EVALUATION OF WATER USE AT SAGANA IRRIGATION SCHEME IN NYERI DISTRICT

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DECLARATION

I, hereby, declare that this thesis is my original work and has not been presented for a degree in any other university.

.... 5.8.97 ....

Sifuma John　　　　Date

This thesis has been submitted for examination with my approval as the university supervisor.

.... 24/10/97 ....

DR. F.N Gichuki　　　　Date

DEDICATION

Dedicated to my late father, Jasper. L. Sifuma.

APPRECIATION

I would like to extend my appreciation to the following people; Mr Macharia Githumbi and other farmers in Sagana Irrigation Scheme for their cooperation and support during my data collection; the coordinator SIDP, Dr.Scheltema for availing the scholarship; the Ministry of Agriculture for granting me study leave; my university supervisor Dr.F.N Gichuki for his support, guidance, and encouragement during the entire course and research work; my colleagues in the Ministry of Agriculture for their support during my field work and report preparation. Finally, I would like to thank my wife Leah and my son Jeff for their support and patience during my absence. To all mentioned above, God bless you.

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LIST OF ABBREVIATIONS

AE	Application Efficiency
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
CAN	Calcium ammonium nitrate
DAO	District Agricultural Officer
DAP	Double ammonium phosphate
FAO	Food and Agricultural Organization of The United Nations
GI	Galvanised Iron
GoK	Government of Kenya
IDB	Irrigation and Drainage Branch
IIMI	International Irrigation Management Institute
ILRI	International Land and Reclamation Institute
JICA	Japan International Cooperation Agency
LBDA	Lake Basin Development Authority
LH	Lower Highland
MIS	Management information system
MoA	Ministry of Agriculture
MoTC	Ministry of Transport and Communication
MoWD	Ministry of Water Development
NIB	National Irrigation Board
ODI	Overseas Development Institute
ODU	Overseas Development Unit
SIDP	Small holder irrigation development project
TARDA	Tana and Athi River Development Authority
UPVc	Unplasticised Polyvinyl chloride

ABSTRACT

The study objective was to improve water use efficiency at Sagana gravity fed sprinkler irrigation scheme. An optimal cropping system for Sagana Irrigation Scheme was developed using; climatic data, crops data, farmers preferences, and market prices. An irrigation schedule to promote water use efficiency was developed for crops in the optimal cropping system using the FAO package CROPWAT. French beans, which is the main cash crop at Sagana Irrigation Scheme was subjected to different water application depths and Nitrogen fertilizer rates to:

i) determine the yield response factor; and

ii) study water and fertilizer interactions.

A line source sprinkler irrigation system was used to apply different amounts of water with irrigation scheduling according to the soil water balance. The water application depths were; 211 mm, 180.3 mm, 158.2 mm, and 138 mm. Four Nitrogen fertilizer rates (0 kg/ha, 80 kg/ha, 120 kg/ha, and 160 kg/ha) were randomized within the experimental plots.

The major findings of the study were:

i) Water use efficiency at Sagana Irrigation Scheme can be improved by designing an optimal cropping system that exploits the existing climatic conditions.

ii) The developed optimal cropping system had a peak water requirement of 114 mm during the month of January.

iii) For efficient water use under the optimal cropping system, rotational irrigation as opposed to on-demand irrigation is recommended.

iv) A yield response factor of 1.1 for French beans was determined.

v) Increased use of Nitrogen fertilizer at the same water level had a positive effect on the yields of French beans.

1. INTRODUCTION

1.1 IRRIGATION DEVELOPMENT IN KENYA

In Sessional Paper No.1 (GoK, 1986) and the 6th Development Plan (MoA, 1990) the Kenya Government plans to promote smallholder irrigation projects owing to their low operational costs and efficiency in achieving the following goals:

i) food security;

ii) earning more foreign exchange;

iii) higher levels of rural developments; and

iv) higher rural incomes.

According to the National Water Master Plan(MoWD, 1992), it was estimated that at the end of 1992, the total area under irrigation in Kenya was about 73,025 ha . This was about 21% of the irrigation potential of 352,400 ha. The 73,025 ha under irrigation was comprised of the following categories:

i) 26,600 ha under commercial large scale farmers;

ii) 12,000 ha under central managed authorities; and

iii) 28,000 ha under small holder farmers.

