of inorganic fertilizer and credit, and by the perceived climatic risk.

High dependency on land and water resources

Most of the inhabitants of the semi-arid areas of Africa are dependent on agriculture (crop and livestock production). Continental level data show that the dependency on agriculture decreased from 78% to 56% between 1961 and 2000 (see Figure 9). In the Nile Basin, agriculture contributes 17-52% of the GDP and employs 30-94% of the labor force. Livestock form an integral part of agriculture and human welfare in rural areas. Most of the agriculture is not commercially oriented and is characterized by small landholdings, low use of inputs and low crop yields. Agricultural support services including input supply, agro-processing, and marketing are poorly developed.

Due to the low purchasing power of most semi-arid inhabitants, adapting to a situation of increasing water scarcity by increasing reliance on trade is not a feasible option. Consequently, continued dependence on land and water based sources of livelihood is going to create enormous stress on the scarce water resources.



Source: Ashton, 2000

Figure 9. Total and agricultural population data for Africa.

Water use conflicts

The semi-arid and arid areas of Africa have variable and erratic rainfall patterns, high evaporation rates and a striking absence of perennial rivers and lakes. Ashton (2000) highlighted the remarkable correspondence of the distribution pattern of perennial rivers and lakes, and those areas where some form of dispute or conflict has occurred or has been threatened, either over the availability of water or over some aspect of water supply (see Figure 10).

(Source: Ashton, 2001)

Figure 10. Distribution of large perennial rivers and actual or potential areas of water conflicts.

Rising demand for the increasingly scarce water resources is leading to growing concerns about future access to water, particularly where two or more countries share water resources. With over 60 river basins shared by two or more countries, access to water from any of these shared rivers could provoke conflict, particularly in the Nile, Niger, Volta and Zambezi basins (Johns Hopkins 1998). The threat is more real for countries like Egypt, Botswana and Niger which obtain respectively, 97%, 94% and 68% of their total fresh water from neighboring states. There are also a wide variety of more local, inter- and intra-community conflicts over water that occur within the boundaries of a single community or country as in the case of the Ewaso Ngiro (Gichuki et al. 1998) and the Ruaha (SMUC 2001). Water use conflicts generally arise where users compete to derive the maximum possible benefits from the available water resources. This situation is accentuated in those situations where there is an increasing level of water pollution and where the downstream users may be economically "poorer" or politically and militarily "weaker" than their upstream neighbors. Consequently, competition between upstream and downstream countries for the same water resource is considered to pose the greatest potential threat of conflict over water in Africa (Ashton 2000).

Crippling effects of periodic droughts

Climatic droughts occur when rainfall is below normally expected amounts. Droughts of different intensities have been reported for different parts of semi-arid areas. Gichuki (2000) reported that in the semi-arid areas of Makueni District, Kenya, the probability of light, moderate and severe droughts ranged from 43-55%, 32-43%, and 13-30%, respectively. The chronology of drought indices shows that droughts come in runs of 2-5 seasons.

Semi-arid regions experience periodic droughts with adverse and sometimes crippling food security impacts: high risks for crop failure, a reality every 5th year, and risk of yield reductions associated with water constraints every 2nd year (Rockstrom et al. 2001). The impact of drought is illustrated by the southern African experiences highlighted below. In the 1994-95 cropping season in southern Africa, cereal harvests declined by 35% compared to the previous year. The maize harvest fell by 42% due to drought (SADC 1995). Drought was equally devastating during the 1991-92 cropping season in the SADC region, where cereal production was nearly halved, with more than 20 million out of 85 million people affected by food shortages (UNEP 2000c).

Agricultural droughts occur when water supply is insufficient to cover crop or livestock water requirements and is influenced by weather factors, investments in water conservation and water management strategies adopted to cope with drought conditions. A series of droughts results in severe hardship, loss of planting material, desiccation of the land, loss of animals, and a high dependency on external assistance (food aid, remittance from relatives etc.). The poor are the most disadvantaged by drought and its associated water shortages as they (a) pay very high prices per unit volume of water, (b) expend more calories carrying water for long distances, (c) suffer more in impaired health from contaminated or insufficient water, and (d) lose more in diminished livelihoods and, in extreme cases, loss of life. On a small scale, the flourishing dry season vegetable gardening around small earth dams in semi-arid areas of northern Ghana is an indication of the contribution of development of surface water in crop production and food security for the poor and disadvantaged (Sipkens and Nabila 1989).

Securing food for the growing number of poor people

Studies on population growth, food requirements and food production report the incidence of chronic under-nutrition in developing countries decreased from 941 million in 1969 to 637 million in 1988 but in sub-Saharan Africa, it rose from 94 million to 175 million during the same period (IFPRI 1995). They estimated that by 2010, the incidences in developing countries will have dropped to 637 million people while in Africa, the number is expected to rise to 296 million. The population is poorly distributed creating high pressures in semi-arid areas with less favorable rainfall, temperature and soils for crop production. In Africa, the percentage of food insecure people has fluctuated between 37% and 35% between 1967 and 1990 but is expected to drop to 32% by 2010 (IFPRI 1995; FAOSTAT database 2002). This high level of food insecurity is associated with the high levels of poverty.

The twin problems of poverty and food insecurity can be tackled by intensifying agricultural production, by industrialization and by reducing population growth. There is an urgent need to provide policy makers with credible data on the extent to which these strategies can contribute to alleviating poverty and enhance food security. In the foreseeable future agriculture will continue to be the backbone of most national economies. Consequently, from an agricultural perspective, the development challenge becomes, how will agricultural production (broadly defined to include crop (food and non-food), trees, livestock, and fisheries) be increased to enhance food security and alleviate poverty in a sustainable manner? Achieving these increases will require, among other things, huge investments in land and water development and associated rural infrastructure. A challenge associated with this is: "Where should the investments be made - in semi-arid or humid regions? In increasing productivity of existing rainfed and irrigated agriculture or in expanding rainfed and irrigated agriculture?"

Overcoming policy and institutional constraints

Technologies for improving water use efficiency exists and yet only 15 - 30% of the rain water is productively used (productive green water flow as transpiration) (Rockstrom et al. 2001) and average irrigation systems efficiencies are in the range of 30-50%. In some cases, these levels of water use efficiency are acceptable, for example, where some of the green water lost from the cropping system is recaptured and transformed into blue water and where the irrigation water loss is recycled down the system (Keller et al. 1996). Consequently, it can be argued that water problems in Africa are actual water management and governance problems and hence the need to look at the institutional aspects of water resources management. Institutional and policy frameworks have not adequately promoted wise use and management of the scarce water resource.

Policy constraints

Management of water resources to cope with scarcity is heavily influenced by macro-economic policies and sectoral policies that have a strategic impact on water demand, allocation, use and productivity. Policies tend to increase or reduce revenue of producers and/or security of land and water use. For example, policies that favor cheap food imports can have both positive and negative effects depending on the circumstances. For countries with alternative and secure sources of livelihood (non-agricultural), cheaper imported food can reduce the need to produce locally, thereby reducing the competition for scarce water resources. However, cheaper food depresses local prices and reduces the profitability of local agricultural ventures, which leads to insufficient incentives for efficient and sustainable farming practices leading to land, water and vegetation resource degradation.

Inappropriate policies have been blamed for not sending the right signals to the private sector to invest in water development in semi-arid areas, to water users to adopt water-saving technologies, to water polluters to reduce pollution levels, to researchers to generate and disseminate data and information and develop appropriate technologies, to government departments to provide their supportive role of regulation and to the donors to support semi-arid development initiatives. In the past, government policies have generally emphasized exploitation for development at the expense of conservation and sustainability. Policy changes taking place are addressing some of these shortcomings.

Institutional constraints

Lack of coordination and cooperation: Duties and responsibilities pertaining to water management are shared by a number of agencies responsible for different aspects of water resources management. Consequently, fisheries issues, agricultural issues, industrial waste issues, and drinking water issues are addressed separately and without adequate coordination. This is further complicated by the fact that multiple users within the countries and among nations share water resources. Schoneboom (1998) argued, "if coordination within a country is difficult, the task is all the more daunting across political boundaries." Underlying the above problems are deep-rooted causes relating to inadequate management capacities and financial mechanisms to rehabilitate, maintain and operate the water facilities and inadequate cooperation due to sectoral administration and management practices (UNEP 2000b).

Ineffective legal framework: In most cases, laws are limited in scope, reactive rather than anticipatory, poorly implemented and enforced, and uncoordinated. Consequently, the legal system has not adequately protected the water rights[5] of the poor and the disadvantaged semi-arid communities leading to over-abstraction and/or pollution of water by upstream users.

Water governance is in most cases inadequate. This is mainly attributed to (a) sectoral approaches which lead to the fragmented and uncoordinated development and management of the resources; (b) top-down approaches whose legitimacy and effectiveness is increasingly being challenged; (c) inefficient governance; and (d) increased competition for the scarce water resources.

Opportunities for demand and supply management

Developing additional water supplies

The primary sources of water in the semi-arid areas are local rainfall, river inflows from the upper more humid watersheds and groundwater. From a water use perspective, additional water supply can be secured through reuse (secondary sources). The quality of reuse water is generally lower because water picks up pollutants as it flows or is used and because of **the** concentration of pollutants associated with decreasing quantity as water is lost through consumptive use. Thus, as water is progressively recycled the amount and concentration of pollutants in the water increase substantially.

Rainwater harvesting

Considering that as much as 10-25% of the rainfall in semi-arid areas runs off there is a potential for increasing rain water supplies by capturing the water and storing it in the soil or in a farm pond or dam for later use (Rockstrom et al. 2001).

5. Water rights range from the most exclusive forms of individual ownership, to communal rights at the local-community level, to public regulation at the national or state level, to agreements at the international level, or a combination of these.

Water stored in soil or in a dam can extend the crop-growing season by 20-40 days in semi-arid areas where the growing season is very short. Such increases in supply can also be used to mitigate mid-season drought spells by providing water for supplemental irrigation (Baron et al. 1999). Opportunities offered by storage have not been seized by most farmers in the semi-arid areas due to the high levels of evaporation and seepage losses and the high cost of constructing dams.

Groundwater development

Groundwater can serve as a buffer against seasonal shortfall in rainfall. In areas with shallow groundwater resources such as the fringes of wetlands in semi-arid areas this resource can support irrigated agriculture in the fringes of the wetlands. In parts of Nigeria, Niger and Senegal the potential of exploiting shallow groundwater aquifers in semi-arid areas has been demonstrated. The National Fadama Development Project of the Nigerian Government targets to irrigate 100,000 ha by tapping shallow groundwater resources using 50,000 tube wells (WFS 1996). Dougnac (1999) reported that the groundwater in *dambos* (swamps and marshes) in southern African could be an affordable source of groundwater. He reported a two to ten-fold increase in crop yield with appropriate soil, water and crop management and noted that the high profitability of fishing is the main reason why their crop production potential has not been fully utilized and are mainly used for dry season grazing. Similar observations have been made for the swamps within 20 km of the Kenyan shore of Lake Victoria. Environmentalists have also cautioned against utilization of these groundwater resources for fear that the environmental functions of such wetlands may be threatened. Groundwater resources exploitation for livestock watering has been demonstrated to increase livestock production and minimize degradation of grazing resources by controlling grazing pressure by providing livestock water to areas where grazing resources are abundant.

Major surface water development works

Regulation of surface water in the semi-arid areas of Africa through the use of medium- and large-scale dams has not taken place partially due to the poor performance of water development projects in Africa. In Africa only about 3% of cropland is irrigated and there has been a negligible reduction in poverty in the 1990s (sub-Saharan Africa had an estimated poverty headcount of 47.7%

in 1990 and 46.3% in 1998 (World Bank 2000). Africa has lagged behind in the development of water supply and irrigation (Figure 5); a special case can be made for creating a conducive environment for re-investing in major surface water development projects.

Conjunctive use of rainfall, surface and groundwater sources

Conjunctive uses of rainfall, surface and groundwater sources can lead to increased water productivity due to reduced risk associated with water availability at the beginning and end of the rainy season and mid-season dry spells. This is illustrated below for a farmer with a shallow well and a small dam. The farmer utilizes the groundwater to get the crop started before the onset of the rains and when the dam is empty. During this period water requirements are low and hence even shallow wells with low water yield provide the reduced amount of water. When the rains start, they meet the full crop water requirements and also refill the small dam. The water stored in the dam is used for supplemental irrigation if a mid-season dry spell hits or to extend the length of the crop production period past the cessation of the rains and depletion of soil water.

Marginal sources of water

Water stress in the semi-arid areas is expected to intensify as upstream water uses increase. Under such water stress, marginal waters in the groundwater systems such as brackish groundwater and in surface-water systems such as wastewater and irrigation return flow are being considered as major complementary sources of water. Urban areas receive high quality water and discharge low quality wastewater. The potential for reuse of urban waste has been demonstrated. Hide et al. (2001) reported that controlled reuse of effluent from sewage works for irrigation can be undertaken with minimal risks to the workers and the consumers of the irrigated produce.

Reducing storage, transmission and application losses

Most water storage, conveyance and distribution facilities in semi-arid areas are poorly constructed, operated and maintained (Gichuki et al. 1998). Consequently, seepage, evaporation and operation losses are high. Water supply at the point of use can be increase by reducing these losses, particularly if they are not being reused by other users. For example a reservoir in a semi-arid area may lose as much as 0.4-0.7 m of stored water over a period of 100 days through evaporation and an additional 0.2-0.4 m through seepage losses. Cheaper options of reducing seepage and evaporation losses exist but are not widely used.

Reducing water resource degradation

Water resources degradation through inappropriate land use and management and disposal of urban and industrial waste is a major contributor to decreasing the amount of available freshwater resources. Land and water management approaches and technologies that minimize water resource degradation exists but are not widely adopted.

Improving productivity per unit water

In semi-arid areas security and stability of food supplies is closely linked to the success in water control. Farmers with efficient water harvesting and irrigation systems attain higher yields than those solely dependent on in situ rainfall. Maintaining favorable soil moisture conditions in the root level allows for the maximization and stabilization of production by ensuring that fluctuations in the rainfall regime do not result in stress to the crop. Increases in crop productivity per unit volume of water can be achieved by increasing soil moisture availability to the plant and by increasing the proportion of water used by crop transpiration relative to other pathways. Increasing soil moisture availability can be achieved through a combination of rainwater harvesting, irrigation, tillage practices that increase infiltration, multiple cropping with a combination of shallow and deep rooting crops, and application of fertilizers to facilitate more vigorous root development needed to access soil water. Increasing crop transpiration relative to other losses can be achieved through mulching, modifying spacing and plant population, application of fertilizer, and weed, pest and disease control.

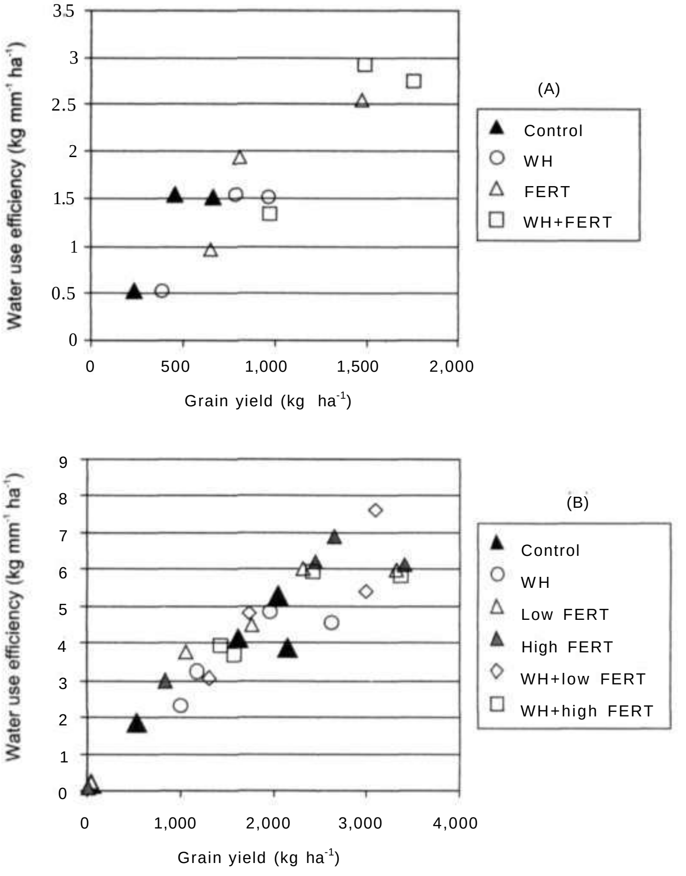
Rockstrom (2001) argues that grain yield in semi-arid areas of Africa can be increased from the currently levels of 0.5-1 t ha^{-1} to 5 t ha^{-1} by increasing the amount of green water that is used for transpiration. He points out that the largest improvement in yield and water use efficiency is achieved by a combination of supplemental irrigation and fertilizer application (see Figure 11). Onken and Wendt (1989) investigated the relationship between soil fertility and water use efficiency for different sorghum varieties and on the importance of selecting the proper variety for fertilizer response, correcting nutrient deficiencies and combining various other cultural practices having a positive effect on yield. They concluded that water-conserving practices that increase soil moisture availability can be economically feasible only when nutrient deficiencies are corrected.

Soil surface management through tillage can also lead to an increase in water use efficiency. Conservation tillage among smallholder farmers in semi-arid Babati District, Tanzania, has resulted in water use efficiency 1.5 kg mm^{-1} per ha in the mid -1980s under conventional disc-plow agriculture, compared with 2-4 kg mm^{-1} per ha, during the 1990s after introduction of conservation tillage using mechanized sub-soiling and rippers (Rockstrom and Jonsson 1999). Kilewe and Ulsaker (1984) investigated the effect of tillage methods on maize grain yield and water use efficiency on Alfisols at Machakos, Kenya. Conventional furrows, wide furrows and mini-bench tillage methods had no runoff loss and during the short rains had favorable soil moisture regime and better yield. Crop residue mulch protects soil structure, reduces the action of rain drops on soil aggregates, reduces evaporation,[6] runoff and soil loss, thereby improving the soil water regime and leading to crop yield increases. The yield advantage of mulching for the semi-arid areas of the Ewaso Ngiro North River Basin is illustrated in Figure 12.

Irrigation project water losses can be reduced through the use of more efficient water application technologies such as drip irrigation and through better irrigation scheduling. Studies on deficit irrigation[7] have shown that by targeting the critical crop growth periods and applying the less than the optimal level of water productivity can be increased (Oweis and Hachum 2001).

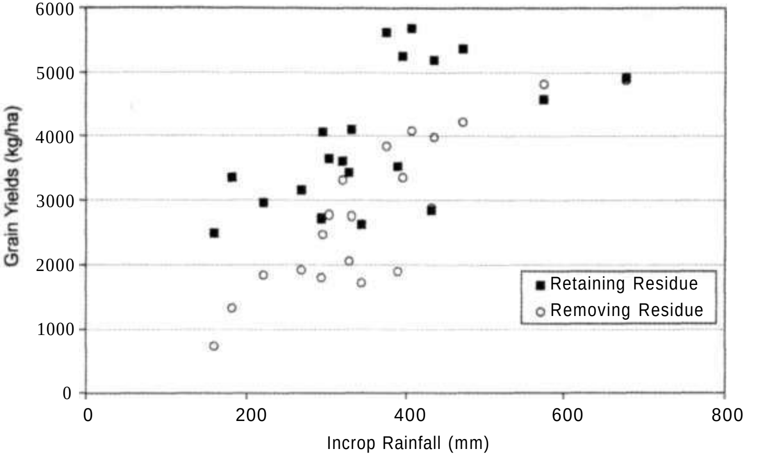
A limited irrigation dryland (LID) farming system was developed to maximize the conjunctive use of rainfall and irrigation water (Stewart et al.

6. Crop residue mulch conserves water by (a) absorbing less solar radiation; (b) acting as a thermal insulator and restricting the flow of heat from the atmosphere to the soil; and (c) creating a zone of limited air movement above the soil surface thereby reducing the transfer of vapor from the soil to the atmosphere.
7. An optimising strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction.



(Source: Rockstrom et ai. 2001)

Figure 11. System water use efficiency (kg grain per unit rainfall + supplemental irrigation) for sorghum in Burkina Faso (5a) and for maize in Kenya (5b). Control = traditional farmers' practice with no fertilizer application, WH = supplemental irrigation using water harvesting, FERT = fertilizer application (30 kg ha^{-1} N in Burkina Faso, and two levels in Kenya with Low - 30 kg N ha"^{1} and High - 80 kg N ha^{-1}).



Source: NRM3 Database

Figure 12. Maize grain yield as a function of in-crop rainfall and mulching.

1983). The LID system consists of three water management zones within the graded furrow irrigation field, namely: fully irrigated zone; zone irrigated with runoff from the fully irrigated zone; and the dry farming zone. The fully irrigated zone consists of alternate furrows in the upper half of the field. The zone irrigated with tail water runoff consist of the alternative furrows in the next quarter that receives runoff from the fully irrigated section whereas the dry farming zone consists of the lower quarter of the irrigated furrows and the non-irrigated furrows. Furrow dams are constructed every 4 m on sections of the furrows that do not receive irrigation water to minimize the runoff that would occur on these graded furrows.

Research on the use of appropriate crops and cultivars with optimum physiology, morphology and phenology to match local environmental conditions (mainly water, fertility and temperature) has yielded more superior cultivars (Oweis and Hachum 2001).

Improving economic returns per unit volume of water

As populations grow and economies expand, the financial and environmental costs of developing new water supplies begin to exceed the economic benefits in the least productive (marginal) uses of existing supplies. The reallocation of existing supplies, rather than the capture of unclaimed supplies, then becomes the least costly way to maximize benefits.

As water resources are becoming scarce and the competition for water increases, water is shifting from low value to high value crops. Increase in economic returns is dependent on availability of markets and a good transportation infrastructure (Tiffen et al., 1994). In the semi-arid areas of Machakos and Laikipia districts of Kenya, small-scale farmers have taken advantage of improved markets for export of horticulture crops to intensify their horticultural production and increase their economic returns per unit volume of water used. Even in areas with small urban populations as their major market, production of horticultural crops for the local market rather than food crop production for domestic consumption has resulted in increases in economic return.