The Irrigation and Drainage Branch (IDB) of the Ministry of Agriculture whose objective is to increase and sustain agricultural production under smallholder irrigation, has on one hand been involved together with the Local District Development Committees in the development of smallholder irrigation schemes. On the other hand, the National Irrigation Board (NIB), the Tana and Athi River Development Authority (TARDA), the Kerio Valley development authority(KVDA), and the

Lake Basin Development Authority (LBDA) are charged with the development of centrally managed irrigation schemes. The hectarage under irrigation per enterprise in Kenya in 1990 is shown in Table 1.1.

Table 1.1: Irrigated crop hectarage in Kenya in 1990.

Crop	hectarage
Vegetables	26,407
Coffee	17,676
Rice	14,088
Fruits	4,940
Others	9,944
Total	73,055

source (MoA, 1992).

Irrigation development in the smallholder category has mainly concentrated on horticultural production. This is attributed mainly to the attractive gross margins associated with this type of irrigation enterprise.

Though smallholder schemes have performed better than centrally managed schemes, these schemes have faced the following constraints(MoA, 1990);

i) Poor water management;

ii) Weak farmers organisation; and

iii) Low production per hacterage.

Water management has a direct bearing on the long term viability of an irrigation scheme. The way irrigation water is distributed among different farmers and within a single farm can make a difference between successful crop production or crop failure. The low crop yields in the smallholder irrigation schemes is due to limited knowledge on proper use of water and other inputs. Furthermore, excess irrigation leads to problems of salinity and water logging.

1.2 JUSTIFICATION AND OBJECTIVES

1.2.1 Justification

Poor water management was identified as one of the problems facing the existing irrigation schemes (MoA, 1990). However, since IDB has not been monitoring the performance off different irrigation schemes, the above statement cannot be quantitatively substantiated. Furthermore, there is inadequate information on the following aspects of irrigation scheme's performance in Kenya:

i) Water use efficiencies at the field level;

ii) Yield response factors and yield potentials for different crops; and

iii) Performance standards at the national level.

Knowledge on the above aspects will lead to:

i) Formulation of improved extension packages to farmers; and

ii) Improved designs of future irrigation schemes.

This will lead to improved water use which will be in line with the Kenya Government policy of optimum utilization of her natural resources (GoK, 1989).

Sagana irrigation scheme in Nyeri district is a smallholder irrigation scheme. Farmers in this scheme mainly grow high valued horticultural crops through overhead irrigation. The scheme was recently rehabilitated and though the pipe distribution network has been put in place, issues pertaining to the operation of the distribution network and method of water delivery at the farm level have not been concluded.

1.2.2 Objectives

The three objectives of the study at Sagana Irrigation Scheme are:

1. To determine the optimal cropping system and irrigation water requirement.
2. To assess the yield response of French beans to different water application depths and fertilizer rates.
3. To identify ways and means of improving irrigation water use.

2. LITERATURE REVIEW

2.1 EVALUATION OF IRRIGATION SCHEMES

2.1.1 Causes of poor performance

The main reason for undertaking evaluation of irrigation schemes has been the unsatisfactory performance of existing irrigation schemes. The overall performance of an irrigation scheme is subject to many factors some of which are beyond the control of the farmer e.g.; produce prices, credit facilities, and marketing. Narrowing down to water use and water supply the causes of poor performance fall under the following categories:

1. Deficiencies in planning, design, and construction of irrigation systems (Jurriens and Kornelis, 1989; Hoecht, 1990).
2. Lack of understanding of how small scale irrigation schemes perform in relation to each other and individually (Hoecht, 1990).
3. Absence of good problem identification research (Lowdermilk *et al.*, 1980).
4. Mismatch between design assumptions and reality of social, cultural and economic factors (Carter, 1991).

Since an irrigation scheme encompasses both technical and social aspects, poor performance can be due to different reasons crossing disciplines. Hence the causes of poor performance will have to be dealt with according to site specific situations.