The way forward

Business as usual is not an option

The observed trends of increasing population, water scarcity and food insecurity in semi-arid areas and their associated social, economic and environmental impacts are raising concerns among semi-arid inhabitants, planners, policy makers, researchers and international communities. The future social, economic and environmental status resulting from failing to act now is unthinkable. Without reversing the negative trends, the impoverished semi-arid area inhabitants would be forced to move to urban areas or encroach on forestland, wetlands and marginal grasslands where they may continue to undertake unsustainable farming. Therefore, we must act to reverse this downward spiral that may lead to the collapse of the agriculture sector and rural livelihoods by making interventions that will improve the water productivity, particularly for the marginalized poor communities, in a sustainable manner. The benefits for such actions will not be limited only to the semi-arid poor, but to everyone as we would all be negatively affected, directly or indirectly, by increasing poverty and misery of the inhabitants of the semi-arid areas.

Desired future state and required interventions

The desired future state of the semi-arid areas can be taken to be one in which the scare water resources are used sustainably to alleviate poverty and raise the standards of living and to continue providing the desired environmental functions. Driven by the above vision, the desired future state would be (a) environmental security, (b) social security (reduced conflicts), (c) food security and (d) sustainability. To achieve the desired outcomes stated above there is need to undertake appropriate interventions, in a timely manner at the right place, efficiently and effectively. A conceptual framework of the linkage between the resource base, the interventions and the outcomes is shown in Figure 13. The interventions are grouped into three categories depending on what their main contribution is:

1. Creating an enabling environment.
2. Facilitating and supporting framework.
3. Resource use and management programs and projects.

Creating an enabling environment

Interventions that contribute to creating an enabling environment include: human resources development; procurement of financial resources; supportive policies;[8] effective legislation; efficient organizations; supporting infrastructure and services.

Facilitating and supporting framework

Interventions that contribute to creating, facilitating and supporting the framework are those aimed at enhancing capacity (human, infrastructural and institutional), promoting cooperation and coordination, and monitoring and evaluation.

8. Water management policy needs to address a multitude of issues, such as: (a) management of supplies (to improve water availability in time and space); (b) management of demands (efficiency of water use, sectoral interactions with economic activities); (c) balancing competing demands (urban-rural; upstream-downstream; riparian states); (d) reducing water pollution; and (e) preservation of the integrity of water-dependent ecosystems

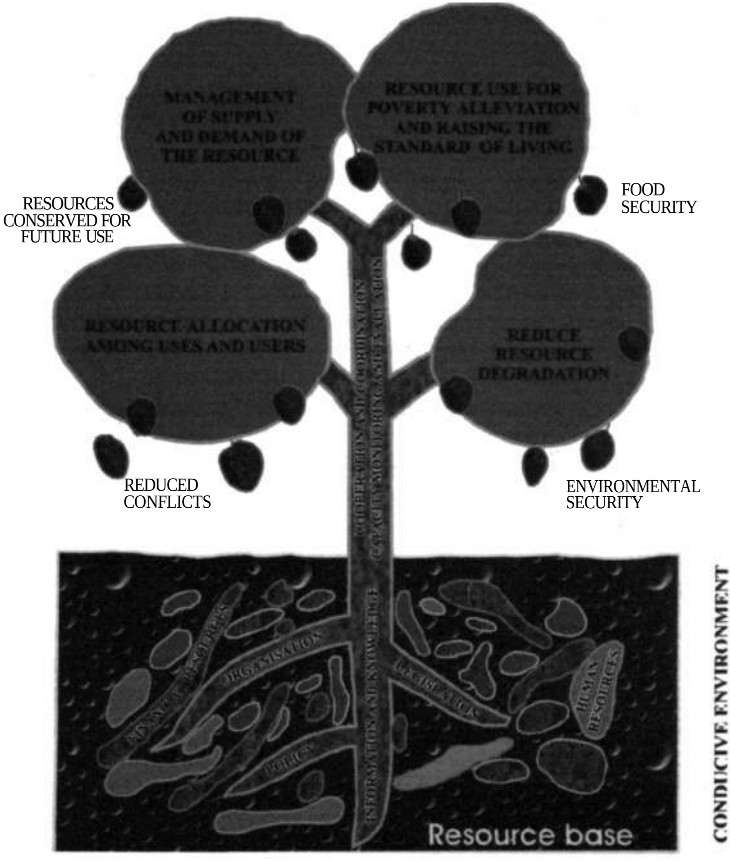


Figure 13. Resource base-interventions-outcomes diagram.

Resource use and management programs and projects

These interventions include those aimed at: (a) reducing resource degradation; (b) promoting fair sharing of resources (assessment, planning of land and water use etc., allocation and conflict management); (c) resource use by the poor to alleviate poverty and by others to raise the standard of living, create jobs etc.; and (d) management of the demand and supply of the resources in ways that promote efficient use and secure resources for future users.

Research needs

Researchers have addressed the challenges of water management in semi-arid areas for many years and have produced valuable insights, technologies and good practices. There are, however, many as yet unanswered questions arising from the changing land use, policies, institutional and socio-economic conditions. The research should respond to the challenge posed by Kofi Annan, the UN Secretary General, in the statement, "We need a Blue Revolution in agriculture that focuses on increasing productivity per unit of water - more crop per drop" (Report to the Millennium Conference, October 2000).

Research needs are grouped under the following categories.

Understanding issues, mechanisms, processes and impacts

Research needs aimed at improving our understanding of the issues, mechanisms, processes and impacts include:

1. Understanding agro-climatic conditions and identifying strategies for alleviating the constraints and seizing the opportunities.
2. Understanding social, economic and environmental impacts of various agricultural water management options and trade-offs associated with using water for food and environment security and win-win options.
3. Understanding how alternative economic policy instruments and institutional mechanisms influence water development, allocation and productivity including encouraging private sector investment in agricultural water management.

Technologies and practices for better soil, water and crop management

Research needs aimed at improving technologies and practices include:

1. Promotion and adaptation of affordable technologies and practices for reducing soil loss, alleviating soil fertility and salinity constraints.
2. Promotion and adaptation of affordable technologies and practices for

improving water management through exploration, development and lifting groundwater resources; reducing seepage and evaporation losses in water storage and conveyance structures and during irrigation applications; treatment of wastewater making it safe for irrigation; and for sustainable use of wetlands in semi-arid areas.

3. Promotion and adaptation of affordable technologies and practices on better crop management such as crop breeding and biotechnology to increase water productivity in agriculture through (a) reduced water requirements; (b) increased drought and salinity tolerance; and (c) better cropping systems.
4. Promotion and adaptation of affordable technologies and practices that lead to improving water productivity in the broadest sense, i.e. include crop, livestock, fishery yields, wider ecosystem services, improved health and equitable distribution of benefits.

Translating research findings to action

Research needs aimed at better information management and use so as to facilitate and support efficient and effective transfer of research findings into action programs include:

1. Development and promotion of cost-effective ways of packaging and improving access of the research findings for the end users (policy, planners, managers and resource users).
2. Packaging research findings in ways that facilitate dialogues on water governance, on water, food and environment and on water sharing.
3. Development and promotion of effective scaling up approaches.

References

Ashton, PJ. 2000. *Southern African water conflicts: are they inevitable or preventable?* Pp. 62 - 105, In: Water Wars: Enduring Myth or Impending Reality, Africa Dialogue Monograph Series No. 2 (Solomon, H & Turton, AR. Eds.). The African Centre for the Constructive Resolution of Disputes (ACCORD), Durban, South Africa.

Barron, J, Rockstrom, J and Gichuki, FN. 1999. *Rainwater management for dry spell mitigation in semi-arid Kenya.* East African Agricultural and Forestry Journal, Vol. 65 No. 1, July 1999.

Day, J. 1998. *Management of freshwater ecosystems in southern Africa: Comparisons and contradictions.* In Science in Africa: Emerging Water Management Issues, America Association for the Advancement of Science, http://www.aaas.org/international/ssa/

Department of Water Affairs and Forestry (DWAF), 1999. *Water conservation and demand management national strategy framework.* Draft Report, Pretoria, South Africa.

Dougnac, M. 1999. *The agronomic use of wetlands.* MD Agriconsultancy, Vange, Sweden.

FAO, 1992. *Water for sustainable food production and rural development.* UNCED agenda 21: Targets and cost estimates. Rome: FAO.

FAO, 1997. *State of the world's forests 1997.* Food and Agriculture Organization of the United Nations, Rome, Italy, p.200

FAO, 2002. *FAOSTAT agricultural database, www.fao.org* FAO, Rome

Gichuki, FN. 2000. *Makueni District Profile: Rainfall variability 1950-1997.* Dryland Research Working Paper No. 2. Drylands Research, Somerset, England.

Gichuki, FN, Liniger, HP, MacMillan, LC, Schwilch, G, and Gikonyo, JK. 1998. *Scarce water: Exploring resource availability, use and improved management.* Eastern and Southern Africa Geographical Journal, Vol. 8, (15-28).

Gichuki, FN, Gichuki, PG, Muni, RK. 1999. *Characterization of the flow regime of Ewaso Ng'iro North River.* East African Agricultural and Forestry Journal 65 (1).

Hecky, RE. 1993. *The eutrophication of Lake Victoria.* Verh. Int. Vereins. Limnol. 25:39-48.

Hide, JM, Hide, CF and Kimani, J. 2001. *Informal irrigation in peri-urban zone of Nairobi, Kenya.* DFID report OD/TN 105, March 2001.

IFPRI, 1995. *Population and food in the early twenty-first century: Meeting future food demands of an increasing population.* Islam N. (ed).

IPTRID, 1999. *Realizing the value of irrigation system maintenance.* IPTRID issue paper No. 2. June 1999. FAO, Rome, Italy.

Johns Hopkins (1998). *Solutions for a water-short world.* Population Report, Vol. XXVI, No. 1, September 1998. Johns Hopkins Population Information Program, Baltimore, Maryland, United States http://www.jhuccp.org/popreport/ml4sum.stm

Jones, Wl. 1995. *The World Bank and irrigation.* Washington D.C., World Bank.

Karekia, JN. 1995. *Background information of the ENNDA region.* Paper presented at the seminar on sustainable resource management in the ENNDA region held from 28 Nov-1 Dec 1995 at Sarova Shaba Game Lodge, Isiolo.

Keller, A, Keller, J and Seckler, D. 1996. *Integrated water resource systems: Theory and policy implications.* International Water Management Institute, Research Report No. 3. Colombo, Sri Lanka.

Kihara, FI. 1998. *An investigation into the soil loss problem in the Upper Ewaso Ng'iro basin.* Msc. thesis. Department of Agricultural Engineering, University of Nairobi.

Kilewe, AM and Ulsaker, LG. 1984. *Topographical modification of land to concentrate and redistribute runoff for crop production.* East African Agricultural and Forestry Journal, Vol. 44: 254-265.

Liniger, HR 1995. *Endangered water-A global overview of degradation, conflicts and strategies for improvement.* Development and Environment Report No. 12, Centre for Development and Environment, Lang Druck AG, Bern.

Murakami, M. 1995. *Managing water for peace in the Middle East: Alternative strategies,* United Nations University Press, Tokyo, The United Nations University, 1995

Mutunga, CN. 1994. *The influence of vegetative cover on runoff and soil loss - A study in Mukogodo, Laikipia District.* MSc. Thesis, Department of Agricultural Engineering, University of Nairobi, Kenya.

Okwach, GE. 2000. *Tillage and cover effects of runoff, erosion and soil characteristics in semi-arid Machakos district of Kenya.* In: Conservation tillage for dryland farming: Technological options and experiences in Eastern and Southern Africa (Biamah, EK, Rockstrom, J and Okwach, GE. eds). Workshop Report No. 3. RELMA, Nairobi, Kenya, pp: 114 -130.

Olivares, J. 1990. *The potential for irrigation development in sub-Saharan Africa.* In: Irrigation in Sub-Saharan Africa: The development of public and private systems, Barghouti, SM and LeMoigne, G. eds. World Bank Technical Paper No. 123, Washington D.C., World Bank.

Onken, AB and Wendt, CW. 1989. *Soil fertility management and water relation.* In Soil, crop and water management systems for rainfed agriculture in the Sudano-Sahelian Zone (Renard, C, van Den Beldt, RJ, and Parr, JF. Eds.). Proceedings of an International Workshop held on 11-16 January 1987 at the ICRISAT Sahelian Centre, Niamey, Niger. ICRISAT.

Oweis, TY and Hachum, AY. 2001. *ICARDA's research on improving water productivity in dry areas.* Paper presented at the Water Week conference hosted by IWMI, held in Colombo (Sri Lanka), November 2001.

Rockstrom, J, Barron, J and Fox, P. 2001. *Water productivity in rainfed agriculture: Challenges and opportunities for smallholder farmers in drought prone tropical agro-ecosystems.* Paper presented at the Water Week conference hosted by IWMI, held in Colombo (Sri Lanka), November 2001.

Rockstrom, J and Jonsson, L-O. 1999. Conservation tillage systems for dryland farming: On-farm research and extension experiences. E. Afr. agric. For. J., 65 (1): 101 -114

Schoneboom, J. 1998. Foreword in Science in Africa: Emerging Water Management Issues, America Association for the Advancement of Science, http://www.aaas.org/international/ssa/

Sipkens, L and Nabila, PM. 1989. Soil conservation and water resources in the Guinea and Sudanian Savanna zone of Ghana. In Soil, crop and water management systems for rainfed agriculture in the Sudano-Sahelian Zone (Renard, C, van Den Beldt, RJ and Parr, JF. eds.). Proceedings of an International Workshop held on 11-16 January 1987 at the ICRISAT Sahelian Centre, Niamey, Niger. ICRISAT.

SMUC, 2001. Annex 1 of the Final Report of the Sustainable Management of the Usangu Wetland and its Catchment (SMUWC) project, Phase 1.

Stewart, JI, Musick, JT and Dusek, DA. 1983. Yield and water use efficiency of grain sorghum in a limited irrigation-dryland system. Agronomy Journal 75:629-634

Thomas, MK. 1995. Development of a GIS based streamflow and sediment yield model for small rural tropical catchments. PhD research progress report.

UNEP 1999. Singh, A, Dieye, A, Finco, M, Chenoweth, MS, Fosnight, EA and Allotey, A. Early Warning of Selected Emerging Environmental Issues in Africa: Change and Correlation from a Geographic Perspective, UNEP/DEIAEW/TR. 99-2., Nairobi

UNEP, 2000a. Coastal Area and River Basin Management Workshop Report, Report of a workshop on Integrated Coastal Area and River Basin Management held in Toulon, France, January 10 to 12, 2000.

UNEP, 2000b. Lower Limpopo river basin: Mozambique. In Coastal Area and River Basin Management Workshop Report, Report of a workshop on Integrated Coastal Area and River Basin Management held in Toulon, France, January 10 to 12, 2000.

UNEP, 2000c. Land and Food. In The State of Environment - Africa Global Environmental Outlook 2000. www.grid.unep.ch UNEP.

UNEP/MAP/PAP, 2001. Conceptual framework and planning guidelines for integrated coastal area and river basin management. Split, Priority Action Program, 1999.

von Benda- Beckmann, F and von Benda-Beckmann, K. 2001. Overcoming water scarcity and quality constraints: Recognizing water rights. IFPRI brief no. 12.

World Bank. 1996. African water resources: Challenges and opportunities for sustainable development. World Bank, Washington.

World Bank, 2001. World development indicators database. World Bank, 7/16/01

World Food Summit (WFS), 1996. web document http://www.fao.org/docrep/003/w2612e/w2612e07c.htm.

Natural resource management research strategies for the semi-arid tropics of sub-Saharan Africa: Patterns and outlook

Nuhu Hatibu[1]

Introduction

The semi-arid tropics of sub-Saharan Africa (SATSSA) are home to an estimated 80 million people most of them poor agro-pastoralists who depend totally on renewable natural resources for their livelihoods. The inhabitants of this region are among the poorest people in the world. The social and economic development statistics for the region are alarming. The region scores very low compared with others, in international human development indicators (Table 1).

Table 1. Performance of sub-Saharan Africa in terms of human development indicators (after UNDP 2001).

Region	Population (millions)	Life expectancy (years)	GNI per capita (Atlas Methods) (US$)	Under 5 mortality rate per 1000	Net school enrolment (%)	Access to clean water (%)
Sub-Saharan Africa	670	47	470	162	55	55
East Asia & Pacific	1855	69	1060	45	91	75
Europe & Central Asia	474	69	2010	25		90
Latin America & Caribbean	516	70	3670	37	97	85
Middle East & North Africa	295	68	2090	54	83	89
South Asia	1355	62	440	96		87

Apparently the inherent poverty found in sub-Saharan Africa is not caused by shortage of natural resources but by a lack of capacity for sustainable management and use of the available resources to bring about social and economic development (UNECA 2000). The magnitude of available resources

1. Sokoine University of Agriculture, Morogoro, Tanzania.

includes more than 200 million hectares of land with arable potential, more than 700 million hectares of rangelands and more than 200 million hectares of woodlands. Furthermore, the region is perhaps the richest in the world in terms of wildlife resources. Livestock and fish resources are also found in abundance in the region. At the same time, more than one-third of rivers draining catchments of more than 100,000 km^2 in the world, are found in sub-Saharan Africa. There are also more than 160 lakes with a catchment area of more than 25 km^2 (UNECA 2000). These represent an incredible amount of water resources. Not to mention that solar radiation is available in abundance throughout the region. Tolba (1993) observed that the level of dehumanizing underdevelopment and poverty found in sub-Saharan Africa stand in sharp contrast to the abundant natural resources found in the region.

The big questions that stand before us include: given all the natural resources potential, why does sub-Saharan Africa face such underdevelopment, poverty, food shortages and sometimes famines? Why was sub-Saharan Africa by-passed by the Green Revolution? Why despite all the research, training and extension efforts directed to agriculture do we see very little improvement, if any, in the welfare of people in rural areas? What role should agriculture (especially subsistence) play in social and economic development of SATSSA ? Is subsistence agriculture the best way of using the natural resources endowment? It is upon answers to these questions that future research on natural resources should be based.

This paper reviews trends and challenges in utilization and management of natural resources in the semi-arid tropics of sub-Saharan Africa. Then the paper makes suggestions of what should be done for each of the identified challenges. The paper concludes with a discussion on the outstanding issues for research, in relation to natural resource management in the SATSSA.

The natural resource base challenges in SATSSA

Sustainable development has three pillars linked to form three sides of a triangle, namely the social, economic and environmental aspects of development. The SATSSA region faces daunting challenges in all the three aspects. The economic situation is worsening due to falling prices of commodities and high rate of loss of capital due to extreme climatic and political events. On the environmental side, although only a small proportion of the natural resources are being used, there is poor management and therefore high rates of degradation. This is partly a consequence of the poor economic performance of the region. On the social side the quality of life in terms of food security, health, education, vulnerability and self-determination, is very low and getting worse among the poor of SATSSA. This is again a result of but also the reason for the poor economic performance and the degradation of the natural resource base.

Therefore, what should be a triangle of sustainable development is in fact a triangle of sustainable poverty. Ten years after the United Nations Conference on Environment and Development, the world is holding another Summit on Sustainable Development. Unfortunately, sub-Saharan Africa has achieved only marginal development since the first summit (Table 2).

Table 2. Trends in Human Development Indicators in sub-Saharan Africa (after UNDP 2001; UNDP 1991).

	Population (millions)	Life expectancy (years)	GNP per capita (US$)	Under 5 mortality rate per 1000	Net school enrolment (%)	Access to clean Water (%)	Average land productivity (grain) (t ha^{1})
2001	670	47	470	162	55	55	
1991		52	470	179	45	40	0.9

As already mentioned, the SATSSA are endowed with many forms of natural resources, but the most important are the renewable ones that are composed of:

- Land and soil.
- Water (in form of rainwater, water in rivers and lakes, and groundwater).
- Genetic resources and biodiversity.

Land resources

Land is the most abundant resource in the SATSSA. It is mostly covered by natural vegetation of great biodiversity. Wildlife habitats are also an important feature of the land, followed by a high potential for range. Similarly land with arable potential is only partially used. The main problems are related to the degradation of the land used for crop, livestock or wood production. These include accelerated erosion, loss of nutrients and organic matter in the soil, salinization and acidification of soils, nutrient leaching, and in some areas extreme degradation leading to desertification. Furthermore, vast proportions of the SATSSA region have inherently poor, sandy, highly leached and/or acidic soils (Table 3).

Table 3. Soil related constraints to agriculture (as % of arable land) - A comparison of sub-Saharan Africa and South Asia.

	Shallow soil	Low fertility	Sandy	Poor drainage	Chemical problems
Sub-Saharan Africa	1	42	36	15	1
South Asia	1	4	11	11	2

In addition to the inherent low soil fertility found in SATSSA, the use of fertilizers (both organic and inorganic) is low at only one tenth of the world average (Table 4). The main reason that fertilizers are not used is that the benefit to cost ratio is often lower than 1. At the same time it is clear that the use of fertilizers is necessary to prevent nutrient mining but also to upgrade the soil fertility. Furthermore, the use of inorganic fertilizers is also necessary because nutrients available from alternative sources are rarely adequate in the levels needed in most farming systems. The outstanding challenge is to design combinations of organic, inorganic and biological sources of nutrients and application techniques that enhance nutrient use efficiency by plants. This will call for crop selection, precision application and targeting of nutrients, and adequate availability of soil moisture.

Table 4. Comparison of regions in terms of use of manufactured fertilizers (after FAO Website).

	Fertilizer use kg (N, P_2O_5, K_2O)/ha		
Region	1980/81	1990/91	1997/98
Sub-Saharan Africa	8	10	9
Africa	21	22	21
Middle East & North Africa (excluding Egypt)	45	67	62
East Asia, South-East Asia & China	121	179	235
South Asia	37	80	104
Latin America & Caribbean	100	100	75
Developed countries	120	112	86
World average	88	100	100

However, in some SATSSA areas, long-term erosion and deposition have increased the fertility of soils located at the bottom of the topo-sequences and in alluvial plains. These areas have great potential that is yet to be utilized.

Furthermore, Vertisols are estimated to cover some 55 million hectares in the semi-arid areas of Chad, the Sudan, Ethiopia, Kenya, Tanzania and 11 other countries in sub-Saharan Africa (Syers et al. 2001). Most Vertisols are inherently fertile due to their occurrence on lower lying land where floodwater and nutrients accumulate each season. They, however, remain largely under-utilized because they are difficult to manage. Therefore, facilitating the sustainable utilization of Vertisols presents one of the leading technological challenges in the development of the SATSSA region.

While the reported trends show that land resources used for agriculture in the SATSSA are at risk, considerable work has been done to develop technologies and practices for land/soil management and conservation. A review of these technologies has been carried out several times (see Hudson 1987; Reij et al. 1996) However, despite all the research, adoption of the technologies and practices has been disappointingly low and land degradation trends continue in many ways. Farmers in many SATSSA areas are agro-pastoralists, but do not utilize the ample farmyard manure available to them. Benefits from fertilizers have been demonstrated, but as shown in Table 4, are hardly used in the region. Therefore, the most important technological challenge lies in accelerating adoption and utilization of known technologies, rather than in developing new ones.

Water resources

In the SATSSA region, water is also available in abundance in the form of renewable annual rainfall. The total renewable water resources in sub-Saharan Africa are estimated to be about 4,000 km^3 $year^{-1}$. This is a lot of water, but most of it is not accessed and put into beneficial use before it evaporates or flow into saline sinks. The main reason is the practical difficulty posed by the nature of rainfall in the SATSSA region. The rain is very poorly distributed both spatially and temporally. Often there is too much water during a few days of the year, while water supply is insufficient during most of the year. Agarwal (undated) estimated that in most of the semi-arid tropics (SAT), the time when it is actually raining is in total about 100 hours per year, out of the 8760 hours there are in a year.

Climate variability is perhaps becoming worse due to the climate change phenomenon. Floods and droughts are among the major constraints to development. A study of 100 years of disaster records in Tanzania reveal that

38% of the disasters were caused by floods while 33% were related to drought (Hatibu et al. 2000). The seriousness of the problem of alternating floods and droughts has recently been seen in southern Africa, a region that in 2000 suffered massive damages due to floods and this year (2002) famine is looming due to drought. Therefore, mitigating the effects of extreme climate events will continue to be an important challenge in the SATSSA.

The technologies, skills and capital resources required to overcome the poor and extreme distribution of water resources through storage and transfer, although well known, are not available in the SATSSA region. As a consequence there is critically low access to water for agriculture, drinking and sanitation, and the environment. Poor access to water is therefore among the leading factors hindering sustainable development in the region. Approaches to overcoming this problem include technologies for enhancing the productivity of water in rainfed production, rainwater harvesting and precision irrigation.

a) Rainfed production

Rainfed agriculture produces by far the highest proportion (>60%) of food crops in the world. When animal grazing is counted the contribution of rainfed agriculture to food and commodity production is very high indeed. In sub-Saharan Africa it is estimated that over 90 % of agricultural production is rainfed. Yet, water resources planning for agriculture has largely neglected rainfed agriculture. Irrigation has been tried in sub-Saharan Africa, but only a limited effort has been directed to upgrading rainfed agriculture through improved water use effectiveness.

Research has shown that in the SAT often only a small fraction of rainwater reaches and remains in the root zone, long enough to be useful to crops. It is estimated that in many farming systems, more than 70% of the direct rain falling on a crop field is lost as non-productive evaporation or flows into sinks before it is used by plants. In extreme cases only 4-9% of rainwater is used in crop transpiration (Rockstrom et al. 1998). Therefore, in rainfed agriculture, wastage of rainwater is a more common cause of low yields or complete crop failure than absolute shortage of cumulative seasonal rainfall. This fact is demonstrated by experience in the USA FAO 1995. Adoption of improved water conservation technologies in the Central Great Plains are said to have made the largest single contribution (45%) to increases in average wheat yields. This was significantly ahead of improved varieties (30%) and fertilizer practices (5%) (FAO 1995).

The necessary technologies for overcoming loss of water in rainfed agriculture, are the well known soil and water conservation techniques. The principle requirement is the improvement of infiltration, water holding capacity and water uptake by plants.

The effect of sub-soiling and manure application in semi-arid areas of Tanzania is shown in Figure 1. Sub-soiling coupled with manure led to a fourfold increase in yield (Falkenmark et al. 2001).

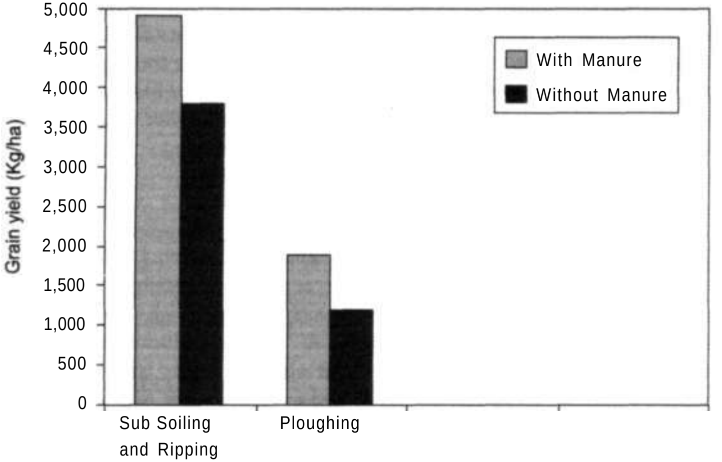


Figure 1. Effect of sub-soiling and manure application on maize yield in Babati, Tanzania (after Falkenmark et al. 2001).

There are therefore win-win benefits of converting erosion-causing runoff into plant available soil water, and non-productive evaporation to productive transpiration. The production of dry plant matter is often linearly correlated to seasonal transpiration, while the amount of available water taken up by plants is dependent on the extent to which roots are in contact with water (Azam-Ali and Squire, 2002). The challenge is to improve the amount of soil water available to plants and the efficiency of its uptake by plants.

b) Rainwater harvesting

Rainwater harvesting is the process of collecting rainwater and reducing its unproductive depletion. It may involve collecting it where it falls (as in soil and water conservation) or collecting it from a catchment area and channeling the runoff to increase the water available in a relatively smaller growing area. In micro-catchment systems, water is collected from land adjacent to the growing area, while with macro-catchment systems, large flows are diverted and used directly or stored for supplementary irrigation.

Experience in Tanzania, for example, shows that farmers are aware that both crop and livestock production can be improved substantially through concentration of the scarce rainwater and by provision of supplementary water during critical times. This facilitates production/growing of high water demanding crops. This strategy is manifested in the concept of mashamba ya mbugani (fields located at the bottom of landscape). Farmers grow high water demanding crops such as vegetables, rice and maize in the lower part of landscape. The aim is to exploit the natural concentration of rainwater and nutrients flowing into the valley bottoms from the surrounding high land (TAJAS 1999). Furthermore, a survey of farmers' innovations in the semi-arid areas of Tanzania, Kenya and Uganda, found that rainwater harvesting innovations constituted 30% of the total, soil-nutrient management innovations (20%), and forestry innovations (4%). In total, water management innovations constituted 50% of the total (Critchley 1999).

In the semi arid areas of Tanzania, the mashamba ya mbugani concept has been improved to facilitate the cultivation of paddy rice in the SAT. The technology involves the construction of water storage reservoirs to facilitate concentration of high volumes of water and storing it for a longer period. It is designed to capture and store rainwater where it falls with provisions for supply of extra water from external catchments. The cultivated reservoirs are constructed in relatively flat to medium slope terrain by building a bund of 0.3-0.7 m high, around the field perimeter. The environment that is created is only conducive for the growth of paddy rice. For this reason therefore, farmers have changed from the cultivation of sorghum and millet, to rice.

This system is now widely used in nearly all the semi-arid areas of central Tanzania. The system accounts for over 70% of the area cultivated with rice and over 35% of the rice produced in Tanzania. It has enabled farmers to grow a marketable crop in dry areas, providing opportunity for poverty reduction (Shaka et al. 1996; Meertens et al. 1999). Research has shown that gross margins obtained by a farmer improve significantly by adopting this technology (Figure 2). Paddy rice is now a SAT crop in Tanzania.

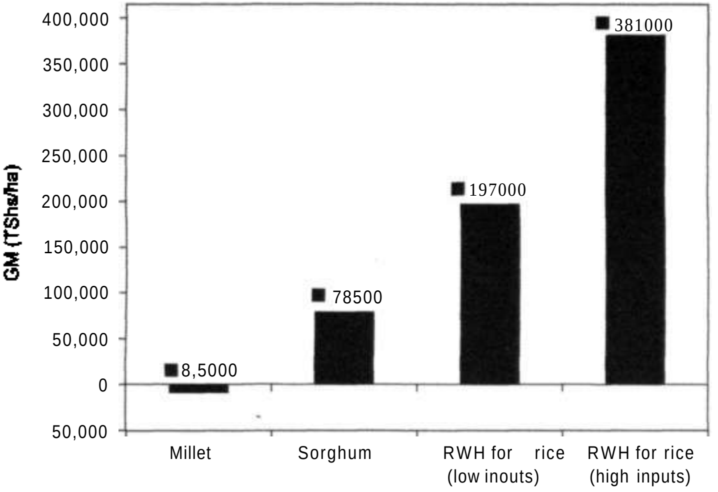


Figure 2. Benefits of adopting RWH for crop production in the SAT of Tanzania

c) Precision irrigation

Most irrigation in sub-Saharan Africa is supplementary as it often involves the application of an extra amount of water during the rainy season, over and above that supplied by direct rainfall, to optimize water available for plant growth (Oweis et al. 1999). However, irrigation is dominated by the classical approach of flooding the entire field to saturation at particular intervals. This approach often leads to high losses of water to evaporation from the soil and water surface, leading to low productivity of water.

The productivity of water can be improved by introducing precision irrigation (Lambert and Faulkner 1989). This involves applying the required quantity of water when it is required and in the root zone where it is required. This will include, for example, application of a small amount of water to overcome a stressful dry spell within the growing period. Technologies for achieving the necessary high levels of control are already available. One example, are micro-drip techniques for high frequency, low volume, partial-areas application of water and nutrients to crop fields (FAO 1997).

Precision irrigation overcomes the problems of unproductive depletion of water from the soil. By applying the water directly to the root zone, transpiration by plants is increased due to improved contact between water and roots while soil evaporation and deep percolation are reduced. This increases the productivity of water. Furthermore, improved control of the timing of application of water makes it easy to implement supplementary irrigation strategically to overcome within season dry spells. Oweis et al. (1999) showed that water productivity in rainfed wheat production in Jordan can be increased from 0.33 kg m^{-3} to 3 kg m^{-3} through strategic supplementary irrigation.

Genetic resources and biodiversity

The SATSSA region is rich in biodiversity of plant, animal and microbial species providing the raw material for crop, livestock, wildlife and tree based production systems.

Many years of breeding have led to the selection and/or development of highly productive crop cultivars and livestock breeds. However, these remarkable achievements have been attained at the expense of diversity in the species and strains regularly used in agriculture. Globally, about *30,000* crop species are known to be edible but only 7,000 have been cultivated or collected for human food. Furthermore, only 3 crops (rice, wheat and maize) are used to supply 60% of crop-based food for humans (Azam-Ali and Squire, 2002). At the same time most of this production comes from high yielding varieties of the Green Revolution, which are, however, vulnerable to production stress as often found in the SATSSA areas. The varieties only perform well if supported by high use of fertilizers and irrigation (Figure 3). It may be that the Green Revolution was not significant in sub-Saharan Africa because none of the "green revolution crops" have their centers of diversity in the region!

There is therefore a potential to tap the species that are indigenous to SATSSA while conserving and extending the existing pool. Recent development in molecular biology can be used to rapidly assess the potential products that can be obtained from these species.

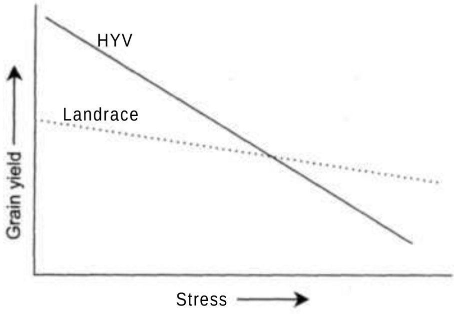


Figure 3. A generalized, theoretical relationship between grain yield and increasing stress for modern HYV and landraces (After Azam-Ali and Squire, 2002).

Outstanding development challenges in relation to natural resources in SATSSA

Accelerated adoption of existing technologies

The discussion in the previous sections has shown that technologies for sustainable use and management of natural resources to increase productivity and development in the SATSSA region, are available but adoption is very low. This is an outstanding development challenge. Very little development will occur in the SATSSA region unless people can be liberated from the current food security situation that depends on self-sufficiency. This is because due to the climatic limitations, subsistence producers often give priority to minimizing risks and not increased productivity and profit. This is a strategic survival mechanism but it denies the people in these areas the capacity to build capital resources required to invest in new technologies, participate in the market economy and protect oneself against extremes of climatic and economic downturns.

The current approach to rural development puts too much emphasis on increasing production of commodity crops. It is always assumed that the market exists and development and research interventions often focus on removing production constraints. For example, it is often assumed that if problems of access can be overcome, farmers are likely to embrace inorganic fertilizers. Hence, packing fertilizer into 1 kg packets is now presented as a novel approach to promote adoption of fertilizer. It is forgotten that the fertilizer still costs the same and if the farmer cannot sell her/his produce and make a profit, she/he will not be willing to buy even the 1 kg packet. If the risks facing the farmers are not reduced, these "novel" approaches are not likely to work.

Reduction of risk facing producers in the SATSSA should therefore be one of the most important objectives of intervention efforts. There is a need to do away with the notion that agricultural production is the only option for all people and focus should be put in diversification into other natural resource and non-natural resource based enterprises. Furthermore, efforts should be made to refocus economic activities to tradable and high value products rather than production of food and other crop based commodities that are currently fetching very low prices in the world market. Interventions in research or development should start at the market and product end and should engage marketers, processors, transporters and producers. A schematic presentation of the necessary paradigm shift is shown in Figure 4.

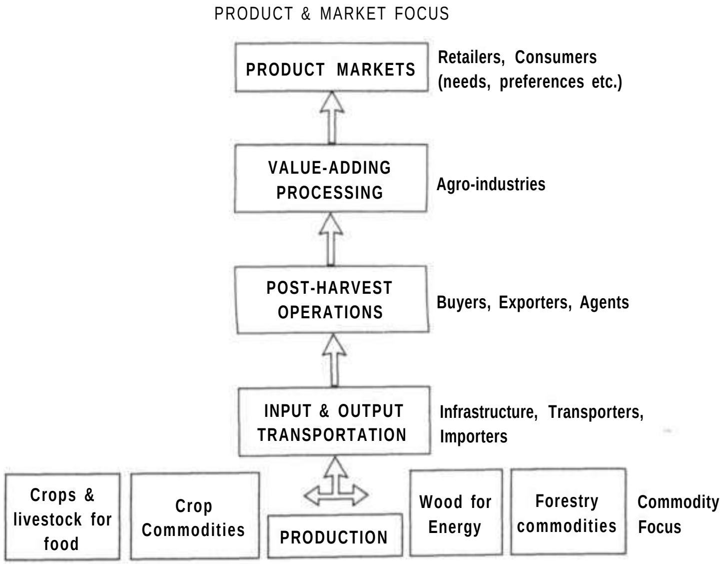


Figure 4. Paradigm shift from commodity to product focus.

Realization of sustainable development in the SATSSA will require intervention programs that simultaneously address all the three pillars (economics, social and environmental). These interventions should be strategically designed to exploit synergies in these three aspects of sustainable development.

Commercialization of agriculture

As already said commercialization must start by identifying markets for products where a given area has a comparative advantage for its production. This should then drive the need for increased productivity and competitiveness leading to demand and adoption of technologies for achieving these. This approach leads to genuine demand-driven technology development and research. For example, there may be a need to deal with the soil water and soil fertility constraints that limit productivity. These two factors complement each other, and one without the other is not effective. Unfortunately, the SATSSA is short of both and is often difficult to make a decision on which could be the entry point. But as mentioned earlier, semi-arid areas receive relatively large volumes of rainwater that is "lost" each season. Perhaps the capture, retention and effective utilization of this water could be the entry point. It is expected that improved water supply will reduce the risk of crop and livestock failure, which will in turn give the farmer the necessary confidence to invest in fertility management options. Stabilization of production at higher levels is also an important condition for investment in the product chain.

The most important technical options for achieving sustainable commercial agriculture in the SATSSA will include the following:

i. Products and/or market identification and development to offer the rural population of the SATSSA a choice of natural resource-based enterprises that offer tangible economic, social and environmental benefits,
ii. Improved rainwater management to reduce impacts of variability and minimize non-productive water depletion and erosive runoff,
iii. Improved soil fertility through integrated nutrient management that exploit alternative and combination sources for optimum effectiveness and benefits to cost ratio,
iv. Better matching of crops and livestock with biophysical, economic and social conditions followed by improved management in relation to inputs, management of pests and diseases, and post-harvest operations.

These are basic principles that should be combined in a number of forms determined by the most binding constraints and available technologies.

Suggested strategic issues for research

i. Product and market focus, and diversification

Sustainable income and profitability is among the most important incentives for investing in natural resources conservation. Farmers like any businessperson pass their losses to something or somebody else. Often, poor farmers pass the losses to the natural resources in form of over exploitation and degradation. Therefore, we need to unlock the potential of the natural resource base through diversification of products, enterprises and markets for the purpose of increasing incomes and profitability in the SATSSA region. What can research do?

- Use the existing body of knowledge, recent developments in genetic and information technologies to identify, map and quantify uses and markets for possible products from the diverse genetic resources found in SATSSA.
- Develop new products or upgrade existing ones for existing or new mass or niche markets.
- Use the power of the information technology to design effective production to market chains, in collaboration with key players, stakeholders and other sectors such as infrastructure, power supply, telecommunication and agro-industry.

ii. Reduction of risk and vulnerability

Sustainable income generation and profitability is a requirement for increasing resilience to risks and shocks. However, this capacity can be enhanced further, if technology can be used to reduce the extent of the risks. The main aspect for intervention is in integrated management of soil nutrients and water. The component technologies are mostly known but outstanding research issues include:

- Developing optimal integrated systems that have high benefit to cost ratios (i.e. more income per kilogram of nutrients, drop of water or hectare of land etc.) and positive effects on the natural resource base.
- Developing governance and institutional mechanisms that enhance adoption of these systems.

Concluding remarks

This paper has argued that there is very little economic and social development to show for the abundant natural resources that exist in the semi-arid areas of sub-Saharan Africa. At the moment poverty is the most serious threat to environmental and natural resource conservation. Furthermore, the poor of these areas are likely to be marginalized more by globalization and the new technologies such as biotechnology and information. The challenge facing researchers with mandate for the SATSSA is to contribute knowledge that will facilitate the reversal of these trends. The entry point will be in developing means for linking the existing natural resources with the opportunities made possible by recent development in genetic and information technologies and the vast research knowledge and natural resource management technologies now available globally.

We believe that there is an urgent need for a paradigm shift from production and food self-sufficiency focus to product and market focus. Although poverty has many forms, the major one is income poverty. Therefore, sustainable and meaningful reduction of poverty requires serious engagement with markets, from local to global levels. However, this is bigger than just research. Successful integration of the poor people of SATSSA into the markets requires a concerted effort by many actors. The challenge lies in making it worthwhile for each actor. The role of research will be in dynamic identification of opportunities and threats and the supply of relevant technologies to overcome the threats and exploit fully the opportunities.

The natural resource management research strategy should focus on reducing production risks caused by climatic variability and poor soil fertility in the SATSSA areas. This will require efforts to be directed to developing optimal integrated nutrient and water management systems that have high benefit to cost ratios and positive effects on the natural resource base. Component technologies already exist and the remaining challenge is in their integration and adaptation under different conditions.

References

Agarwal, A. (undated). *Drought? Try capturing the rain.* Occasional paper. The Centre for Science and Environment, New Delhi, 16pp

Azam-Ali, SN and Squire, GR. 2002. *Principles of tropical agronomy.* CABI Publishing, Wallingford

Critchley, W (ed). 1999. *Promoting farmer's innovation:* Harnessing local *environmental knowledge in East Africa.* Workshop report no.2. RELMA, Nairobi

Falkenmark, M, Fox, P, Persson, G and Rockstrom, J. 2001. *Water harvesting for upgrading of rain fed agriculture: Problem analysis and research needs.* SIWI Report 11, SIWI, Stockholm.

FAO. 1995. *Agricultural investment to promote improved capture and use of rainfall in dryland farming.* Investment Center Technical Paper No. 10, FAO, Rome.

FAO. 1997. *Small scale irrigation for arid zones:* Principles and options. FAO, Rome

Hatibu N, Mahoo, HF, Kajiru GJ. 2000. *The role of rainwater harvesting in agriculture and natural resources management: From mitigating droughts to preventing floods.* In Hatibu, N and Mahoo, HF. (eds). Rainwater harvesting for natural resources management: *A planning guide for Tanzania.* RELMA Nairobi, 144pp.

http://www.fao.org/WAICENT/FAOINFO/ECONOMIC/ess/fert.pdf

Hudson, NW. 1987. *Soil and water conservation in semi arid areas.* FAO Soils Bulletin 57. FAO, Rome

Lambert RA and Faulkner, RD. 1989. *A low cost irrigation package for micro-scale irrigation in Africa. In:* Land and Water Use, Dodd & Grace (eds)] Balkema, Rotterdam. P 603-611.

Meertens, H, Ndege, L and Lupeja, P. 1999. *The cultivation of rainfed lowland rice in Sukumaland, Tanzania.* Agriculture, Ecosystems and Environment 76: 31-45

Oweis, T, Hachum, A and Kijne, J. 1999. *Water harvesting and supplementary irrigation for improved water use efficiency in dry areas.* SWIM Papers No. 7. IWMI, Colombo.

Keij, C, Scoones, I and Toulmin, C. 1996. Sustaining the soil: *Indigenous soil and water conservation in Africa.* Earthscan Publications, London

Rockstrom, J, Jansson, P-E, Barron, J. 1998. *Seasonal rainfall partitioning under run-on and runoff conditions in sandy soil in Niger: On-farm measurements and water balance modeling.* Journal of Hydrology, 210:68-92.

Shaka, JM, Ngailo, JA and Wickama, JM. 1996. *How rice cultivation became and indigenous farming practice in Maswa district, Tanzania.* [In: Reij et al. 1996 op cit.]

Syers, JK, Penning de Vries, FWT, Nyamudeza, P. (eds). 2001. *The sustainable management of Vertisols.* CABI Publishing, Wallingford

Tanzania Journal of Agricultural Sciences. 1999. *Special issue: Rainwater harvesting for crop production in semi arid Tanzania (Preface).* 2(2): v-vi.