2.1.2 Evaluation methodology

As a result of numerous and possible diverse causes of poor performance of irrigation schemes as mentioned in section 2.1.1, different methodologies of evaluating irrigation schemes have been suggested. Biswas (1990) suggested the following as fundamentals for designing any monitoring and evaluation system for an irrigation scheme:

i) timeliness;

ii) cost effectiveness;

iii) maximum coverage;

iv) minimum measurement error;

v) minimum sampling error;

vi) absence of bias; and

vii) identification of users information.

Though many studies have incorporated the above fundamentals, identification of users information has been biased since most studies have ended up benefitting researchers more than farmers. According to Jurriens and Kornelis (1989), a logical approach in evaluation comprises of:

i) assessing the objectives of the schemes; and

ii) seeing if the objectives have been realized.

This points out the need of having specific measurable objectives, and since at the scheme level irrigation organizations provide a service to the beneficiaries, the quality of this service should be assessed against the scheme's goal (Hoecht, 1990). However, a bottleneck in using the above approach is the fact that most projects are formulated in such a way that their objectives remain vague and conflicting (Bos and Clemmens, 1990; Jurriens and Kornelis, 1989), hence making it difficult to evaluate them.

A methodology of evaluation known as problem analysis and causes was developed by Bottral (1981) as quoted by Jurriens and Kornelis (1989). The methodology comprised the following three phases:

i) identification of resource base;

ii) identification of project performance; and

iii) identification of causes.

The above approach was biased towards identifying problems and causes than in comparing objectives and results. A major shortcoming of the approach was lack of farmers involvement. Improvements on the above approach were made by Lowdermilk *et al.* (1980) whereby the whole system is analyzed as opposed to isolated components, and the research is multidisciplinary and rooted in field activities. Due to the time and expense involved in extensive action research, the rapid appraisal approach was proposed by Carruthers and Chambers (1981) as quoted by Jurriens and Kornelis (1989). The focus was on situation analysis so as to identify future alternatives rather than the detailed description of present problems in the extensive action research method. The rapid appraisal approach presents the following advantages which are in the interest of the farmer:

i) the results and recommendation are released quickly; and

ii) alternatives are presented for the farmer to choose from.

However, despite all the above approaches, there seems to be no universally agreed methodology on evaluation of irrigation schemes. Jurriens and Kornelis (1989) summarized this point by saying that anyone evaluating a project or its operation has to set up his or her objectives and criteria in order to identify possible areas for improvement. Though most of the methodologies were developed bearing in mind centrally managed irrigation schemes, they can also be used in farmer managed irrigation schemes.

2.1.3 Evaluation criteria

The choice of parameters to be evaluated will depend on project conditions and objectives (Bos and Clemmens, 1990). The parameters can range from yield and irrigation efficiencies to equity, stability, and cost effectiveness (Jurriens and Kornelis, 1989). According to them, low yields and irrigation efficiencies used to be the main indicators of poor performance but with the broadening views on irrigation, these were considered inadequate since they did not incorporate the human element in assessing scheme performance. Indeed Mao (1989) attributed causes of poor performance to both technical and social aspects. He consequently proposed the following parameters:

1. Parameters of irrigation water utilization viz:

(a) efficiency of utilizing irrigation water resource;

(b) gross annual irrigation water quota; and

(c) irrigation application efficiency.

2. Parameters of irrigation area and engineering aspects viz:

(a) efficiency of actual irrigated area;

(b) percentage of area provided with field irrigation and drainage system; and

(c) percentage of facilities in good condition.

3. Parameters of economic benefit viz:

(a) yield per unit area;

(b) yield per unit quantity of irrigation water;

(c) incomes from irrigation water charges per unit area;

(d) irrigation benefit per unit area;

(e) irrigation benefit per unit quantity of irrigation water; and

(f) percentage of financial self sufficiency.

Hoecht (1990) proposed the following parameters:

1. productivity;
2. equity;
3. environmental stability;
4. cost recovery; and
5. quality of water delivery services.

No methodology of identifying potential performance indicators is detailed enough. Furthermore, Nijman (1992) pointed out that use of performance indicators does not address the issue of the effectiveness of the indicators. Consideration of farmers criteria for performance evaluation has not been considered in details and here again it is up to the person doing the evaluation to use suitable parameters depending on site specific conditions.