Tolba, MK. 1993. *The Earth Summit and Africa's development.* 4^{th} Distinguished Scientists Lecture. ITTA, Ibadan, 22pp.

United Nations Development Program. 2001 & 1999. *Human Development Report.* UNDP, New York.

United Nations Economic Commission for Africa. 2000. *Trans-boundary river/lake basins water development in Africa: Prospects, problems and achievements.* UNECA, Addis Ababa, 60.

Adoption of agroforestry technologies in the drylands of sub-Saharan Africa: ICRAF's experiences and challenges in West, southern and eastern Africa

Steven Franzel, Aamadou Niang, Bashir Jama[1]

Introduction

Drylands are the areas most threatened by desertification and they cover about 34% of the earth's surface. Although desertification is a worldwide problem, it is particularly serious in Africa, where about 330 million hectares are affected. During the 1990s, the World Agroforestry Centre (formerly the International Centre for Research in Agroforestry - ICRAF) operated in four ecoregions of Africa (Figure 1): the semi-arid lowlands of West Africa, the highlands of East Africa, the unimodal plateau of southern Africa, and humid lowlands of West Africa. Only one of these zones, the semi-arid lowlands of West Africa, is entirely within the semi-arid tropics, as defined by Freeman et al. (2002). In addition, three of the six southern Africa sites, Tabora and Shinyanga, Tanzania, and Harare, Zimbabwe, can be considered semi-arid. Table 1 shows the main characteristics of the semi-arid tropics and partner sites of ICRAF. Whereas none of the current sites where ICRAF works in the eastern African highlands could be considered semi-arid, the ICRAF East and Central Africa Regional Program is planning to extend its work in semi-arid areas. In this paper, we first outline selected experiences and challenges in developing technology and assessing adoption in the Sahel, focusing on live fences and fodder banks. Next we review work at Tabora, Shinyanga, and Harare focusing on fodder banks, woodlots, and improved fallows for improving soil fertility. We then discuss experiences promoting agroforestry practices in the dry lands of East and Central Africa. Selected cases include those where considerable adoption has taken place as well as those where adoption has been limited. Finally we outline some of the lessons learned related to the development and adoption of agroforestry practices.

1. World Agroforestry Center (ICRAF), Nairobi, Kenya.

Figure 1. Sites in Africa where ICRAF is working.

Table 1. ICRAF partner sites in the semi-arid tropics.

Site	Mean annual rainfall (mm)	Altitude (m)	Farming systems	Main agroforestry intervention	Other agroforestry interventions
Segou, Mali	600	280	Sorghum-millet-livestock	Live fences around off-season vegetable gardens	Fodder banks for sheep/goat fattening, improved local fruit cultivars
Shinyang and Tabora, Tanzania	850	1200	Maize-tobacco	Woodlots to provide fuelwood for curing tobacco and for domestic use	Fodder banks for peri-urban dairy, improved tree fallows for soil fertility, improved local fruit cultivars
Harare, Zimbabwe	900	1475	Maize-livestock	Fodder shrubs for peri-urban dairy	Improved shrub fallows, improved local fruit varieties

At each site, a common approach was used to identify problems and possible solutions. First, an interdisciplinary, inter-organizational team was identified to conduct informal diagnostic and design studies to identify farmers' problems and opportunities where agroforestry could contribute to improving household welfare. Most of these surveys took place in the late 1980s and early 1990s. The teams involved both ICRAF and representatives of national agricultural research systems (NARS) of the region. Following the surveys, the teams launched collaborative research and development programs involving both on-station and on-farm experiments and follow-up surveys.

The Sahel

The West Africa section of the Sahel is a narrow strip of 700 000 km^2 of land, covering less than half of the total area in Senegal, Mali, Burkina Faso and Niger. With a population of 36.4 million in 1993, the semi-arid lowlands account for 53% of the total population of the four countries. The area is characterized by low and highly unpredictable rainfall patterns (400-1000 mm $year^{-1}$) with a nine-month dry season per year, and frequent periods of drought coupled with high temperatures often reaching lethal levels of 40-50°C. The region also has a high population growth rate (3% per annum) that exceeds growth in food production (2% per annum), which has led to continuous decline in per capita food production and incomes since 1980. This set of circumstances has led to accelerated degradation of the natural resources base by a poverty-stricken population forced to overexploit soils, rangelands and forests in order to subsist.

Soil erosion, because of low vegetation cover at certain crucial periods of the year, is another degrading factor. Estimated at 10 times of the level of natural soil formation, soil erosion affects 72% of arable land. Soil lost through erosion has been estimated at 2.5 times richer in nutrients than the remaining soils. Wood consumption, particularly firewood for heating and cooking, is one of the most important accelerating factors of deforestation, affecting 90% of the Sahelian region. The annual rate of firewood consumption exceeds the mean annual growth of tree stocks and forest reserves by 30%. Afforestation efforts are insufficient, covering yearly only 1-3% of the deforested areas.

Overgrazing is another crucial factor that is exacerbating land degradation. It has caused the disappearance of nutrient-rich perennial grasses, and their replacement with annual grasses and unpalatable plants. Because of the decline in crop yield, agricultural activities are spreading to marginal lands and areas traditionally used by livestock leading to numerous conflicts between agriculturists and pastoralists, people with different and often conflicting land use rights.

The manifestations of these factors are:

- Low agricultural crop production, with yield of the major food crops ranging between 200-500 kg ha^{-1} per year with a potential of 2.5 tons ha^{-1} per year;
- Low animal productivity with daily live weight gain (cattle) of 70-150 g animal"[1] per ha with a genetic potential of 750 g $animal^{-1}$ per day;
- General chronic food insecurity with cereals importation estimated at 15-20% of the region's food supply in a normal year.

Sahelian farmers have been coming up with several new ways to improve their own food and nutritional security and living standards by generating cash, through farming and non-farming activities. One important new activity takes advantage of the long and otherwise unproductive dry season, during which farmers can generate cash by growing market crops - vegetables, fruits, cassava - in small market gardens that they water by hand, using local wells or streams. However, free-roaming and hungry livestock during the annual nine-month drought are a major obstacle to the success of these market gardens. To prevent destruction of their valuable cash crops, farmers have been fencing off their market gardens with "dead" material - wood, thorny branches or crop residues such as millet and sorghum stalks. But, there are drawbacks to these dead fences. Considerable amounts of time and energy are spent collecting the increasingly scarce woody materials needed to enclose a garden. Living tree and shrubs suffer from over-exploitation as farmers lop them to procure the branches they need. This also adds to the pressure on the increasingly sparse natural vegetation in fields and communal lands - exacerbating deforestation and desertification. Furthermore, the crop residues used in dead fences are no longer available for soil protection and nutrient cycling in the farming system.

An agroforestry option based on farmers' practices, live fences or hedges, was developed, tested and disseminated in the last 10 years in the Sahelian region. The main advantages of the live fence species that ICRAF and partners are extending in the Segou region are that they are faster growing than traditional species and that they provide by-products that can be sold or used by the household. Some of the most successful fences are made up of a combination of species such as *Acacia nilotica, A. Senegal,* *Bauhinia rufescens* and *Ziziphus mauritiana.* These trees provide gum and fruits for consumption and for sale. In its second year after planting, fruit production from a 200 m fence of Z. *mauritiana* was estimated to be worth US$ 100.

Economic impact of live fences was assessed in Burkina Faso, demonstrating that the usual dry-season garden of 0.25 ha generates about US$ 400 per year in gross revenue; every 10% expansion of area therefore results in a US$ 40 increase in revenue at a cost of only US$ 6 for the living fence. In the Segou area, widespread dissemination of the practice began in 1997 and by 2001 about 1100 farmers had planted them (Ayuk 1997; Bonkoungou et al. 1998). Main constraints to adoption included:

(1) Lack of planting material and lack of technical information about establishing nurseries and transplanting seedlings.

(2) Lack of labor for planting nurseries and transplanting seedlings. Whereas dead fences require more labor than live fences on an annual basis, live fences do require considerable inputs at specific periods such as for planting and weeding.

(3) Some traditional leaders resist live fences because the fences are seen to compromise their role in allocating land among community members.

Several other practices are being disseminated successfully in the Sahel. For example, approximately 11,000 farmers have planted improved varieties of Z. *mauritiana* that produce fruits up to 10 times as large as local varieties. About 600 farmers have planted baobab *(Adansonia digitata)* food banks, providing fresh leaves of the region's staple vegetable throughout the year, for home consumption and marketing. An introduced practice with much less success involves fodder shrubs, such as *Gliricidia sepium* and *Pterocarpus lucens.* These species were introduced to address the lack of high-quality feed during the dry season and farmers' interest in fattening sheep for sale for festivals. The main constraints to adoption include the need for protection during the dry season (farmers prefer to plant higher value crops in their fenced-in off-season gardens, such as vegetables) and the high cost of nurseries, relative to the benefits of fodder production. Current research focuses on the planting of cuttings, to replace costly nurseries. Researchers are also exploring the planting of dense stands, to minimize the area needed within off-season gardens.

Harare, Zimbabwe, and Shinyanga and Tabora, Tanzania

Large cities such as Harare and towns such as Shinyanga and Tabora share a common feature throughout semi-arid eastern and southern Africa: a rapidly growing dairy sector. Milk demand and production are concentrated around towns and cities where incomes are relatively high and marketing costs are relatively low. Furthermore, farm sizes are also smaller in these peri-urban areas, exacerbating feed constraints. In fact, the low quality and quantity of feed resources is the greatest constraint to improving the productivity of livestock in sub-Saharan Africa (Winrock International 1992).

While farmers have successfully grown grasses (Napier, Bana, *Cynodon* spp., *Chloris gay ana)* to provide energy, they have been largely unsuccessful in growing herbaceous legumes. Species such as *Macroptilium atropurpureus, Stylosanthes guainensis* and *Chaemacrista rotundifolia* have not been productive and have failed to persist under the levels of management that obtain in these smallholder farms (Clatworthy et al. 1985). Thus, many farmers either have very low productivity or buy expensive protein concentrates to meet the protein needs of their cows.

Several hundred farmers around each of the three cities/towns have planted fast-growing leguminous shrubs to alleviate their feed problems. Main species include *Acacia angustissima* and *Leucaena leucocephala* in Tanzania and Zimbabwe and *Calliandra calothyrsus and Cajanus cajan* in Zimbabwe. Fodder from these shrubs is rich in protein and unlike grass species the shrub leaves maintain their levels of protein even during the dry season. Farmers use the fodder trees either to increase milk production or as a substitute for the expensive protein concentrate.

The expansion of tree fodder plantings at least once after the initial introductions was taken as an indicator of adoption. Out of 55 farmers who planted in Chikwaka area around Harare in 1996/97 or earlier, 40 (73%) expanded their tree fodder plots at least once (Hove et al. 2001). In expanding, most farmers (57%) used seedlings from their own nurseries, reversing the trend in first plantings to rely on seedlings from ICRAF. The mean number of trees per farmer was 305 (SD 334). Two-thirds had more than 100 trees each. Most of the farmers planted the trees in areas reserved for forage production. Half of the farmers planted the trees as pure stands while half intercropped, primarily with Napier grass or other fodder species.

Survival rates from the first plantings were low but increased significantly in later plantings. For example, survival rates averaged 42% (SD 37%) in farmers' first plantings but increased to 72% for later plantings. These data suggest that farmers have gained valuable experience over time, which resulted in increased survival rates. Farmers attributed low survival rates to drought, browsing, termites, water logging and late planting. General problems limiting tree growth were termites (41% of all plantings), browsing (16%), drought (11%) and water logging (10%). Other problems limiting the spread of the practice included lack of seed and skills in establishing nurseries and transplanting (Hove et al 2001).

Woodlots are another agroforestry practice that has been widely adopted by over 1000 farmers around Shinyanga and Tabora. These areas were denuded in the early years of the 20th century as part of a campaign by colonial authorities to rid the area of the tsetse fly. Woodlots have proved especially attractive around Tabora, where farmers use fuelwood for curing the tobacco they grow. The best tree species for woodlots include *Acacia crassicarpa* and *A. jurifera.* Farmers raise seedlings in on-farm nurseries and plant maize between the trees during the first two years of establishment. Farmers greatly appreciate substituting relatively abundant land and slack season labor for scarce cash required for purchasing fuelwood that is harvested in the forest and trucked to their farms. Adoption of rotational woodlots in Tabora District alone can conserve 8675 ha forest per year, or 0.8% of total wooded area in the district.

The profitability of rotational woodlots was assessed by comparing it with a maize-fallow rotation, because farmers planted woodlots on fields that they indicated would have been used for growing maize for 2 years followed by a 3-year fallow. Wood was valued at the price farmers pay to have it delivered from forests. In spite of higher costs and a longer payoff period, the woodlot achieved returns to land 6.3 times greater, and returns to labor 2.0 times greater, than the maize-fallow system. A household with 1.33 ha under woodlot, planting and harvesting portions of 0.265 ha each year, would be able to provide enough wood to meet its tobacco curing and domestic needs each year. Such a household would use 75 workdays and earn US$ 180, 3.4 times the net returns that a family would earn using the same amount of labor to produce maize.

Farmers' interest in planting more of the trees was extremely high; 87% expanded their area under woodlots, increasing from 0.07-0.16 ha in the experimental plots to 0.5 to 0.8 ha per farm. Farmers' interest is enhanced because land is plentiful, and maize can be grown in the plot during the first two years of tree establishment. Research and development projects can benefit individual farmers and society by helping them to make the transition from depleting forest resources to planting trees on their own farms.

Improved tree fallows for improving soil fertility, in contrast, have not been adopted by many farmers around Tabora. Soils tend to be sandy, limiting tree growth and thus the biophysical performance of the practice. Furthermore, land is not particularly limiting, so farmers have less interest in devoting labor to increasing maize yields. But improved fallows have been widely adopted in Eastern Province, Zambia, where rainfall is somewhat higher, soils are less sandy, and population densities are higher.

Agroforestry technology adoption trends in arid and semi-arid lands of East and Central Africa

ICRAF's East and Central Africa (ECA) regional program had an active agroforestry project at Machakos District, Kenya, between 1982 and 1995. Upon closure of the program for budgetary reasons, we have little direct engagement in the arid and semi-arid lands (ASALs) of ECA but continued indirectly through collaborative activities with many research and development partners. The key ones in Kenya include:

a) KEFRI (Kenya Forestry Research Institute), ARIDSAK (Arid and Semi-arid Kenya) at Kibwezi,
b) KEFRI/JICA (Japan International Cooperation Agency), SOFEM (Social Forestry and Extension Project) at Kitui,
c) KARI (Kenya Agricultural Research Institute), Katumani Dryland Research Centre and,
d) Meru Dryland Farming Project (MDFP).

We interact significantly with MDFP through ICRAF's Flagship Tree Nursery Programme. Some of the promising agroforestry technologies developed and promoted by these projects are described below:

Timber production. Melia volkensii is one indigenous hardwood promoted by the KEFRI/JICA project. It is fast growing and produces marketable timber in about 15 years. It has good fodder value. Woodlots of melia (and other species such as eucalyptus) are common and often more preferred than boundary in order to reduce competition with crops. Wide-scale planting of melia was, for a long time, limited by its hard and difficult-to-germinate seeds. Because of high fodder value, livestock helped overcome germination problems once it passed through their rumen system. The project developed an appropriate technology, using local artisans, that overcomes germination problems. As a result of this breakthrough, there is increasing adoption of this timber tree in Kitui and neighboring districts. This trend is encouraged by the multiple benefits of the tree - both fodder and wood. Following the ban on forest logging that is currently on in Kenya demand for melia wood is high among timber merchants and the construction industry. It is becoming a substitute for popular wood such as camphor and mahogany. To address potential shortfalls in planting materials, KEFRI's biotechnology research is developing techniques for clonal propagation at its Karura center in Nairobi. This is a technology that could easily be picked up the private commercial nurseries.

Fuelwood and charcoal. These are major products from the ASALs with firewood being consumed mostly by the rural communities and charcoal by the urban ones. Demand is fairly high. Most of the trees currently used for these products are indigenous hardwoods (e.g. acacia and terminalia species). The demand for fuelwood and charcoal has destroyed many species and environments, particularly those close to urban centers. Several exotic species like casuarina that are good for both fuelwood and charcoal have been introduced into the ASALs. However, there is little planting of trees for these products. This will probably continue as long as there is free wood from the forests and national reserves. Poor legislation and weak enforcement of existing legislation also discourage farmers from planting trees. For example in many areas of Kenya, farmers need a permit to cut down a tree on their own farm. The trouble and costs incurred are a strong disincentive for planting trees.

Windbreaks. Multi-row windbreaks on the windward side of crops including hardy species such as *Shinus molle,* leucaena and senna species are becoming popular. Trees planted for windbreaks also provide wood and timber. They also act as boundary markers and have aesthetic value. With the growing population in the ASALs, planting of windbreaks is likely to continue, particularly for boundary marking. Planting trees as boundaries is also one way to minimize competition with crops and avoid interfering with plowing lines.

Fruit trees. Mangoes, citrus and papaya are some of the popular fruit plants in the ASALs. Grafted mangoes are particularly in high demand. There is fairly skilled labor among farmers and private nurseries in grafting mangoes. Production is also improved through water harvesting techniques (micro-catchments) and irrigation schemes. Farmers are identifying markets in Nairobi and urban centers close to the points of production. While this is encouraging and likely to grow, two major problems face fruit production: a) seasonality creating gluts and shortages and, b) pests and diseases, particularly the African fruit fly. Research investment in both is essential, particularly in developing markets, introducing a wide range of varieties that fruit at different times, and integrated pest management.

Indigenous fruits. Fruits such as the tamarindus and baobab are widely used by the local population. Some such as the fruit of marula tree that occurs widely in the ASALs is rarely used.

Commercial liquor is made in South Africa from the fruits of this tree. From the ASALs of eastern Kenya, there is some limited marketing of tamarindus and baobab to urban centers, particularly the coastal cities such as Mombasa where they are used for drinks and in cooking. There is greater scope for improving both the production and marketing of these species in the future that is currently underutilized compared with their wide-scale use in regions such as the Sahel. Towards this, collaboration with the Sahel programs and projects will be necessary.

Non-timber tree products (NTTPs)

1. Oil products - In the ASALs of eastern Uganda, the shea butter tree grows well and the local population has traditionally used shea for various oils. Over the last 5 years, a USAID-supported project has helped with conservation and propagation of the trees on farm as well as commercialization of the oil products. Market trends look promising for the shea products as more urban communities become aware of it, especially among those seeking natural oils and creams.
2. Medicinals - Many people in the ASALs rely on products from trees and shrubs for their medicine. There is also rich indigenous knowledge and local expertise on traditional medicine. With the increasing costs of modern medicine against a backdrop of low and decreasing incomes among both rural and urban communities, the reliance on traditional medicine is likely

to grow in the future. A very popular species for this purpose is the neem tree *(Azadirachta indica)* that grows easily in the ASALs. Another species that is gaining popularity is *Moringa stenopetala* that can be used for purifying water. The crushed seed can clear turbid water and has bactericidal properties. Research and development efforts towards developing medicinal products from trees and shrubs in the ASALs are, however, at present limited.

3. Gums and resins - Ethiopia is probably the leader in the region in production, utilization and marketing of these products. Products such as frankincense and myrrh (mostly of the *Boswellia* species) form a significant component of Ethiopia's exports. A lot of it is also used locally. From the ASALs of northern Kenya, some limited quantities of gums and resins of *Acacia Senegal* are exported for use in the pharmaceutical industry. Demand for these products is likely to grow in the future if matched by investments in improving both product quality and marketing.
4. Honey production - Honey continues to be the main product from the ASALs that is marketed widely. Quite a bit of locally produced honey is beginning to find its way to the supermarkets especially in Kenya. There are also some growing exports, particularly to the countries in the Middle East. This trend is likely to grow if more investments are made in product quality and marketing.

Fodder species. Because of the significance of livestock in the ASALs, trees and shrubs with fodder value are popular among farmers in the region. A wide range of species (both exotic and indigenous) are promoted and planted by farmers, and some examples of promising exotic species include morus and leucaena species. Extension efforts are geared to diversifying the range of species available. This is likely to be the trend in the future. ICRAF's collaborative research program is, for instance, screening several leucaena species in the drier Mbeere District of eastern Kenya. Existing soil and water conservation structures along contour lines provide a good niche for establishing fodder trees. Towards improving fodder supply, trees and shrubs that have other uses such as timber (e.g. *Melia volkensii)* would have greater acceptance and utility. A challenge to guard against is some of the species becoming weeds. An example of this is *Prosopis juliflora* that is now becoming an ecological disaster in the ASALs of northern Kenya and Ethiopia.

In summary, there are a wide range of trees and tree products that are already being used for various purposes in the ASALs of the ECA. Utilization is, however, limited and often localized. So are the efforts of the research and development partners. With improved coordination of efforts by various institutions and with additional resources for research and development, trees and their products can make a significant contribution towards improving rural incomes, mitigating poverty and protecting the environment. In many areas in the ASALs, growing trees is limited by problems of pests (in particular termites), grazing by livestock and wildlife, inadequate water and planting materials. The biggest problem, however, is poor markets and skills in marketing of tree products. Mitigating these challenges is, indeed, the thrust of ICRAF's ECA for the ASALs that is now being developed in partnership with several research and development organizations in the region.

Lessons learned in promoting adoption

Several critical lessons can be drawn from the above case studies. First, agroforestry offers great potential for improving the welfare of households in semi-arid areas while improving environmental services as well. Live fences in the Sahel and woodlots in Tanzania are increasing household incomes as well as reducing deforestation.

Second, agroforestry appears to be most attractive to farmers when it can substitute relatively small amounts of land and labor for farmers' most scarce resource, cash. Important examples are farmers' strong interest in fodder shrubs as a substitute for purchased concentrates and woodlots as a substitute for purchased fuel wood for tobacco curing.

Third, many agroforestry practices can be said to be information-intensive and, therefore, they will not likely expand much on their own. Facilitation is usually required. For example, to promote fodder trees, farmers need to be trained in establishing nurseries, transplanting seedlings, and feeding tree leaves to cows. Partnerships with a range of different type of organizations - government extension services, non-governmental organizations, community based organizations and private businesses - are needed to promote these practices. Farmer exchange tours can greatly assist so that farmers in areas without agroforestry practices can see for themselves how the practices work.

Fourth, a further constraint to the adoption of certain agroforestry practices is labor, especially during busy periods such as the planting season. Greater efforts are needed to reduce the labor required for planting trees. For example, improved fallows involving direct seeding, instead of costly nurseries, and intercropping trees with crops during the first year of tree establishment are two practices that reduce labor requirements, making practices more attractive to farmers.

Fifth, free grazing is an important constraint to tree growing in all three regions; during the dry season livestock are not controlled and young trees need to be protected. More efforts are needed at the local level to help the various stakeholders resolve these problems; some promising developments are beginning to emerge in Zambia (Ajayi 2002).

Finally greater farmer participation in the design, testing, evaluation, and dissemination of agroforestry practices can greatly increase the effectiveness and efficiency of the technology development process.

References

Ayuk, Elias. 1997. *Adoption of agroforestry technology:* The case of live hedges in the Central Plateau of Burkina Faso. Agricultural Systems 54:2 189-206.

Bonkoungou, EG, Djimde M, Ayuk ET, Zoungrana I and Tchoundjeu Z. 1998. Taking *stock of agroforestry in the Sahel - harvesting results for the future:* end of phase report. 1989-1996.

Franzel, S, Arimi, H and Murithi, F. 2002. Calliandra calothyrsus: *Assessing the early stages of adoption of a fodder tree in the highlands of central Kenya. In:* Trees on the Farm: Assessing the Adoption Potential of Agroforestry Practices in Africa (Franzel, S and Scherr, SJ, eds.). CABI, Wallingford, UK, pp. 125-144.

Freeman, HA, Rohrbach, DD and Ndjeunga, J. 2002. *The future of agriculture in the semi-arid tropics of Africa: an issues paper.* ICRISAT. 1992.

Hove, L, Franzel, S, and Moyo, PS. 2001. *Farmer experiences in the production and utilization of fodder trees in Zimbabwe:* Constraints *and opportunities for increased adoption.* Paper presented at the workshop on Forage Demand and Adoption by Smallholder Livestock Keepers, International Livestock Research Centre, Addis Ababa, Ethiopia, 23-25 June 2001.

Ramadhani, T, Otsyina, R and Franzel, S. 2002. *Improving household incomes and reducing deforestation; the example of rotational woodlots in* Tabora District, Tanzania. Agriculture, Ecosystems, and the Environment. 89/3. pp. 227-237.

Winrock International. 1992. *Assessment of animal agriculture in sub-Saharan Africa.* Little Rock, Arkansas: Winrock International Institute for Agricultural Development.

Evolution of Agricultural Research Organizations

Technological change takes place through institutions, whether for development and dissemination (research, extension, policy) or for adoption (markets, credit, input supply). This session focuses on the nature and functioning of institutions, and how they could be strengthened in order to speed change. One aspect is broader partnerships with both conventional and new partners including NGOs and especially the private sector. Another and more fundamental aspect is a new paradigm for institutional arrangements, i.e. move from an "optimal" blueprint to a more adaptive framework that supports change, institutional learning and innovation, and responds more quickly to changes in the external environment. This new system would move away from traditional NARS-led arrangements towards new institutional arrangements that include a much broader and more dynamic range of partners. Research partners would define their roles within the context of these broad-based systems.

Evolution of collaboration between NARS, SROs and IARCs: Patterns and prospects

Lewis K Mughogho[1]

The International Agricultural Research Centers, IARCs, alone, cannot do everything in the R&D chain. They can however fulfill their goals through collaboration.

During the past 15 years IARCs' collaboration in agricultural R&D focused on placement of IARC scientists in national programs, establishment of regional centers with teams of scientists, and working with National Agricultural Research Systems, NARS, directly from headquarters. Sub-regional research organizations, SROs, were established to articulate regional priorities, promote regional cooperation, and coordinate regional projects and donor support. SROs used IARCs as implementing agents of their regional projects. There was a multiplicity of commodity and other networks. The system was dominated by the IARC with considerable donor influence in funding projects and networks.

The prospects for the evolution of agricultural R&D over the next 10-15 years in contained in a number of recent policy documents. The May 2001 Durban statement by heads of FARA, SPAAR, ASARECA, WECARD (CORAF) and SACCAR set the agenda for R&D in sub-Saharan Africa. It urged the IARCs to forge more effective and efficient partnerships with African NARS and achieve greater programmatic integration. This can be christened "The New Partnership for Agricultural Development (NEPAD)". It aims at having NARS and SROs set the agenda based on national and regional priorities and plans, congruence of priorities and integration of programs among all research partners. It also sought a broadened and inclusive partnerships with producers, agribusiness and consumer organizations, better coordination of IARC activities with NARS, improved operational efficiency, and capacity building for a stronger science base.

Yet, there are problems in NARS that has implications for collaboration. Many NARS are financially unstable and scientifically weak. This implies that IARCs will become more involved in technology exchange programs at national level to achieve impact. IARCs will also need to reconsider capacity

1. Tea Research Foundation, Mulanje, Malawi

building in NARS in order to build a scientific base for technology generation. Budgetary pressures also imply that IARCs will need to revisit their mandates, reset priorities and integrate their programs.

There are other implications arising from the continuing dependence of NARS on germplasm and varieties from the IARCs. Most NARS lack the capacity to develop fully fledged breeding programs but IARCs can develop new varieties more efficiently than by individual NARS. Experience has shown that countries prefer to have finished varieties from IARCs with the NARS conducting varietal evaluation. Therefore varietal development should remain a key function of the IARCs.

There has to be a balance between regional versus nation collaborative programs. Regional priorities are derived from national priorities but implementation and impact of research occurs at national level. The top priority for IARCs should therefore be to strengthen collaboration at the national level- since regional priorities derive from national priorities

In the future IARCs should consider phasing-out applied breeding and move to upstream research that is determined by the nature of the problem.

NARS and IARCs need broader partnerships for agricultural R&D. There is need to tap on resources from agribusiness, development NGOs, farmers and consumer organizations and improve the image and support for agricultural research.

There is also the need for a new relationship between NARS and SROs with IARCs on agricultural research priorities. These priorities should be based on those established by NARS and SRO's. This relationship should rationalize and streamline programs and activities to achieve impact. It should also set out mutually agreed performance targets and standards for both NARS and IARCs.

New institutional arrangements in agricultural R&D in Africa: Concepts and case studies

Andy Hall and B Yoganand[1]

Introduction

Current debates on the future landscape of agricultural research and development (R&D) in Africa place great emphasis on the role of the private sector, on partnerships and on poverty impacts. Underneath these headline grabbing themes are a series of complex institutional[2] and organizational issues that need to be resolved by both public national agricultural research and extension institutions (NAREIS[3]) and the international agricultural research institutes. The context of these issues relates to the now widespread recognition that the performance of conventional NAREIS arrangements in much of Africa needs urgent attention (Rukuni et al. 1998) and that it is organizational and institutional problems that need to be addressed rather than technical capacity per se (Byerlee 1998, Byerlee and Alex 1998).

At the heart of this agenda for institutional change lies the need to devise R&D arrangements that are client responsive; that are consensual in priority setting, planning and implementation; that are well integrated into market and entrepreneurial sector activity; that include sustained financial and political support; and above all, are driven by the goal of poverty focused development.

Unfortunately, while these concepts and lofty ideals have been widely discussed, sparse conceptual or empirical insights are available (especially Africa-specific material) to inform the policy making process or predict what recent developments may mean for research arrangements and procedures. This paper is an attempt to draw together recent thinking and experience and, in particular, to provide a platform from which to explore the implications for

---

1. ICRISAT, Patancheru, India.

2. The term institutional is used in the governance sense referring to rules, norms and power structures associated with R&D. It is also used as an embedded concept referring to the behavior of individual and physical organizations (the manifestation of their own rules and norms with regard to priority setting, accountability, level of stakeholder participation and so forth).

3. Throughout this paper the terms NAREIS is used to refer to the public agricultural research and extension institutions or agencies. This is done to distinguish from the broader and often misused term national agricultural research and extension system (NARS), which as a concept refers to a diverse, **well** integrated research and extension system with many public and private actors.

research arrangements in the,semi-arid tropics of Africa and the strategies of ICRISAT and its partners in the region

For ICRI SAT, changing institutional arrangements for agricultural R&D means it has to make hard decisions about both its focus and its strategy and about where to allocate its increasingly scare resources. Like its NAREIS partners ICRISAT needs to consider the relative desirability of pursuing a broader partnership and development agenda as a route to improving impact. Inevitably this includes questions about whether the Institute should divert resources from traditional public sector partners to a wider set of development actors, including the private sector.

One of the problems with much of the debate on these issues is that while the conventional (and simplistic) linear model of agricultural innovation driven by public sector science is widely rejected (and has been for sometime), consensus on a framework to replace it has yet to emerge in the mainstream debate. This is not to say that the broad contours of institutional change are not widely discussed. They certainly are (see for example Byerlee and Alex 1998; Rukuni et al. 1998). The problem is that there is not yet broad acceptance of an alternative model of innovation that is sufficiently holistic in its treatment of institutional and organizational issues to provide a useful framework for the planning and evaluation of evolving R&D arrangements.

This paper argues that a starting point for a more holistic analysis needs to be a shift in focus to innovation rather than the narrower concept of research and technology development. This provides a much more inclusive organizing principle and one which requires the investigation of the wider institutional and behavioral factors (especially learning and evolutionary processes) that underpin economic change. It is in this context that notions such as the innovations systems framework can be so potentially valuable in the debate of institutional change and development.

To provide some reality to these conceptual positions, three recent African case studies are presented illustrating institutional development in agricultural R&D. The case studies are interesting for a number of reasons. First and foremost, they document tangible examples of interventions in which private sector involvement, partnership and impact focus have been attempted, and with a promising degree of success. Secondly, they illustrate the way the involvement of the private sector may be very different in African countries to other regional contexts. In Africa much of the role of the private sector is likely to be in input and output markets, rather than as a major research player, although naturally there will be exceptions. Thirdly, poverty focus and impact more generally is being given much more attention and new patterns of accountability are strengthening this focus. Nevertheless, institutional arrangements that give voice to the poor in the face of entrenched patterns of social dynamics, remains a challenge. Fourthly, the case studies illustrate that to understand, and even to describe these interventions, the interactions and processes in a very wider institutional and organizational arena have to be explored. This needs to be appreciated by the planning and evaluation process.

In the discussion of these case studies the key institutional changes are summarized as a way of analyzing what the implications of these new arrangements might be. The innovation system framework is then used to draw out some of the challenges that still remain for evolving new arrangements for poverty focused rural innovation. The exercise helps determine future patterns of development and the implications for NAREIS and ICRISAT

The remainder of the paper begins in section 2 by making a very brief introduction to the historical development of NAREIS in Africa. Section 3 explores the conceptual debate concerning institutional models of agricultural innovation. The case studies and the general discussion then follow in sections 4 and 5.

Historical development of the NAREIS in Africa[4]

The evolution of the NAREIS has taken place in three distinct phases. The initial period took place during the pre-independence era, focusing on R&D support (both public and private) for major commercial commodities - cotton, sugar, tea, coffee etc. In the second phase, following independence, these research institutions were often consolidated under one publicly funded umbrella organization. This period also saw attention start to focus on wider agricultural technology needs, particularly the problem of increasing food production.

4. This is a vast topic that cannot be comprehensively covered in a short paper like this. This section draws from several useful overviews (Byerlee and Alex 1998; Byerlee 1998; Rukuni et al. 1998. Also see Hall et ai. (2000) for discussion of the evolving policy agenda and its implication for NAREIS.)

These developments were usually accompanied by the establishment of a public agricultural extension organization to facilitate the dissemination of new production technology to farmers to help "modernize" agriculture. The general pattern that emerged was one of widespread public investment in agricultural research and extension systems (often with external donor assistance for capacity development). While there was regional variation in the precise timing of this growth phase, the 1970s witnessed an annual growth rate of 6% in public investments in agricultural research (Alston et al. 1998). This rapid growth phase was accompanied in many cases by the proliferation of research institutes and a rapid expansion of staff numbers.

The third phase, beginning during the 1980s, saw investments in research start to decline in Africa. With large staff numbers and declining research funding, many NAREIS found themselves spending ever larger proportions of research budgets on salaries, with little left for research. This slowdown in research continued during the 1990s.

The declining level of public funding available for agricultural research has focused attention on the need to reform NAREIS (and the indeed CGIAR centers also felt this pressure). However, the need for change was not brought about by shortage of funds *per se,* but by a complex of political, economic and institutional factors that started to take shape during the 1980s. Triggering this has been an almost universal tendency to re-examine the appropriate role of the state, taking place at a time when, despite evidence of high rates of return to public investment in agricultural research, it was clear that NAREIS were struggling to fulfill an increasingly complex role (Byerlee 1998). Three related issues have been important.

(i) ***New policy agendas.*** Many national agricultural research organizations were established on an institutional model designed to apply science to problems of agricultural productivity and the need to produce more food. Over time, not only did this initial goal reveal itself as much more complex than initially anticipated, but also policy agendas began to move from food production alone, to include natural resource management and environmental protection.[5] During the 1990s the donor community began to shift attention towards a much more explicit poverty focus. While the CGIAR centers have felt the brunt of this change, NAREIS

5. See for example Byerlee (1992) for discussion of the need for institutional change in agricultural R&D to address the emergence of salinity problems from the green revolution vintage of technology packages.

have also had to respond to the poverty agenda in cases where they have been dependent on donor funding (Byerlee 1998). Underpinning this shift has been a wider set of agendas concerning the role of the poor in the development process and patterns of governance of agricultural research more generally. Advocacy for participatory agricultural research[6] has been one manifestation of this.

(ii) ***New players.*** While public sector agricultural research has become increasingly embattled, agricultural research and related capacity in technology promotion and application has emerged in other quarters. Most notable has been the growth in the private sector. Internationally, this has emerged from a combination of technical advances associated with biotechnology, strengthening intellectual property regimes and increasingly liberal trade and economic policy regimes in many countries. In many African countries the most obvious expansion has been in the seed industry, but is evident too in animal health, crop protection, horticulture and commodity trading. Research and allied expertise, however, is also emerging among non-governmental organizations (NGOs) in rural development sectors, farmers' and producers' associations (Marter and Gordon 1998). Similarly it is increasingly being recognized that universities and other public research institutes have expertise that is relevant to agricultural research (ISNAR 1999). Private research foundations also play a potentially important role (ISNAR 1999). These developments present the opportunity to network public sector efforts into a wider set of players that have complementary strengths in both research and technology promotion. It also highlights the need to redefine the most appropriate role for the public sector.

(iii) ***Institutional inertia.*** The response of NAREIS to the new policy agendas and the opportunities presented by the emergence. of new research capacity has taken place against a background of apparent conservatism, although there are exceptions. Even within the public sector it has been difficult to restructure institutional arrangements. So

6. The use of participatory methods in development and in agricultural research refers to a cluster of approaches whereby emphasis is given to the perceptions of the "beneficiaries" of development initiatives and their participation is sought in the development and implementation of solutions. In agricultural research this has included giving farmers a much greater role in the technology development and testing process. It has been criticized by some for its lack of acknowledgement of the wider institutional context in which research (and rural development more generally) inevitably takes place and the power structures that this context implies (Biggs and Smith 1998; Hall and Nahdy 1999).

for example, even though it is now widely recognized that conventional institutional distinctions between research and extension are flawed, moves towards the creation of more holistic and integrated national agricultural research and extension organizations are yet to emerge in many countries. World Bank support of training-and-visit based extension systems tended to reinforce this conservatism and top down technology development and transfer approach (Kidd 1999). Re-mapping relationships with private and other non-governmental agencies represents a significant alteration to accepted working practices and norms and has been very slow and recent in many countries.[7]

Commentators such as Rukuni et al. (1998) trace the problems of African NAREIS back to the transition from colonial to national governance and management, and the associated need for different patterns of patronage and partnership. Eicher (1989) suggested that some of the blame lies with the donors, who prematurely inflated the size of NAREIS and took the pressure off managers to mobilize domestic political and financial support to sustain the system after foreign aid was withdrawn.

However, as discussed above, the lacuna was not financial alone. Unfortunately the NAREIS were not able to adapt to meet evolving development imperatives and as a consequence their performance declined in terms of technologies produced and adopted by farmers. In other words, institutional development in the NAREIS did not keep pace with the institutional and political development that was driving national development plans. And of course where institutional developments become disconnected from society, patterns of governance and accountability become increasingly tenuous.

It is widely acknowledged that the core of this problem is institutional in nature (Gijsbers, 2001). Donors have pursued this theme encouraging a reform process that includes privatization of some research and extension activities, a stronger role for NGOs, competitive research funds, private funding and execution of research, and stronger collaboration between the public and private sectors. Byerlee and Alex (1998) define seven features (all institutional) of good practice in NAREIS. These include:

1. Separation of research funding from research execution.
2. Pluralistic structure (a system conceived as a combination of public and private actors).
3. Focus on public good and diversification of funding.

7. For example,, Hall and Nahdy (1999) discuss this institutional conservatism in the context the introduction <of participatory methods in Uganda.

4. Complementary nature of public and private sectors, with a sharing of resources and skills.
5. Institutional autonomy for participating public research organizations.
6. Stakeholder participation in defining the research agenda.
7. New models of technology transfer that include broader stakeholder participation.

However, as Tripp (1993)[8] cautions, the enthusiasm for replacing public agencies with those from the private and NGO sector needs to be tempered by the fact that these organizations, while often complementary to the public sector, can rarely replace it. The ability of the private sector to "fill the gap" is also questioned by Pray and Umali-Deininger 1998). Tripp (1993) insists that a much more important policy task is to define a new and more effective role for public sector research and extension in this evolving environment. The corollary being that the new role of the public sector and its relationship with other development actors will be country specific, will be dynamic (Eicher 1989; Thirtle and Echeverria 1994) and will not be amenable to policy processes that rely on generalized institutional blueprints.

This will be particularly so in relation to level of private sector development which is likely to be lower in the Africa region than it is in Asia and Latin America, and with large country to country variability. Rukuni et al. (1998) describe the way indigenously driven institutional developments have been so important in reforming agricultural research in the southern Africa region. Here the dual agrarian societies of commercial and smallholder systems provides a very specific (although evolving) institutional and political context in which the role of the public sector needs to be defined.

The process of evolving new institutional arrangements for agricultural R&D in Africa is ongoing. Based on the above, critical institutional issues that still need to be fully resolved would appear to include the following:

1. Involving a wider set of actors from the research and non-research sectors in the research process.
2. Defining a new role for the public sector, and evolving new types of relationships with partners relevant to the agricultural sector.
3. Establishing priority setting and technology development and testing approaches that broaden the participation of stakeholders, particularly poor technology users, but also the enterprise sector.

---

8. Tripp (1993) comments emerged from a detailed analysis of; maize research in West Africa.

4. Establishing mechanisms to improve the accountability of publicly funded research and to explore and demonstrate impact, specifically on the poor, but also on economic development more generally.
5. Responding to, and contribute towards a more broad-based vision of rural development that goes beyond increasing agricultural productivity and includes developing wider livelihood opportunities including those in the non-farm sector and the development of wider market opportunities.
6. Defining the most appropriate organizational focus for capacity building given the broader patterns of participation being sought and the expanded objectives that are being addressed.

Models of agricultural innovation

The challenge that faces the policy process is that the imperatives for change and the types of institutional development required, suggest a fundamentally different R&D system to that embodied in the conventional institutional arrangements of the NAREIS. In the latter the main elements of the research system were scientists working in public sector organizations. Roles and relationships were fixed reflecting the acceptance of an institutional model that envisages a straightforward progression from fundamental research to applied and adaptive research, to technology transfer and diffusion. Replacing this is a vision of a dynamic, evolving system that includes a variety of research and non-research organizations from the public and private sectors and one which recognizes its existence in a dynamic political economy.

It is this combination of institutional issues and the dynamic element of this new vision, along with the associated process learning and evolution that conventional theories of agricultural innovation find most problematic. For example, in the induced innovation model (Hayami and Ruttan 1971) factor prices and user demand are predicted to induce scientists to develop appropriate technology - a demand-pull theory. This has not proved to be the case, the chief reason being that such a model ignored the political and institutional context in which resource allocation decisions are made in R&D. Rogers (1962) diffusion of innovations model is blind to similar institutional issues that not only determine the types of technology developed, but decision over how it is promoted and to who - a technology push theory.

The essentially neo-classical economics underpinnings of these models tend to exclude institutional issues from the analysis. One branch of economics that recognizes the importance of institutions, albeit in the formal rules sense, is the new institutional economics (NIE) school. Writings from the transaction cost tradition of NIE tend to suggest that this type of analysis can lead to the necessary institutional developments that will go hand-in-hand with technical developments generated by R&D systems (Kydd 2002). Presumably this refers to the incentive structures necessary to allow the induced innovation model to operate effectively, although it is less clear how this will deal with the power structure. However, since NEI sees organizations as a governance structure to reduce transaction costs and is more concerned with allocating existing resources rather than creating new ones, learning plays a minor role (Gijsbers 2001). (As shall be discussed below, learning and systems evolution are central to contemporary theories of innovation.)

What then is a more inclusive framework to think about the agricultural innovation? Biggs' (1990) proposition of multiple sources of innovation model is one that is widely cited in the literature. He observes that agricultural innovations (both technical and institutional) come from multiple sources: research staff, development agencies, farmers, NGOs, private companies and entrepreneurs, and artisans. Biggs' key contention is that each set of actors has its own set of agendas and these may often be divergent and contested. This implies a model of agricultural innovation where interactions between actors are multiple, iterative and evolving, and where the groupings of actors that exist at a given point in time reflect the relative strengths of current political and institutional interest groups. These types of process are well known to many research practitioners at the sharp end of agricultural research and rural development.

Such systems ideas can be seen elsewhere. For example Lynam and Blackie (1994) talk of the need for a chain of technologies, institutions and policies that function as an effective system rather than as disarticulated parts. The concept of an Agricultural Knowledge and Information System (Roling 1990) also adopted this systems perspective. Similarly Echeverria (1998) pursues this common theme, discussing a system characterized by evolving institutional arrangements where the financing and execution of agricultural research takes place through a matrix of public and private sectors involvement.

More recently the notion of an innovation system has started to be discussed as a way of thinking about institutional arrangements in agricultural R&D (Hall et al. 2001; Ekboir 2002; Clark 2002).[9] There are a number of interesting features of this framework.

9. This builds on the idea of a "national system of innovation' (Freeman 1987; Lundvall 1992) developed to examine the differential performance of national economies and the factors underpinning innovation performance.