2.1.4 Performance improvement

Most recommendations from evaluation studies have resulted in the rehabilitation of irrigation schemes. Rehabilitation has mainly been in the form of:

i) improved water conveyance and distribution structures;

ii) improved water distribution and irrigation schedules;

iii) strengthened farmers organization; and

iv) improved on farm water management.

Due to the numerous programs undertaken worldwide suggestions on issues of importance during rehabilitation and design have been made. Merriam (1980) according to Tiffen (1990) stated that irrigation systems should be designed so that as conditions change (e.g. crops, farm sizes, and water supply) the physical system and its operational capabilities can be upgraded. Vermillion (1989) suggested that conventional systems should only be preliminary approximations since systems objectives and needs may change over time. He further suggested the maximum use of local information in rehabilitation programs. Horst (1990) emphasized on simplification whereby the users of the system understand its operation. According to Levine and Coward (1989), the question of equity should be considered from the beneficiaries point of view since they perceive a pattern of water allocation as equitable if claims to water are based on some social principles that are accepted as fair or right.

The involvement of farmers in all aspects of irrigation scheme management leads to better performance of the irrigation scheme (Steiner and Walker, 1992; Makhado, 1990; Horst, 1990). This approach has been adopted by the Irrigation and Drainage Branch, Ministry of Agriculture in Kenya. Since the objective of most farmers in small scale irrigation schemes is to maximize benefits (Carruthers and Clark, 1983), evaluations should aim at increasing yields of crops high on the priority list of farmers while at the same time improving water use efficiency.

2.2 WATER USE

2.2.1 Cropping patterns and crop water requirement.

Crop water requirements are dependent on the type of crops cultivated. Accurate information on crop water requirements is necessary to establish the adequacy of the water sources especially at the peak demand period. Furthermore, a properly designed cropping system can improve water use efficiency by efficiently exploiting the existing climatic conditions (Stewart and Steiner, 1990). The choice of crop to be grown by the farmer is in some situations controlled by the irrigation agency (e.g. Mwea Irrigation Scheme in Kenya). However, in the farmer managed smallholder irrigation schemes in Kenya, the choice of crops to be grown is left entirely to the farmer who gets a fixed amount of water based on the available river flow. This is similar to the method advocated by Wamana (1985), and quoted by Jurriens and Kornelis(1989). According to Carruthers and Clark (1983), crops will be grown depending on relative market prices. To cater for the different crops that may be grown, they proposed a "model" crop mix with four crops for North India to be used in determining monthly cropping pattern water requirements. According to Hossain *et al.* (1987), quoted by chambers, (1989), farmers are continuously changing their cropping patterns and hence scientists should design several alternative packages with which farmers can experiment and choose from. Farmers in small scale irrigation schemes in Kenya are free to grow crops of their choices. However, they have a fixed water flow, demanding a "model" cropping pattern approach in computing crop water requirements.

Doorenbos and Pruit (1977) defined reference crop evapotranspiration (Et_o) as the rate of evapotranspiration from an extensive surface of 8-10 cm tall grass of uniform height actively growing, completely shading the ground and not short of water. By using the reference crop evapotranspiration the crop water requirements can be estimated as:

$$Et_c = k_c \times Et_o \qquad [2.1]$$

where, Et_c is the crop water requirements in mm, k_c is the crop coefficient and Et_o is the reference crop evapotranspiration.

Many methods both empirical and scientific have been developed to compute crop evapotranspiration. Of the scientific methods the combinations equations have proved to be most accurate in the estimation of crop water requirements (Jensen, 1983). Details of these method are well documented by Doorenbos and Pruit (1977) and Jensen (1983). Commonly used methods in determining crop water requirements are briefly explained below.

Pan evaporation method

The Pan evaporation method gives a measure of the integrated effects of radiation, wind, temperature, and humidity on evaporation from a specific open water surface. Reference crop evapotranspiration (Et_o) is computed as:

$$Et_o = K_p \times E_{pan} \qquad [2.2]$$

Where, E_{pan} is the Pan evaporation in mm/day, and K_p is the Pan coefficient.

Advantages of using the Pan evaporation method include:

1. similarity in response to climatic variables between plants and Pan evaporimeters;
2. proper siting of the pans enable evaporation to be estimated with an error of only 15% ; and

3. the method involves very simple computations.

Disadvantages of using the method include:

1. heat storage in the pan can result in equal evaporation during day and night, whereas most crops do not transpire at night;
2. heat transfer through pan walls (as opposed to crops) can result in appreciable differences; and
3. values of Pan coefficients have to be developed or calibrated for local conditions, which is not the case for most meteorological stations in Kenya.

Penman method

Penman equation is composed of the energy and aerodynamic terms. Under calm weather conditions the aerodynamic term is less important than the energy term. However, under windy conditions especially in the more arid regions, the aerodynamic term becomes more important (Doorenbos and Pruit, 1977). Doorenbos and Pruit revised the wind function term resulting in the modified equation:

$$Et_o = c\{W.R_n + (1-W)f(u)(e_a-e_d)\} \qquad [2.3]$$

Where, Et_o is the reference crop evapotranspiration in mm/day, W is the temperature related weighting factor, R_n is the net radiation in equivalent evaporation in mm/day, f(u) is the wind related function, (e_a-e_d) is the difference between the saturation vapor pressure at mean air temperature and the mean actual vapor pressure of the air both in millibar, and c is the adjustment factor to compensate for the effect of day and night temperature. Doorenbos and Pruit also modified the weighting factor to cater for the effects of both temperature and altitude. Though it requires the most amount of recorded data, compared to other methods the Penman method gives results with the highest accuracy.

Penman equation for Kenya

In the original Penman equation the weighting factor was assumed to be a function of temperature alone. However, in studies at Muguga, Kenya this weighting factor was also found to be influenced by altitude (Mc. Culloch, 1965). A modified Penman equation for Kenya was hence developed. To simplify computations using the modified Penman equation, Mc. Culloch developed "Tables for the rapid computation of the Penman estimate of evaporation". However, this modification was superseded by that of Doorenbos and Pruit.

Penman - Monteith equation

Monteith modified the Penman equation to include aerodynamic and surface resistances representing the effect of vegetation on the rate of transpiration. Though the Penman-monteith method of computing reference crop evapotranspiration is applicable to all crops, its use is limited by knowledge of the aerodynamic and surface resistances. However, the method has been used successfully by many scientists and indeed the FAO expert consultation meeting held in May 1990 in Rome Italy, recommended the use of the Penman-Monteith approach in calculating reference crop evapotranspiration (Smith, 1992). An added advantage of the Penman-Monteith approach is that FAO has developed a software for it known as CROPWAT which apart from calculating crop evapotranspiration allows one to plan irrigation schedules for a wide variety of crops, irrigation methods, and soil types. Furthermore, CROPWAT enables present irrigation schedules to be evaluated so that performance can be improved.

2.2.2 Yield response to water and fertilizer

Functions relating crop production with water and fertilizer may result in better irrigation management options and improved crop production. Hexem and Heady (1978) investigated the relationship between water and fertilizer for; corn, wheat, cotton, and sugarbeets in the United States of America. The crop production functions developed by Hexem and Heady were analyzed using economic concepts. From these studies they concluded that decision rules for optimal water use will depend on knowledge of water production functions relative to various soils, environmental, and management variables. Fox (1973) demonstrated the effects of fertilizer on crop yields by obtaining the yield response of sweet corn to small increments (5.5 Kg/ha) of Nitrogen fertilizer. To obtain a well defined response surface, Fox (1973) suggested the variation of a second variable at right angles to the fertilizer. The development of the line-source sprinkler system by Hanks *et al.* in 1976 provided a convenient method of investigating the interaction of water with fertilizer and other management variables in irrigated agriculture. The line source sprinkler system consists of a single water supply line with sprinklers spaced as closely as practical with spacing not exceeding 25% of the wetted diameter. The system is used to obtain a continuously variable gradient of water application at right angles to the water supply line and a uniform water application parallel to the water supply line. By applying a fertility variable at right angles to the water variable, the linesource system offers a convenient means for developing crop production function data. An advantage of the system is the fact that the system test area and water supply are both small. According to williardson *et al* 1987, any sprinkler can be used in a line source application if the infiltration rate of the soil is not exceeded.