- Firstly, it focuses on innovation (rather than research) as its organizing principle. The concept of innovation is used in its broad sense of the activities and processes associated with the generation, production, distribution, adaptation and use of new technical and institutional, organizational or managerial knowledge.
- Secondly, by conceptualizing research as part of the wider process of innovation it helps identify the scope of the actors (including public, private, research, enterprise, technology users sectors) involved and the wider set of relationships in which research is therefore embedded.
- Thirdly, because it recognizes the importance of both technology producers and technology users and that their roles are both context specific and dynamic, it breaks out of the polarized debates of technology push versus demand pull theories. Instead it recognizes that both processes are potentially important at different stages in the innovation process.
- Fourthly, it recognizes that the institutional context of the organizations involved and particularly the wider environment that governs the nature of relationships, promotes dominant interests and shapes outcome of the system as a whole. This aspect is necessary for introducing a poverty focus. The framework provides a lens to examine and reveal which agendas are being promoted, highlighting the arena in which the voice of the poor can (and usually needs to be) be promoted.
- Fifthly, it recognizes this as a social system. In other words, it does not just focus on the degree of connectivity between the different elements, but the learning and adaptive process that make this a dynamic evolutionary system.
- Sixthly, it is only a framework for analysis and planning. It can draw on a large body of existing tools from economics, anthropology, evaluation, management and organizational sciences, and is not bound to any one disciplinary convention.

From a planning and intervention perspective the innovation system framework places particular emphasis on the importance of learning processes as a way of evolving new arrangements specific to local contexts. This draws from a very large body of thinking on innovation performance where learning and the ability to build up new competencies, often through interaction with others are central analytical parameters.[10] This contrasts with the

10. The literature on learning, competency building and innovation performance is very large indeed. Edquist (1997) provides a useful review of concepts in the context of innovation systems. See also Foss (1998) for debate on competency building. For discussion and illustration of institutional learning see Hall et al. (2002).

conventional approach of seeking "optimal" blueprints, and instead recognizes the importance of supporting adaptive systems and the value of the growth of diversity in approaches and practices.

One result of this is that capacity building becomes a much more important objective, as even research interventions become concerned increasingly with establishing relationships and process that will underpin future technology and innovation outcomes. The advocates of the approach suggest that its use for the evaluation and planning of agricultural technology development and promotion activities is a useful way to build locally adapted, collective operational capacities where institutional concerns such as a poverty focus can be monitored and sustained.[11] It is precisely these perspectives that seem to be required to support the development of the new institutional arrangements in agricultural R & D in Africa.

The next section illustrates what this might look like in practice.

Case studies

a) The SADC/ICRISAT sorghum and millet improvement program (SMIP) in southern Africa: A case of the evolution of a technology program through learning and partnership development.[12]

SMIP is a 20-year initiative supported by the United States Agency for International Development (USAID) and implemented by ICRISAT at its Matopos station in Zimbabwe on behalf of the Southern Africa Development Community (SADC). The project started in 1983 and was implemented in four 5-year phases, the fourth running from 1998-2003. The first two phases concentrated on developing research infrastructure and human resources in the national agricultural research institutes (NARIs) in the region. This involved establishment of breeding programs, including research infrastructure and the sponsorship of PhD and vocational training for scientists. This was done with a view to building capacity to produce a stream of technologies, mainly improved varieties. During these first two phases considerable technology development work took place, with 15 varieties being released.

The third phase, 1993-1998, while continuing capacity building and technology development activities, started to shift focus towards technology

11. Biggs and Smith 1998, Hall 2002.

12. This section draws on one of the author's visit and discussion with SMIP scientists and partners in Tanzania, Botswana and Zimbabwe in May/June 2001; further details can be seen in Hall (2002).

transfer. This change related to developments in research methodology, particularly farming systems and participatory approaches, and the way these developments started to impinge on the thinking and agenda of SMIP. An equally important influence was the wider political economy of international agricultural research at that time. In particular, a growing disillusionment among donors with agricultural research and an increased scrutiny of the impacts of research efforts.

During phase III, SMIP began to engage in partnerships with actors other than NAREIS. This was a response to the need to have more direct contact with farm communities and the perceived value of working with NGOs as a way of achieving this. Analysis of constraints to adoption of technology had highlighted weakness in variety release and dissemination systems. It became increasingly apparent that to achieve wider improvements in seed systems (as well as in other spheres), SMIP and NAREIS scientists would have to link much more strongly with a range of other partners - the private sector, including NGOs, and CBOs.

Phase IV was seen by USAID as a way of capitalizing on early investments in capacity building, research and technology development. This technology transfer theme meant that SMIP needed to continue to broaden it focus beyond strictly scientific activities and the generation of new technology, adopting a stronger developmental orientation. Pursuing these goals through a broader range of partnerships became an explicit objective.

The developmental focus and the partnership approach were re-enforced by the USAID project structure and its monitoring procedure. This entailed identifying a number of intermediate results. Not only were these prioritized by a group of regional stakeholder, the quantitative indicators for the achievement of these intermediate results were defined, with annual targets set to monitor performance. The SMIP scientists leading the program component under each result became directly accountable for achieving these targets. These included: area sown to new varieties; metric tons of sorghum and millet entering commercial markets in key locations; quantity of seed produced of new varieties. This pattern of accountability was a significant new feature of SMIP IV. The SMIP scientists quickly realized, based on their past experience, that if they were to achieve these targets an entrepreneurial approach to partnership would be essential.

Perhaps what is most interesting about SMIP IV is the key institutional questions that it poses for international organizations such as ICRISAT, namely:

- Pursuing a broader range of partnerships is justified because it improves the poverty focus and impact of research.
- Pursuing developmental agendas (through partnerships) is justified because it helps define strategic scientific research priorities through better partners of stakeholding of technology users and their representatives. This improves ownership, relevance and uptake of technology.
- Better impact and research priority setting justifies diverting resources from strategic science to developmental activities and justifies diverting resources from traditional public sector partners to a wider set of developmental actors.
- New patterns of accountability are an important trigger for wider institutional change.

An institutional analysis undertaken after two years of phase IV (Hall 2002b)[13] found that the SMIP scientists had entered into a broad range of partnership with NGOs, CBOs and the commercial sector, as well as with their conventional NAREIS partners. This had been done by drawing together clusters of partners around specific themes or tasks. Hall referred to these as task networks and suggested that this represented a significant departure from conventional institutional arrangements for R&D. The key institutional differences between SMIP task networks and conventional arrangements are summarized and contrasted in Table 1. Some of the notable points included:

- SMIP scientists played multiple and different roles in task network - sometimes facilitator; sometimes a source of information; sometimes as a researcher; and sometimes a recipient of information.
- The mixture of partners in a task network were specific to a task theme (due to resources interests and agendas), and to a particular location and institutional context (who was available and how their interaction was governed).
- The adoption of objectives articulated in developmental terms rather than scientific points had been critical in allowing the clustering of a broad based set of partners around particular tasks. It broadened the scope for shared interest.

13. This review took place after only two years of phase IV and was an explicit attempt to explore some of the institutional implications of recent program developments.

Table 1. Key features of the research management and technology promotion approach of the SMIP task networks and conventional agricultural research arrangements.

	Conventional agricultural research arrangements	SMIP task networks
Guiding agenda	Scientific	Developmental
Relationships involved	Narrow, hierarchical	Diverse, consultative
Partners	Scientists in other public agencies	Scientist, entrepreneurs and development workers from the public and private sectors
Selection of partners	Predetermined by institutional roles defined by the arrangement of the research system	Coalitions of interest; determined by the nature of task, national institutional context and skills and resources available
Role of partners	Fixed; predetermined by institutional roles defined by the arrangement of the research system	Flexible. Determined by the nature of task, national institutional context and skills and resources available
Research priority setting	Fixed; by scientists	Consensual; by regional stakeholders and by needs of task network
Work plans and activities	Fixed at beginning of project	Flexible, iterative
Mandate for research/task approach adopted	Fixed by institutional norms of the research system	Negotiated through coalitions of interest
Knowledge produced	Technical/scientific	Technical/scientific and institutional
Indicators of performance	In scientific terms to other scientists	In development terms to donors; in terms of fulfilling role in task network to other partners
Responsibility for achieving impact	Other agencies dedicated to extension and technology promotion	SMIP scientists and their partners in task networks
Capacity building	Trained scientists and research infrastructure	Collective capacity of task networks, social capital, partnership skills

- There was evidence of the task networks as a mechanism for priority setting for further research, but this was limited and had not been exploited.
- By adopting this task network approach and thereby broadening patterns of participation, there was strong evidence from the program's monitoring system suggesting that significant impact was being achieved.

- SMIP's task networks appeared to represent new innovation system capacity and that important lessons could be drawn from this and shared with scientists and research managers at both ICRISAT and in the southern African region.

The notable point of this case is the intuitive way SMIP scientists learnt some crucial institutional lessons, particular in phase III where they innovated with partnership approaches. Subsequently they were able to use these lessons about diversifying their partnership base to respond to a major institutional change in terms of accountability. This led to a series of institutional and organizational innovations creating different R&D arrangements to meet specific task contexts in different southern African locations. While there are many caveats to the nature of this intervention, it does highlight the potential value of adopting a developmental rather than scientific agenda and of adapting roles of public research organizations to suit the types of relationship entered into with new partners.

b) The National Agricultural Advisory Service in Uganda: A case of indigenous institutional innovation in an evolving policy and political context.[14]

The public agricultural research and extension system in Uganda, like in many countries in Africa, has faced many challenges and changes. Civil disturbances during the 1970s and 1980s saw a rapid decline in what had once been an effective and well-resourced research and extension system. As peace returned to the country in the late 1980s and early 1990s there was a need to rebuild both the physical research infrastructure and a need to re-establish a well trained and adequately paid public agricultural research and extension system. The research system was reorganized in the early 1990s by the creation of the National Agricultural Research Organisation (NARO).

The agricultural extension service remained a separate administrative entry. An agricultural extension program was introduced in 1992, taking a unified (crop and livestock) approach based around the training-and-visit system. This was widely criticized (World Bank 1996).

Despite the reorganization of both the research and the extension system, the broad institutional features of the research and extension system remained unaltered. A classical hierarchy of relationships existed between the research organization that was responsible for technology development and

14. This section draws on discussions with the NAADS director and member of the NAADS taskforce as well as MAAIF (2000) and Kidd (2001).

testing, and the extension service responsible for technology transfer. This hierarchy also related to the relationship between extension service and farmer, where accountability and relevance were critical concerns. Subsequent developments in extension such as the village level participatory approach and the devolution of extension responsibility to district level did little to alter this board institutional design.

A further feature of the system was that even though there was considerable NGO activity in the rural development and agricultural development sectors this was weakly linked in any formal way to the public research and extension system. However, by the late 1990s pluralism was increasingly a reality, with NGOs contracting public agents to deliver services (Kidd 2001).

In the period 1997-2001 a key institutional change took place that was to have fundamental implications for both research and extension services. This change began with the development of the Poverty Eradication Action Plan in 1997 and the subsequent adoption of this as the Poverty Reduction Strategy Paper for Uganda.[15] A core initiative to emerge from this was the Policy for the Modernisation of Agriculture: Eradicating Poverty in Uganda (PMA). This sector wide approach provided a broad vision of ways of improving livelihoods in a sustainable manner. Interestingly, in acknowledgment of the wide range of factors responsible for the modernization of agriculture that lie outside the scope of the Ministry of Agriculture, Animal Industries and Fisheries (MAAIF), the responsibility for elaborating the plan was given to the Ministry of Finance. Kidd (2001) highlights the seven pillars of the PMA as follows:

- Deepening decentralization for efficient service delivery;
- Reducing public sector activities and promoting the role of the private sector;
- Supporting the dissemination and adoption of productivity enhancing technologies;
- Guaranteeing food security through the market and improved incomes;
- Enhancing and strengthening stakeholder consultation and participation in the planning and implementation of programs;
- Designing and implementing gender-focused and gender-responsive programs; and
- Ensuring the coordination of the multi-sectoral interventions to remove any constraints to agricultural modernization (MAAIF 2000, 4).

15. Prepared under the debt relief terms of the highly indebted poor countries initiative.

Quite clear in the vision of the PMA is a very strong focus on extension - and notably less on research. It was in this context and with the growing frustration with poor access and lack of accountability of agricultural extension services that the National Agricultural Advisory Service (NAADS) emerged. In 2001, under the PMA, a NAADS taskforce was established with broad participation from NGOs and other public agencies. It was also supported and linked closely to the Joint Donor Agricultural Sector Support Programme. The design phase relied on a wide ranging consultation process, involving stakeholders involved in research and technology transfer, and political stakeholders whose advocacy was required in the support and promotion of a new approach in a major public sector sphere of activity.

At the end of 2001 the NAADS bill was passed by Parliament and the phased introduction of the program began in six districts. The vision of NAADS is that in the next 25 years the public financing of advisory service will be gradually reduced to 50%. The financial support for the program is to come from the revenues of central government, districts and sub-counties, from donors and from farmers. The flow of funds from a central common basket through districts and then sub-counties is integrated into normal planning and budgeting systems. The release of funds is based on the plans of registered farmer groups aggregated through farmers' fora and submitted to the NAADS Secretariat. Sub-counties then make contracts with private service agents.

The NAADS program has five key elements.[16]

- Advisory and information services to farmers.
- Technology development and linkages with markets.
- Quality assurance - regulation and technical auditing of service providers.
- Private sector institutional development (development of the private sector so that it can play the expanded role that is envisioned for it).
- Program management and monitoring.

At the core of the NAADS initiative is the commitment to give technology users (farmers) control over financial resources to contract in advisory services and (ultimately) to generate private funds for private delivery of these services. A further feature is the establishment of an innovation fund, which the farmer groups can use to buy technology development or research services. Part of the novelty of the approach is that

16. Full details can be seen in MAAIF (2000).

the farmers are able to buy advisory and research services from any organization that they choose. This could be the old public extension system (which is still in place), public research organizations, NGOs or private organizations. There has been the emergence of local private advisory enterprises to service the needs of farmers, and indeed this is being promoted by NAADS. Although the emergence of such services will undoubtedly mature and evolve considerably, the development of new organizational types in response to a market for knowledge services is an important development.

Of equal interest is the tendency for research organizations from NARO (perennially short of operational resources) to seek funds from these farmers groups. This is a significant institutional change with respect to the emergence of a more demand driven model of R&D. Perhaps more significantly this suggests a more fundamental institutional change with respect to the respective roles of research and extension in the design of the technology system. Under these new arrangement the priorities and approaches of NAADS, and their facilitation of the farmers' voice in the research and technology promotion process, is starting (albeit in a limited way) to become a driver for the research organization. This overthrows the convention research - extension hierarchy.

NAADS is clearly an ambitious initiative with significant implications for the institutional arrangements of R&D. These implications are summarized in Table 2. NAADS is at an early stage and it will be expanded as the wider processes of government decentralization reach more districts. There are also some eligibility criteria that are NAADS - specific, including a willingness to retrench extension agents, the provision of counterpart contributions and the "institutionalization" of mechanisms for producer empowerment. It is arguably this last point that is the most critical challenge and at the same time one of the most important new institutional arrangement that NAADS and the wider centralization process embodies.

Kidd (2001) is cautious about the ability of NAADS to provide access to services for poor producers (often women), often those with the least social capital. Also the danger of males and elites "capturing" farmers' organizations and other decentralized structures; and the conflicts of interest that may arise in the contracting process. The paradox is that by insisting that producers register as groups, having social capital is a pre-condition for accessing services targeted at those who have least social capital. NAADS accepts that these issues will need close attention. Similarly the initiative is distinguished by its

Table 2. Key institutional differences between conventional agricultural extension and NAADS.

Institutional features	Conventional extension	NAADS
Funding	Public only	Combination of public and private from farmers
Delivery	Public (some times through *de facto* privatization)	Multiple service providers from public and private agencies
Scope	Technology transfer	Advisory, including technology and market information
Organizing principle	Technology transfer	Livelihood support through modernization and commercialization of agriculture. (Facilitating operation of rural innovation system.)
Program planning and implementation	Centralized, by public agency	Decentralized with participation of farmers and local government at sub-county level
Accountability	To central bureaucracy	To farmers through decentralized governance structures
Role in research	Promoting findings	Supporting client initiated priority setting and resource allocation through innovation funds
Sources and modes of institutional innovation	External; donor driven through introduction of static blueprints	Indigenous; designed though consultation with provision for learning and development of situation specificity
Role of donors	Funding and policy intervention	Funding and policy support through sector wide approaches

adoption of a flexible learning approach. It needs to pay particular attention to monitoring and steering the shifting power relation that the program envisages among the various players related to agricultural extension (Kidd 2001). What does seem clear, however, is that the ability of the NAADS initiative to contribute towards the livelihoods of the poor in Uganda is inextricably linked to the emergence (and success) of wider efforts to develop decentralized governance mechanisms for the public sector and development services that are truly accountable to poor stakeholders. This is an enormous task.

A number of points arise from this case study. Firstly, the importance of the historical context, and contemporary institutional developments such as the PMA and decentralization, that have helped shape and generate support for this initiative (in competition with the contending, conventional extension approach). Secondly, the implications of adopting an organization principle for agricultural extension that is more relevant to livelihood. The broadened scope of extension to technology and market advisory services that links the goals much more strongly with contemporary development needs of the producers. Thirdly, the implications this has for the conventional research - extension hierarchy and the emergence of a potential role for NAADS as organizing and facilitating the rural innovation system.

Fourthly, the establishment of a new organizational focus for priority setting and resource allocation (farmer groups) and service provisional within new decentralized governance and accountability arrangements. A notable aspect of this has been the emergence of associated, rurally based entrepreneurial activity and opportunities in the provision of advisory services.

Fifthly, the relationship between NAADS, the wider institutional and political process concerned with decentralization and the (attempted) creation of new patterns of governance in the development process. Critical is the fact that the success of NAADS depends to a large degree on the success of the institutional change taking place in the wider political process in the country. A related point concerns the role of a range of stakeholders, including political ones in support and advocacy for a new and potential controversial type of public intervention. Note also that while the donors have played a large role in this intervention, this has been much more concerned with nurturing an indigenous institutional innovation within a wider vision of poverty-focused development. This contrasts strongly with the introduction of other extension paradigms such as training-and-visit, where the approach had been to introduce an institutional blue print. NAADS seeks to further evolve its approach through learning and innovation.

c) Banana tissue culture in Kenya: A case of multi-agency collaboration in biotechnology development and promotion.[17]

Cooking and dessert bananas are key staple food and cash crops in much of East Africa. While cooking types have traditionally played the central role in rural economies, domestic and export trade of dessert varieties presents an important opportunity for small-scale producers. However, the emergence of a

17. This section is based on Wambugu et al. (2001).

number of plant pathogens, spread by the vegetative propagation of the crop, has increasingly threatened production. This case study describes an intervention that brought together public sector scientific organizations and a number private sector companies. It concerns a project that exploited tissue culture technology to generate, multiply and distribute disease resistant planting material.

The intervention was lead by the International Service for the Acquisition of Agri-biotechnology Applications (ISAAA). As an advocacy and facilitation organization the role of ISAAA was to conceptualize the nature of the intervention required, attract financial support from the donor community and to identify and form partnerships with the range of public and private organizations relevant to tissue culture R&D and the production and distribution of banana plantlets. The Kenya Agricultural Research Institute (KARI) was chosen as a partner to host the project because of its research and extension infrastructure throughout Kenya, and because of its scientific capability in cultivar evaluation and agronomic studies of introduced varieties.

ISAAA also needed to identify a source of disease-free planting material for tissue culture multiplication. A South African company - DuRoi Laboratories was chosen to supply banana plantlets, as this expertise was not available in Kenya. A local Kenyan company, Genetic Technologies Limited, with expertise in tissue culture in other crops was identified to handle the materials supplied by DuRoi. Technical backstopping in, for example, virus diagnostics, was provided by the John Innes Centre, UK, and the Institute of Tropical and Sub-tropical Crops, a South African public research organization. ISAAA identified these partners.

ISAAA was able to attract financial support from the Rockefeller Foundation and the International Development Research Centre (IDRC) of Canada. The African Technology Policy Studies Network paid for research to examine technology diffusion. This was carried out by the Centre for Development Research, University of Bonn, Germany.

As a result of this approach plantlets of a range of banana cultivars were transferred from South Africa, multiplied in Kenya and tested in different agro-ecological zones, in different farm production scenarios, and the characteristics were assessed for agronomic features, quality traits and production costs and returns. The participation of farmers was sought in these evaluations. Improved material was found to increase bunch weight from 15-30 kg to over 40 kg.

However, it was found that certain introduced varieties were not popular and emphasis shifted to producing disease-free plantlets of local varieties.

Since expertise to propagate local germplasm was not available in Kenya, assistance was sought from the Ugandan National Banana Programme, which had received funding from the Rockefeller Foundation.

The project was also able to respond to gender-differentiated variety preferences, the men and women cultivating varieties to cater to different market segments. This became an important determinant in the selection of local varieties for the development of disease-free material.

As the project progressed and marketing problems were revealed, Banana Growers' Associations were formed to improve the bargaining position of farmers. To meet the rapidly rising demand for tissue culture planting material KARI and ISAAA identified church groups and key farmers to establish nurseries and distribution points.

Ex post impact analysis suggested that average per acre incomes for small, medium and large-scale farms could rise 156%, 145% and 106%, respectively. Evidence of strong effective demand for plantlets, with farmers willing to pay as much US$ 3 underlines the perceived value of this new technology. The project was not without its problems. It was found that a major bottleneck to technology adoption was the availability of credit to buy banana plantlets. To resolve this the project linked to local micro-finance institutions. However, these arrangements are still evolving appropriate approaches that include the development of community-based credit and saving groups.

Other important outcomes from the project were viewed as the development of a national capacity in banana tissue culture, plantlet production and distribution. There are now five tissue culture laboratories in Kenya. While this capacity was contained jointly in the experiences of Kenyan public and private organizations, it also recognizes linkages with the international research community that this initiative has strengthened. Similarly the need for plantlet distribution has presented an important entrepreneurial opportunity to NGOs and CBOs.

A number of interesting points arise from this case. The first is the important role played by organizations like ISAAA in conceptualizing and facilitating a network of partners around a key development task. Note that while the intervention is technologically based, its goals relate to setting up a technology development and supply system and achieving and sustaining impact on the farmer. This has acted as an important organizing principle for the partnerships and strategy established. The other role of ISAAA is in identifying potential funding.

Secondly, there is a great diversity of tasks that need to be achieved to introduce this new technology. As a consequence a wide range of organizations is required - scientific, entrepreneurial, technology users, community based, voluntary, market actors, national and international public agencies - with a diversity of roles that they need to play (Table 3). These go beyond the

Table 3. Summary of the organizations involved in the banana tissues culture initiative and their roles and responsibilities.

Organization	Role and responsibilities
ISAM	Program oversight, fund raising, partnership development and advocacy
Rockefeller and IDRC	Financial support, later on networking into complementary initiatives that it had also funded
KARI	Initially, evaluation of introduced varieties. Later the selection of local varieties for development and subsequently technical backstopping and plantlet production in promotion phase, including training and extension role; also had a role in selling banana plantlets
DuRoi Laboratories South Africa	Supply of banana plantlets of new varieties and associated technology
Genetic Technologies Limited	Tissue culture expertise to multiply imported disease free plantlet from South Africa
African technology policy studies network	Funded research on technology transfer mechanism and adoption performance and impact
Centre for Development Research	*Ex ante* impact assessment studies including market assessment, and later *ex post* impact assessment including adoption studies
Men and women farmers	Evaluation of imported material and selection of preferred local varieties
Banana Growers' Association	Collective negotiation in output markets and to assist access to credit
Micro finance institutions	Credit for replanting with improved material
Micro-entrepreneurs	Distribution of banana plantlets and related inputs at village level
Private Kenyan companies	Production and sale of banana plantlets; linkage to export markets for bananas
Ugandan National Banana programme	Expertise in generating improved disease free material from local varieties
John Innes Centre, UK	Virus diagnostics expertise
Institute for tropical and Sub-tropical Crops, South Africa	Designing field management practices and developing commercialization strategy jointly with others

Source: Adapted from Wambugu et al. (2001).

conventional institutional roles of strategic, adaptive research and technology transfer tasks (although these still are important). Furthermore, organizations like KARI that initially have a critical role in evaluating new varieties have changed their role to as the intervention has matured into a distribution task.

Thirdly, a key characteristic of the intervention is the strongly interactive nature of the intervention and the success emanating from adopting new strategies and partners. Fourthly, the importance of an effective and impact focused monitoring system that was used in the design and implementation phases. Fifthly, the capacity building effects of developing systems of this type and particularly those arising from the combined capacity of new networks of partners. And sixthly, the potential of such interventions to create entrepreneurial opportunities, particularly in rural areas where new livelihood options are often limited.

New institutional arrangements for agricultural R&D in Africa? Implications and ways forward

To analyze the implications of the institutional developments illustrated in the case studies, it is useful to return to the two perspectives introduced earlier in the paper. Firstly, the six institutional changes mentioned as being needed in R&D arrangements; and secondly, the analytical foci introduced on innovation systems. Taken together this suggests six broad themes of analysis are useful to evaluate the developments observed in these case studies:

- Systems features;
- Roles of different actors;
- Governance of R&D;
- The wider institutional and policy context and its implications;
- Capacity building; and
- Poverty focus and impact.

Table 4 presents a summary and comparison of the three case studies using these six broad themes.

Table 4. New institutional arrangements compared.

Features	SMIP	NAADS	ISAAA banana biotechnology
1. System features			
1.1 Actors and new patterns of partnership involved	Diverse combinations of actors from public, enterprise, NGO and CBO sectors.	Diverse combinations of actors from public, enterprise, NGO and CBO sectors.	Diverse combinations of actors from public, enterprise, NGO and CBO sectors.
1.2 New patterns of partnership and relationship	Flatter more consultative partnership relationships to exploit complementary resources.	Partnerships encouraging broader participation of farmers in planning and accountability of service delivery agencies.	Partnerships fostering the complementary of public and enterprise sectors.
1.3 Sources of institutional innovation and learning	Experimentation with partnership in earlier phases of the program. External advocacy by donor for broader partnerships. Intuitive process in program driven by need to deliver impact.	Indigenous institutional innovation through wide ranging consultations. Explicit recognition of learning and flexibility in program design.	External advocacy for public private sector partnership in biotechnology. But considerable iterative institutional innovation during implementation and scale up.
2. Role of different actors			
2.1 Role of private enterprise	Commodity output markets.	Supplying advisory services.	Production expertise in tissue culture. Delivery systems, input markets.
2.2 Role of NGOs	Implementing initiatives. Market studies, enterprise development. Facilitating linkages between farmers and other agencies.	Supplying advisory services.	Delivery systems, facilitating rural micro-enterprise development.
2.3 Role of CBOs	Community based seed production.	Priority setting and planning of advisory service programs.	Collective bargaining and access in output markets and micro-finance.

Continued

Table 4. ***Continued.***

Features	SMIP	NAADS	ISAAA banana biotechnology
2.4 Role of NAREIS	Partner providing research services, technology and technical backstopping. Creating regulatory framework for seed sector. Linkage with international scientific community.	NAADS - facilitating the development of decentralized, accountable and relevant advisory service.	Providing access to research and extension infrastructure. Providing expertise in technology evaluation. Linkages with international scientific community. Role evolved as program matured.
3. Governance of R&D			
3.1 Role of donors	Source of funds directly. Advocacy of private sector led development model.	Financial and policy facilitation through sector wide approach.	Financial support. Informal network of other complementary projects and expertise.
3.2 Role of international agencies	Program management and oversight. Linkage to source of funds. Technology supply. Research services. Linkage facilitation.	External evaluation.	Program management and oversight. Linkage to sources of funds. International advocacy.
3.3 Scope of participation in priority setting, resource allocation, technology development and testing	Consultative with many partners, including farmers and technology users. Some evidence of research priorities emerging from task networks.	Program farmer led. Potential to generate research priorities.	Farmer participation in technology evaluation. Program responded to variety selection criteria of men and women farmers.
3.4 Accountability and associated mechanism	SMIP scientist directly accountable to donor for developmental impact. Rigorous monitoring system in place.	Accountability decentralized to farmer groups and sub-county government through competitive service provision. Overall program monitoring system in place.	Donor funded ex ante and ex post impact assessment studies.

Continued

Table 4. ***Continued.***

Features	SMIP	NAADS	ISAAA banana biotechnology
3.5 Scope of vision and goals	Developmental. Food and livelihood security through better access to markets technology and a greater role of the private sector.	Developmental. Food and livelihood security through better access to markets technology and a greater role of the private sector.	Developmental, through frontier science. Improved access to technology and markets through private sector involvement.
4. *Wider institutional and policy context*			
4.1 Relationship with developments in wider institutional and political environment	Embedded in the debates in SACR concerning the need to introduce private and other plays in research.	Embedded in wider political and institutional changes associated with decentralization and new patterns of pro-poor governance.	Embedded in advocacy for exploiting biotechnology in smallholder agriculture.
5 Capacity building			
5.1 Scope of capacity building	Transitory capacity in task network. Longer-term capacity in partnering skills. Development of formal network.	Specific focus on private sector capacity development with the long term vision of a more pluralistic, integrated poverty focused rural innovation system.	Emergence of board based capacity in activities associated with the exploitation of tissue culture.
6. Poverty focus and impact			
6.1 Impact	Monitoring targets achieved, but no specific quantification of poverty impacts. To be addresses *ex post.*	Too early to assess.	Adoption and impact studies indicate initial income impact of more than 100% improvement.
6.2 Mechanisms to address access and governance of the poor specifically	Develop stronger partnerships with organizations with developmental focus and operational access to the poor. Voice and power structure not explored.	Awareness of the need to monitor evolving power relationships and "capture" of decentralized structures explicit in program design.	Attention given to the perceptions of both men and women farmers in technology evaluation and testing. Impact assessment examined differential impact on different farm size.

There are three broad lessons that can be drawn from these cases helps in the discussion of the institutional architecture of agricultural R&D.

Firstly, that new institutional arrangements for agricultural are starting to emerge in Africa - both in a partnership sense and in a governance sense. They maybe experimental and isolated, but nevertheless it is an indication that institutional developments are starting to take place and that there is an empirical basis for discussion of these issues.

Secondly, while these cases address the six key areas of institutional change mentioned in section 2 to varying degrees, overall institutional arrangements in these cases are exhibiting many of the features that one would expect based on an innovation systems conceptualization. This gives some confidence to the earlier assertion that the innovation systems framework can offer a conceptual basis for exploring institutional change and development.

Thirdly, and perhaps most importantly, all three cases, with the exception of NAADS, which is at an early stage of development, suggest that these types of institutional arrangement are leading to enhanced developmental impacts.

There are a number of more specific issues that arise from the case studies relating to the way R&D institutional arrangements are responding to changing development policy imperatives.

Systems features

All three case studies illustrate the value of forming partnerships with a range of both conventional and new partners. Furthermore the types of relationship involved are also new, being much more consultative and less hierarchical. Arguably the most important lesson from the features of the systems observed is the way these institutional arrangements have arisen and evolved. This has required both intuitive and explicit learning processes to be in place, leading to a significant degree of institutional innovation (see further discussion below on evolving roles).

Evolving roles

The case studies have some useful things to say about the new role of the public sector. In fact there is no new generic role that can be defined; the public sector is likely to have multiple roles - facilitator, implemented research and technology developers, sources of funding and contractors pf privately funded research and technology services. These roles are highly contextual relating institutional and task contexts.

This feature of contextual roles also applies to the NGO, CBO and, particularly, the private sector. The case studies clearly suggest that there will be involvement of more actors and certainly the private sector. But this should not be thought about in terms of a necessarily greater research role of the private sector. The case studies suggest that their involvement in input and output markets is going to be much more crucial. The NAADS case perhaps takes this conclusion one step further and suggests that if more broad-based innovation systems are to emerge in much formal skill enhancement capacity development in the private sector will be necessary. In this context quality regulation therefore becomes another role for the public sector.

A corollary of this has to be that learning is going to be key to developing location specific arrangements and that locally devised institutional innovations are going to be key. This has important implications for both the donors and the international agencies. It suggests that a reliance on blueprints is misplaced. For donors the initial experience with the sector wide approach seems to conform to this perspective. For international agencies, even the scientific ones, it suggests that they must divert resources to stimulate institutional innovations, through experimentation, facilitation and greater analysis of existing interventions, and through well-informed advocacy. Another way of saying this is that the technology development prowess of these international agencies needs to be accompanied by institutional knowledge concerning the research process.

Governance

All three case studies exhibit a consultative process for planning and implementation with wider participation with a range of stakeholders. This seems to be a general feature arising out of working with broad-based partnerships. The way this has been translated into new patterns of governance and accountability is less clear. SMIP has indeed got a very strong accountability regime, but to the donor, not necessarily to technology users and partners, although presumably these partnership rely on implicit accountability. NAADS has made organizational and institutional changes in an explicit attempt to improve the voice of poor farmers in program implementation. The emergence of new research priorities is less clear.

However, the action-orientated framework of both the SMIP and the ISAAA interventions demonstrates the importance of flexible iterative research approaches.

Wider institutional context

The NAADS case stands out in the way it is embedded in and emerges from the wider institutional and political developments associated with the development paradigm being pursued in Uganda. Neither of the other interventions has such close integration with local development processes. However even in the other initiatives the organizing principles that inform their vision and scope are much more closely related to contemporary development agendas than the conventional scientific lead programs would be.

Capacity building

Formal R&D capacity building has not been a feature of any of the case studies. Instead what has been highlighted is the importance of creating stronger linkages between different organizations - sometimes through formal mechanisms sometimes through informal networking. An important aspect of this capacity building is the development of partnering skills. An important role for both national and international research and extension organizations is to help facilitate the development of such skills, as this will strengthen the connectivity in the innovation system develop.

Poverty focus

The poverty focus of NAADS is particularly interesting, as perhaps, of all the cases, this one has acknowledged that some of the difficult power dynamics in R&D and technology promotion are embedded and the ways these are likely to affect the overall direction of the program. It is just this sort of institutional context that innovation systems framework encourages the analysis to reveal and explore. This type of perspective is going to be required if a stronger poverty focus is going to be achieved in interventions.

Conclusions

The following points need to be considered when NAREIS contemplate their future:

1. ***Priorities and approaches change.*** Research and technology promotion activities are embedded in a changing world, programs need to be able to adapt and evolve. Strategic changes need to be recognized and debated.
2. ***Learning is important.*** Making institutional learning processes explicit appears to be a way of developing better programs and working practices. Resources should be diverted to this activity as a complement to technology development.
3. ***Developmental objectives help broaden participation.*** Adopting a developmental agenda shifts the overall organizing principle and in doing so draws in new partners and creates new roles. In part this concerns giving R&D programs a shared perspective with a wider spectrum of organizations. By working with development-orientated partners the evidence suggests stronger participation from technology users. Overall this underlines the value of blurring the distinction between research and development. New patterns of accountability accompany a developmental framework, and can also be a way of strengthening partnership development.
4. **Working with new partners particularly the private sector involves a learning process.** Working with the private sector was initially difficult requiring them to adapt to the procedures and skills of their partners. Institutional learning improves program evolution and design and helps organizations learn how to partner better. Institutional innovations of this type need to be recognized as equally important as technological innovations.
5. ***Partnerships need to be structured around problems and local contexts.*** Grouping partnerships and relationships around a problem or task is important. The value of this relates to drawing together a system of partners with a shared or intersecting interest, or agenda, with competencies relevant to the solution of the problem and with the physical and financial resources required. The partners and relationships and roles involved are therefore determined by local task, organizational and institutional contexts. This underlines the importance of allowing diversity of approach and partners to evolve in specific context, rather than mandating blueprints, and the critical role of institutional innovation.

6. ***Partnership can be used as a mechanism for identifying re searchable issues.*** While the evidence from the case studies only showed limited examples of this, it does suggest that partnership groups offer a potentially valuable arena for identifying researchable issues and negotiating priorities.
7. ***The importance of flexibility and iterative work plans and procedures.*** Some of the success of interventions is that they are able to be slightly opportunistic. This both in terms of developing relationships with new partners and being able to address emerging research constraints and opportunities. This suggests the value of flexible and iterative planning and implementation procedures. Since the program is much more development/output orientated, the process by which this is achieved becomes an iterative management issue rather than a component of the initial planning process.
8. ***Greater emphasis on systems capacity building.*** A broad planning implication from the above is that if these types of systems processes and relationship are encouraged, the impact of research and technology promotion programs can be improved. This suggests therefore that systems capacity needs to be built by strengthening linkages, broadening participation, allowing local networks to evolve, and making learning and institutional innovation an explicit output of research and technology programs. This systems perspective on capacity building needs to complement conventional investments in scientist training and research infrastructure.

References

Alston, JM, Pardey, PG and Roseboom, J. 1998. *Financing agricultural research: International investment patterns and policy perspectives.* World Development, 26: 1057-1071.

Biggs, SD. 1990. *A multiple sources of innovation model of agricultural research and technology promotion.* World Development, (18) 11,pp 1481-1499

Biggs, SD and Smith, G. 1998. *Beyond methodologies: Coalition building for participatory technology development.* World Development, 26(2):239-248.

Byerlee, D. 1992. *Technical change, productivity, and sustainability in irrigated cropping systems of South Asia: Emerging issues in the post-Green Revolution era.* Journal of International Development, 4: 477-496.

Byerlee, D. 1998. *The search for a new paradigm for the development of national agricultural research systems.* World Development, 26: 1049-1055.

Byerlee, D and Alex, GE. 1998. *Strengthening national agricultural research systems: policy issues and good practice.* Washington DC: World Bank.

Byerlee, D, and Echeverria, RG. 2001. *Introductory Chapter.* In: Agricultural Research Policy in an Era of Privatisation: Experiences from the Developing World (Byerlee, D, and Echeverria, RG. eds.). Wallingford, U.K.: *CABI.* (In press).

Clark, NG. 2002. *Innovation systems, institutional change and the New Knowledge market: Implications for Third World agricultural development.* Journal of the Economics of Innovation and New Technologies, March (forthcoming in press).

Eicher, CK. 1989. *Sustainable institutions for African agricultural development.* Working Paper No 16. The Hague: ISNAR.

Echeverria, RG. 1998. *Agricultural research policy issues in Latin America:* An *overview.* World Development, 26: 1103-1111.

Edquist, C. (ed.) 1997. *Systems of innovation approaches: Technologies, institutions and organisations.* London: Pinter, Cassell Academic.

Foss, Nicolai, J. 1998. The competence-based approach: *Veblenian ideas in the modern theory of the firm.* Cambridge Journal of Economics, Vol. 22 (4): 479- 495.

Freeman, C. 1987. *Technology and Economic Performance:* Lessons from Japan. London: Pinter.

Gijsbers, G. 2001a. *Governance and institutional innovation.* Discussion Paper NO. 01-09. The Hague: ISNAR

Gijsbers, G. 2001b. *What drives the engine of agricultural innovation? A look at process, factors and actors.* Discussion Paper NO. 01-10. The Hague: ISNAR

Hall, AJ and Nahdy, S. 1999. *New methods and old institutions: The systems context of farmer participatory research in national agricultural research systems. The case of Uganda.* ODI, Agricultural Research and Extension Network (AgRen) paper no 93. London: ODI.

Hall, AJ, Rasheed Sulaiman, V, Clark, NG, Sivamohan, MVK and Yoganand, B. 2000. *New agendas for agricultural research in developing countries: Policy analysis and institutional implications.* Knowledge, Technology and Policy, 13(1): 73-91.

Hall, AJ, Sivamohan, MVK, Clark, NG, Taylor, S and Bockett, G. 2001b. Why *research partnerships really matter: Innovation theory, institutional arrangements and implications for developing new technology for the poor. World Development,* 29(5): 783-797.

Hall, AJ, Clark, NG, Rasheed Sulaiman V, and Taylor. Sarah. 2002. *Institutional learning through technical projects: Horticultural technology R&D systems in India.* The International Journal of Technology Management and International Development. In press

Hall, AJ. 2002a. *The development and use of the innovation systems framework in India: Northern perspective.* In North South Cooperation: International Conference 3 December 2001: Amsterdam. Royal Netherlands Academy of Arts and Science, pp 217 ISBN 90-6984-348.

Hall, AJ. 2002b. *New patterns of partnership in agricultural research and development: Recent experiences from SADC/ICRISAT.* Sorghum and Millet Improvement Program, Phase IV. *ICRISAT Working Paper Series. Draft Manuscript.*

Hayami and Ruttan. 1971.

ISNAR. 1999.

Kidd, AD. 1999. *Reviewing the Neuchatel initiative vision in action: A case study from Uganda.* Stockholm: Swedish University of Agricultural Sciences.

Kidd, A. 2001. *Extension, poverty and vulnerability in Uganda: Country study for the Neuchatel initative.* Working Paper 151. London: Overseas Development Institute.

Kydd, J. 2002. ODI AgREN Network Paper.

Lynam, JK and Blackie, MJ. 1994. *Building effective agricultural research capacity: the African challenge.* In Agricultural Technology: Policy Issues for the International Community (Anderson, JR ed.). Wallingford, UK: CAB International, pp 106 - 134.

Lundvall, BA. ed. 1992. *National systems of innovation and interactive learning.* London: Pinter.

Pray, CE, Umali-Deininger, D. 1998. *The private sector in agricultural research systems: Will it fill the gap?* World Development 26: 1127-1148.

MAAIF. 2000. *National Agricultural Advisory Services Programme (NAADS): Master document of the NAADS task force and joint donor groups.* Entebbe: Ministry of Agriculture Animal Industries and Fisheries

Marter, A and Gordon, A. 1996. *Emerging issues confronting the renewable natural resources sector in sub-Saharan Africa.* Food Policy. Vol. 21, No. 2, pp 229-241.

Rogers, EM. 1962. *Diffusion of innovations.* Free Press, Glencoe III.

Rukuni, M, Blackie, MJ and Eicher, CK. 1998. *Crafting smallholder-driven agricultural research systems in southern Africa.* World Development. Vol. 26 No 6 pp 1071-1087.

Roling, NG. 1990. *The agricultural research-technology interface: A knowledge systems perspective.* In: Making the Link: Agricultural Research and Technology Transfer in Developing Countries. Westerview Press, Boulder.

Thirtle, C and Echeverria, RG. 1994. *Privatization and the roles of public and private institutions in agricultural research in sub-Saharan Africa.* Food Policy, 19: 31-44.

Tripp, R.1993. *Invisible hands, indigenous knowledge and inevitable fads: Challenges to public sector agricultural research in Ghana.* World Development, Vol. 21. No. 12, pp. 2002-2016.

Wambugu, F, Karembu, M, Njuguna, M and Wanyangu. 2001. *Biotechnology to benefit small-scale banana producers in Kenya.* Paper presented at the Global Development Network conference.

World Bank. 1996. *Agricultural extension and research: Achievement and problem in National Systems.* Agricultural Sector Study.

Agricultural R&D for the African SAT: The Way Forward

This session looks at R & D priorities from the perspective of regional organizations and donor agencies. Inputs from the three major regional organizations (SACCAR, CORAF, ASARECA) that manage and coordinate agricultural research in sub-Saharan Africa, and from IDRC, a key development investor in the region, provide an overview of the broad research and policy issues to be addressed. Regional and international efforts must be dictated by national priorities. There is a clear need for more focused, targeted research - technology development complemented by socio-economic and policy research - in order to create impact at farm level. The R & D agenda must encompass a range of objectives including equity, efficiency, capacity building and environmental impact. But with such a broad mandate and limited resources it is important to prioritize research activities, and pool skills and resources from a range of partners.

Agricultural R&D priorities for the African SAT

Dhaneshwar Dumur[1]

The presentation gave a brief synopsis into the mandate of the SACCAR and the challenges it faces in facilitating agricultural development in southern Africa region. It identified the areas future research and development should focus on and highlighted potential for regional cooperation in research.

Status of SACCAR

- Functionally present.
- Its mandate has changed to focus on activities that promote regional cooperation.
- SACCAR to change into SADC Directorate of food and environment, but still function as a sub-regional research organization (SRO).
- Due to be incorporated into the Council of Ministers of SADC.
- Has a mid-term plan to 2005 in which the EU has pledged support, subject to new status.

SACCAR's perspectives on SAT research agenda

1. What is the research problem?
   - Should research and development stress so much on adoption and impact?
   - Is the problem of low adoption and impact of technologies that of information constraint or service constraint?
   - How do we move beyond production, i.e. what pathways should a technology move through? Can developing linkages improve access to technologies
2. Have we given a social dimension to the work of the research organizations?
   - What are the expenditure profiles of farming households in households?
   - What would have happened if lARCs like ICRISAT did not contribute?
   - Is the current choice of criteria and indicators for R4D still valid?

1. Food and Agricultural Research Council, Quartre Bornes, Mauritius.

3. Priority setting for research: if people are moving out of agriculture, given more resources, what priorities should research set to target farmers who genuinely require investment? We need not work with rich man's crops - SAT has own profile of environment, farmers, etc.
4. In emphasizing the physical and market environment, R4D must not lose sight of technology environment. Issues of biotechnology still need some reflection and research, i.e. what are the likely benefits, costs, policies, etc.
5. Technological dissemination - if IARCs' role is developing technologies and international development partners for dissemination, then we need to exploit the comparative advantages within partner organizations through effective linkages and partnerships.

The elements of technology development for sub-Saharan Africa

Adiel Mbabu[1]

The objective of this presentation was to synthesize the proceedings of the workshop and link them with ASARECA's mission and challenges to R&D in eastern and central Africa region. In his presentation, Dr Mbabu drew a parallel between workshop deliberations and the work and challenges of ASARECA. He constructed a problem tree to illustrate the R&D challenge and give an analysis of the strengths and weaknesses of the current research set-up in a Q&A format:

What did I hear?

Goal: Economic growth and social welfare
Purpose: Sustainable productivity gains, competitiveness and value added agriculture

Outputs:

- Demand-driven technologies utilized
  - Demand-driven technologies disseminated
    - Demand-driven technologies generated
- Supportive Policy environment
  - Policy advocacy
    - Policy options availed
- Supportive Institutional Arrangements
  - Institutional innovations - supply and demand
    - Institutional analysis - supply and demand

What do I think?

- Excellent framework
  - Goal is worth pursuing for R4D
  - Purpose is achievable with a lot of help from others

1. ASARECA, Entebbe, Uganda.

- Outputs are necessary and sufficient to deliver the purpose

- Question is, are we willing and able to re-distribute our limited resources to deliver the three outputs?
  - From the papers in the conference, a lot of emphasis is laid in the first output (technologies), but scanty on the other two (policies and institutions).

Considerations for priority setting

1. Entry points: Asking the right questions at the right units of analysis. For example:

- What does it take to transform subsistence economies into commercial enterprises? (Politico-economy)
- What is the role of research in the transformation process? (Research sector)
- What is the role of ICRISAT in the transformation process? (Research sub-sector)
  - The answers to these questions provide a basis for vision and strategy.
  - Further, the questions are legitimate for social scientists in R4D institutions.

2. Scope for R4D

- Production to consumption chain
  - Farm productivity
  - Natural resource management
  - Processing/value-adding
  - Supportive policy
  - Supportive institutions, including markets
- Type of research
  - Basic - adding to the pool of knowledge
  - Applied-problem solving:
    - Strategic - generating interventions
    - Adaptive - suitability to given environments (socioeconomic, biophysical)
    - Uptake pathways (delivery process considering the nature of the product and the recipient, as well as the varying environment.

3. Scale for R4D

- Capacity, in relation to scope
  - Human resources- disciplinary mixes
  - Physical resources
- Value-adding Partnerships - Complement in-house
  - Consider institutional core business; important, and only you can do! Take leadership.
  - Consider institutional non-core business; important, but others can do! Play catalytic role.

Conclusion: Emerging conceptual framework is a big step in the right direction, but the challenge is in initiating the necessary institutional innovation to deliver the promise!

Setting the R&D agenda for semi-arid regions in Africa

Marcel Nwalozie[1]

IARCs should follow the mandates for regional research established by the Sub-Regional Organizations (SROs). In West Africa, sorghum and millet research priorities have been placed on product market development, improving awareness of new varieties, and seed system development. For groundnut, priority has been placed on improving resistance to drought and diseases. Key issues include how to add value to the production of small-scale farmers and how to accelerate adoption of new technologies. Can the IARCs assist with processing research, strengthening market linkages?

Regional consultations have been underway between CORAF and the CG Centers; this is an on-going dialogue on how best to share the task of research in the region. There are 19 different collateral coordinating mechanisms including networks, councils and related bodies.

A chief objective should be to add value to what the national agricultural research institutes (NARIs) are doing. The SROs will coordinate, not implement research.

1. CORAF, Dakar-Yoff, Senegal.

Issues in agricultural R&D priorities for sub-Saharan Africa

Luis Navarro[1]

The main objective of the presentation was to give an overview of IDRC's mission and work in the SAT/SSA and then link this to the workshop objectives, giving indications of the future direction of R&D in the region. Dr Navarro noted that the aim of the IDRC was to enable conscious thinking researchers undertake research that provide Development solutions to the SAT/SSA. He emphasized the need for critical thinking in choosing R&D focus - whether it should be technology or policy or institutional research. The best criterion is to choose the focus while remaining conscious of the existing environment! He further argued that the process of responding to environmental sustainability involves recognizing where researchers and organizations work, what they are working on, and the environment conditioning their operations.

Emphasizing the need for partnerships as a way forward for R&D, he argued that they must be mutual, with a common goal and beneficial to all the partners involved. Partners need not share the core objectives of each other, but need to complement each other. He emphasized the need to improve linkages with development organizations to enhance technology uptake by farmers in SAT. There is also the need to tap and combine the skills and knowledge already existing in the various organizations or partners. In this regard, he indicated that IDRC, in its "Building a Pyramid" project is evaluating and condensing research already done in the region and internationally into a learning tool that can be used for planning by research organizations working in the SAT/SSA.

Addressing the problem of low adoption of policy research results, Dr Navarro reported that the IDRC is already working on it in the region, in its "Closing the Loop" project aimed at increasing the use of research results in policy formulation and setting the research agenda. It is focusing more on multidisciplinary networks that are capable of lobbying policy makers to adopt policies recommended from research. He further argued that close collaboration with stakeholders in policy analysis and research would improve uptake, but the researchers/analysts have to make their work known to policy makers and also know the needs and environments of policy makers. In addition, the packaging of the results also matters.

1. International Development Research Center (IDRC), Nairobi, Kenya.

Workshop Recommendations

Agricultural R&D for the African SAT: Implications for research priorities

1. ***There remains a need for technology suitable for both market and subsistence production systems***
   - Many SAT farmers concentrate on subsistence production because they are poor, live far from markets, face poor infrastructure etc. Of course people need to make some money, but producing mainly for exchange may be too ambitious for many of the groups targeted by R4D.
   - Technology research programs need to move toward greater concern for what SAT farmers can sell in the market. Marketing/commercialization issues are often the weak link limiting the sustained adoption of new technology leading to increased production/productivity.
   - Explore post-harvest technologies for SAT crops so as to add value and develop new markets.
   - Shift from narrow sectoral (agricultural) to a broad inter-sectoral perspective (the rural economy, including the non-farm sector) when formulating research priorities and technology.
   - Focus on market, policy and institutional factors that influence sustainable management and utilization of water as well as factors that limit investment opportunities for diversification and commercialization of SAT agriculture.

2. ***There is a need for a strong policy / economics department in Research Institutes concerned with SAT agriculture.***

This would facilitate a better understanding of the depths of markets and provide information on policies, institutional factors etc., which would help private traders/government/others to sustain demand through transformation and application of the regional dimension of product demand. In addition, the following are important:

- Ex-ante market analysis should be made an integral part of R4D programs
- Should establish an initiative focusing on technology adoption and
- Should identify losers and gainers from new technologies and explore compensation options.

3. *Shift the " Breeding Paradigm"*

- Crop improvement programs should endorse and apply the new plant-breeding paradigm linking breeding with market development. But, how do we implement the new paradigm in research and training?
- Need sustainable and new strategies for capacity building in NARS (broad definition), including rationalization of curriculum in degree, formal educational/technical training institutions.
- Include questions on who does the training, the content, and modalities of training. A consensus is necessary, at least for the immediate future, to train breeders to be impact-oriented and for the economists to undertake a thorough analysis of constraints rather than just concentrating on implementation of solutions.
- Focus at better matching of natural resource based enterprises with biophysical economic and social condition.

4. There is a need for new strategies for Research for Development

- Pursue research priority setting with a wider range of strategic partners in public research systems, development organizations and private sector.
- Pro-actively pursue regional crop improvement based on differences in comparative advantages and competitive edge in IARCs, SROs, and NARS.
- Research for development strategy for SSA should be driven by the main agenda of the African stakeholders.
- Pursue an agenda driven by the demands of end-users, which must increase impact on both livelihoods and science.
- Need for better understanding of how SAT agriculture is evolving under the influence of newly emerging biophysical and socio-economic environment (climate change, droughts, globalization, policy reforms, etc.).
    - Characterize the farming systems, as well as the biophysical systems in the SAT to facilitate proper targeting of research
    - The impacts of these changes on poverty, food security and management of the natural resource base must be accounted for in R4D.

5. *There is a need to reconsider the institutional division of labor, funding, and capacity building*

There are two pertinent questions in this regard:

- Do you build institutions or concentrate on impacts?
- How do we empower NARS to play an increasingly more important and central role in SAT's R4D?

6. *There is a need to build-in consideration of HIV/AIDS*

HIV/AIDS is an increasingly significant factor in the design and implementation of agricultural development programs in Africa. The management and prevention of the pandemic depends on many agencies defining what they can contribute and what will be effective, regardless of the magnitude of contribution.

7. *ICRISAT, in particular, might consider the following interim steps*

- Develop a long-term strategy and adhere to it. Frequent changes in plans and activities disrupt operations and compromises reliability and credibility with partners.
- Prepare a well-formulated 1-year program for reflection within ICRISAT on its future role and relevance in the SSA, e.g. specification of responsibilities, consultation process, and achievement of positions and stated aims so that, by the end of the year, ICRISAT emerges with a clear understanding of its future role(s).
- Initiate a more consultative debate on the nature of the mission and the alternative approaches used.
- Learning from " Best Practices" or success stories:
    - Need to critically analyze the available successful approaches (e.g. SADC/ICRISAT- SMIP) of R4D and incorporate useful and agreeable aspects into rationalizing and targeting agricultural research for SAT.
    - Evaluate progress to-date and the nature of constraints to progress, including evaluating the roles and relevance of partners and altering partnerships according to the target objectives.

Workshop Agenda

Monday, 1 July 2002

Opening

8:30 Welcome — *SN Silim*

8:35 Introductions — *HA Freeman*

8:45 Objectives of workshop — *D Rohrbach*

Session 1: Rural Household Decision Making and Technology Change

Chair: MCS Bantilan (ICRISAT) **Rapporteur: R** Jones (ICRISAT)

9:00 Drought, rural household decision making and technological change in southern Zimbabwe
D Rohrbach, J Alumira (ICRISAT)

9:30 Changes in rural household livelihood strategies and outcomes in Burkina Faso
J *N djeunga (ICRISAT), K Savadogo (Univ. of Ouagadougou)*

10:00 Dynamics of household livelihood strategies: Implications for agricultural research
HA Freeman (ICRISAT), Frank Ellis (Univ. of East Anglia)

10:30 COFFEE/TEA BREAK

11:00 Panel discussion
W Omamo (ISNAR), S Mbogoh (Univ. of Nairobi)

Session 2: The Environment Influencing Technology Choice

Chair: M Mukumbu (USAID) **Rapporteur:** J Alumira (ICRISAT)

12:00 Agribusiness and market linkages
L Busch (Michigan State Univ.)

12:30 Food security challenges in sub-Saharan Africa: The role of research and development
H Sigwele (FANRPAN, Zimbabwe)

13:00 LUNCH

14:00 Panel discussion
J Kariuki (KACE, Nairobi)

15:00 COFFEE/TEA BREAK

15:30 Gender dimensions in SAT's agriculture and their implications on research
C *Kabutha (Consultant)*

16:00 HIV/AIDS and African agriculture
T Quinlan (Univ. of Natal)

16:30 Panel discussion
L Kimenye (Univ. of Nairobi), K Savadogo (Univ. of Ouagadougou)

Tuesday, 2 July 2002

Session 3: Technology Trends and Prospects

Chair: I Minde (ASARECA) **Rapporteur:** S Twomlow (ICRISAT)

8:30 Trends and prospects for livestock systems in the semi-arid tropics of sub-Saharan Africa
T Williams (ILRI)

9:15 Crop technology: Trends and prospects
R Ortiz (IITA)

10:00 Agricultural water management in the semi-arid tropics of Africa: Challenges, opportunities and the way forward
F Gichuki (IWMI)

10:45 COFFEE/TEA BREAK

11:15 Natural resource management research strategies for the SAT of sub-Saharan Africa: Patterns and outlook
N Hatibu (Sokoine University)

12:00 Adoption of agroforestry technologies in the drylands of sub-Saharan Africa: Experiences and challenges in West, southern and eastern Africa
S Franzel (ICRAF)

13:00 LUNCH

Session 4: Agricultural R&D for the African SAT: The Way Forward

14:00 Panel discussion
L Navarro (IDRC), W Oluoch-Kosura (Univ. of Nairobi), A Bationo (TSBF-CIAT)

15:30 COFFEE/TEA BREAK

Wednesday, 3 July 2002

Session 5: Evolution of Agricultural Research Organizations

Chair: M Nwalozie (CORAF) **Rapporteur:** J Ndjeunga (ICRISAT)

8:30 Evolution of collaboration between NARS, SROs and IARCs: Patterns and prospects
L Mughogho (Tea Research Foundation, Malawi)

9:00 New institutional arrangements in agricultural R&D in Africa: Concepts and case studies
A Hall (ICRISAT)

9:30 Panel discussion
/ Minde (ASARECA)

10:30 COFFEE/TEA BREAK

Session 6: Agricultural R&D for the African SAT: Implications for Research Priorities

Rapporteur: D Rohrbach (ICRISAT)

11:00 Panel discussion
K Molapong (SACCAR), M Nwalozie (CORAF), A Mbabu (ASARECA)

Session 7: Summary and Closing

Chair: HA Freeman (ICRISAT)

12:00 Summary of main conclusions
C Ackello-Ogutu (Univ. of Nairobi)

13:00 LUNCH

Participants

Chris Ackello-Ogutu
Resource Management & Policy Analysis Institute
PO Box 63806
Nairobi, Kenya
Tel +254 2 747076
Email ackello@accesskenya.com

Hezekiah Agwara
University of Nairobi
PO Box 640559 00620
Nairobi, Kenya
Tel +254 2 3747076
Fax +254 2 3742653
Email hagwara26@yahoo.com
rempai@accesskenya.com

Andre Batiano
Tropical Soil Biology and Fertility - Centro International de Agricultura Tropical (TSBF-CIAT)
PO Box 30677, Nairobi
Tel +254 2 524755/66
Fax +254 2 524763/4
Email a.batiano@cgiar.org

Margaret Brown
United States Agency for International Development (USAID)
PO Box 30261
Nairobi, Kenya
Tel +254 2 862400
Email mbrown@usaid.gov

Lawrence Busch
Partnerships for Food Industry Development
Michigan State University
East Lansing, MI 48824, USA
Tel 1-517-355-3396
Fax 1-517-353-5149
Email lawrence.busch@sx.msu.edu

Dhaneswar Dumur
Food and Agricultural Research Council
Newry Complex, St Jean Road
Quatre Bornes
Mauritius
Tel +230 4663885
Fax + 230 464 8809
Email areu@bow.intnet.mu

Francis Gichuki
International Water Management Institute (IWMI)
c/o ICRAF
PO Box 30677
Nairobi, Kenya
Tel +254 2 524144
Fax +2542 524001
Email f.gichuki@cgiar.org

Nuhu Hatibu
Soil-Water Management Research Group
Sokoine University of Agriculture
PO Box 3003
Morogoro, Tanzania
Tel +255 23 260 1206
Fax +255 23 260 4649
Email nhatibu@suanet.ac.tz
nuhuhatibu@yahoo.co.uk

Bashir Jama
World Agroforestry Centre (ICRAF)
PO Box 30667
Nairobi, Kenya
Tel +254 2 524000
Fax +254 2 524001
Email j.bashir@cgiar.org

Charity Kabutha
Consultant
PO Box 75608
Nairobi
Tel +254 733 706289
Email c_ kabutha@yahoo.comp

Lydia Kimenye
University of Nairobi
PO Box 29053
Nairobi, Kenya
Tel +254 2 593004
Fax +254 2 631813
Email kenyaweb.com

Adiel Mbabu
Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)
PO Box 765
Entebbe, Uganda
Tel 006 41 320438
Fax 006 41321126
Email asarplan@inforcom.co.ug

Stephen Mbogoh
University of Nairobi
PO Box 29053
Nairobi, Kenya
Tel +254 2 631354
Fax +254 2 631815
Email agecon@insightkenya.com

Isaac Minde
Eastern and Central Africa Program for Agricultural Policy Analysis (ECAPAPA)
PO Box 765, Entebbe, Uganda
Tel (41)321751/52
Email ecapapa@imul.com

Lewis K Mughogho
Tea Research Foundation
PO Box 51
Mulanje, Malawi
Tel +265 467 293
Fax +265 467 209
Email trfca@african-online.net

George Mugo
USAID/Kenya
PO Box 30261
Nairobi, Kenya
Tel +254 2 862400
Fax +254 2 860870
Email gmugo@usaid.gov
georgemugo@hotmail.com

Mulinge Mukumbu
USAID/REDSO/ESA
PO Box 30261
Nairobi, Kenya
Tel +254 2 862400
Fax +254 2 870890
Email mmukumbu@usaid.gov

Luis A Navarro
International Development Research Centre (IDRC)
PO Box 62084
Nairobi, Kenya
Tel +254 2 713160
Fax +254 2 711063
Email l.navaro@idrc.or.ke

Marcel Nwalozie
Conseil Ouest et Centre Africain pour la Recherche et le Developpement Agricole (CORAF)
BP 8237
Dakar-Yoff, Senegal
Tel +221 8259618
Fax +2218255569
Email marcel. nwalozie@coraf.org

Willis Oluoch-Kosura
University of Nairobi
PO Box 29053
Nairobi, Kenya
Tel +254 2 632150
Fax +254 2 632150
Email agecon@insightkenya.com
wokosura@insightkenya.com

Steven Were Omamo
International Service for National Agricultural Research (ISNAR)
PO Box 765
Entebbe, Uganda
Tel (263) 4 792348
Email w.omamo@cgiar.org

Rodomiro Ortiz
International Institute for Tropical Agriculture (IITA)
c/o Lambourn, 26 Dingwall Road
Croydon, CR9 3EE, UK
Tel +234 2 241 2626
Fax +234 2 241 2221
Email r.ortiz@cgiar.org

Tim Quinlan
University of Natal
Durban 4041, South Africa
Tel 031 2602592
Fax 031 2602587
Email quinlan@nu.ac.za
freeman@nu.ac.za

Kimseyinga Savadogo
University of Ouagadougou
03 BP 7021, Ouagadougou 03
Burkina Faso
Tel +226 361286
Email ksavadogo@cenatrin.bf

Howard Sigwele
Food, Agriculture & Natural Resources Policy Analysis Network
PO Box CY 2765, Causeway
Harare, Zimbabwe
Tel +263 4792348
Email hsigwele@fanrpan.org

Kevin Smith
USAID
PO Box 30261
Nairobi, Kenya
Tel 0722696255
Email kevysmith@hotmail.com
agecon@insightkenya.com

Timothy Williams
International Livestock Research Institute (ILRI)
PMB 5320, Ibadan, Nigeria
Tel +234 2 24412626
Fax +234 2 2412221
Email t.o.william@cgiar.org

ICRISAT-India
Patancheru 502 324 Andhra Pradesh, India
Tel +9140 3296161
Fax +9140 3241239

Ma Cynthia S Bantilan
Email c.bantilan@cgiar.org

William D Dar
Email w.dar@cgiar.org

CLL Gowda
Email c.gowda@cgiar.org

Andrew Hall
Email a.hall@cgiar.org

Rex Navarro
Email r.navarro@cgiar.org

Karaturi Purna C Rao
Email k.rao@cgiar.org

Bekele Shiferaw
Email b.shiferaw@cgiar.org

Ajay Varadachary
Email a.varadachary@cgiar.org

Suhas P Wani
Email s.wani@cgiar.org

ICRISAT-Kenya
PO Box 39063, Nairobi, Kenya
Tel +254 2 524553
Fax + 254 2 524001

H Ade Freeman
Email h.a.freeman@cgiar.org

Richard Jones
Email r.jones@cgiar.org

Kate Longley
Email k.longley@cgiar.org

A Babatunde Obilana
Email a.obilana@cgiar.org

KPCRao
Email kpcrao@cgiar.org

Said N Silim
Email s.silim@cgiar.org

ICRISAT-Mali
BP 320, Bamako, Mali
Tel +223 223375 or 227707
Fax +223 228683

Jupiter Ndjeunga
Email n.jupiter@cgiar.org

ICRISAT-Niger
BP 12404, Niamey, Niger
ICRISAT Niamey
Tel +227 722529, 722626
Fax +227 734329

Bruno Gerard
Email b.gerard@cgiar.org

Saidou Koala
Email s.koala@cgiar.org

Ousmane Youm
Email o.youm@cgiar.org

ICRISAT-Zimbabwe
Matopos Research Station
PO Box 776, Bulawayo, Zimbabwe
Tel +263 83 8311 to 18
Fax + 263 83 8253/8307

Jane Alumira
Email j.alumira@cgiar.org

John Dimes
Email j.dimes@cgiar.org

David Rohrbach
Email d.rohrbach@cgiar.org

Stephen J Twomlow
Email s.twomlow@cgiar.org

RA-0O392.

About ICRISAT

The semi-arid tropics (SAT) encompass parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, chickpea, pigeonpea, and groundnut - five crops vital to life for the ever-increasing populations of the SAT ICRISAT's mission is to conduct research that can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services and publishing.

ICRISAT was established in 1972. It is supported by the Consultative Group on International Agricultural Research (CGIAR), an informal association of approximately 50 public and private sector donors. It is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP) and the World Bank. ICRISAT is one of 16 nonprofit CGIAR-supported Future Harvest Centres.

Acknowledgments

ICRISAT and the editors of this volume gratefully acknowledge the assistance and support from various partners. The United States Agency for International Development (USAID) funded the study and the workshop. Participants and discussants from a range of institutions provided valuable inputs into the analysis, and participated in the workshop discussions that helped identify key issues and possible solutions.

Science with a Human Face

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics

PO Box 39063, Nairobi, Kenya

ISBN 92-9066-455-X CPE145 923-2002