The relationship between water and fertilizer in irrigated agriculture has been investigated by among others, James, 1984; Fapohunda *et al.*, 1989, 1990; Singh *et al.*, 1987; Bauder and Bauder, 1977; and El Nadi, 1975. A major limitation of these studies is that they are site specific, making the production functions non-generalizable.

According to Fapohunda and Hossain (1990), in the tropics works on effect of soil water and soil fertility on crop yields have considered only their separate effects, hence a great scope still exists for experiments involving both irrigation water and fertilizer effects.

Efficient water use needs a good understanding of the relationship between evapotranspiration and applied water to dry matter and grain yields (Stewart, 1987). To quantify the relationship between; yield, water, and fertilizer, statistical methods were developed by James (1984), and Hanks *et al.* (1980). According to Doorenbos and Kassam (1979), to quantify the effects of water stress it is necessary to derive the relationship between yield decrease and relative evapotranspiration deficit given by the empirically derived yield response factor (Ky) using the formula:

$$1-\frac{Y_a}{Y_m}=K_y\left(1-\frac{ET_a}{ET_m}\right) \qquad [2.4]$$

where, Y_a is the actual harvested yield, Y_m is the maximum harvested yield, K_y the yield response factor, ET_m is the maximum evapotranspiration, and ET_a the actual evapotranspiration. Values of K_y for most field and horticultural crops together with methodologies for determining ET_a , ET_m , Y_a , and Y_m are well documented by Doorenbos and Kassam (1979). According to Stewart (1987), the relationship between yield and seasonal evapotranspiration is linear while that between yield and applied water is not. Consequently water use efficiency will always be highest at the highest yield.

According to Vaux and Pruit (1983), though evapotranspiration is a better predictor of growth and yield, applied water is more crucial to the irrigator as it is directly under his or her control.

According to Carruthers and Clark (1983), there has been a wide gap between experimental and on-farm levels of achievement, hence care should be taken when applying the results of experiments in irrigation planning. However, despite the limitations, experiments involving yield, fertilizer, and water are advantageous in small irrigation schemes like Sagana Irrigation Scheme due to the following reasons:

i) they enable crop potentials to be established within farmers plots;

ii) they occupy very little land in farmers plots;

iii) they incorporate present farmers practices; and

iv) they can be replicated in different farms within the same irrigation scheme.

2.3 IRRIGATION EFFICIENCY

The flow of water from source to crop can be separated into conveyance, distribution, and field application. Conveyance and distribution networks directly influence field application efficiency in the following ways:

i) providing reliable water supply; and

ii) providing adequate water supply to the field.

Reasons for low irrigation efficiencies include:

i) seepage losses in open channels and leaks in pipelines;

ii) wind losses in sprinkler irrigation;

iii) unequal and excessive depth of wetting;

iv) lack of proper water supply control (Small, 1990); and

v) care taken by the irrigator.

Bos and Nugterene (1982) defined field application efficiency as the relationship between the quantity of water furnished at the field inlet and the quantity of water needed to maintain the soil moisture at the level required by the crop. The On-Farm Committee of the Irrigation and Drainage Division of ASCE (Anderson *et al.*, 1978) defined field application efficiency (AE) as the ratio of the average depth of the irrigation water stored in the root zone to the average depth of irrigation water applied. However, it is pointed out that application efficiency gives no indication of the adequacy and uniformity of irrigation. Keller *et al.* (1990) proposed the use of application efficiency of the low quarter and application efficiency of the low half to incorporate adequacy and uniformity in irrigation. For small scale irrigation schemes which are fully piped as in the case of Sagana Irrigation Scheme, field application efficiency is of major interest since it depends on field practices currently employed by the farmers.

Water use efficiency has been used synonymously with field application efficiency by Bos and Nugterene (1982), Micheal (1978), Jensen *et al.* (1983), and Pearce and Armstrong (1990). Pearce and Armstrong (1990) used the term water use efficiency to assess the level of water use by the beneficiaries of a project. They defined water use efficiency as the ratio of demand to supply i.e.:

$$W.U.E=\frac{CWR+\Delta s}{I+R} \qquad [2.5]$$

where, W.U.E is the water use efficiency, CWR is the crop water requirements in mm, Δs the change in soil moisture storage in mm, I the applied irrigation depth in mm, and R the effective rainfall in mm. Determination of effective rainfall is a problem in equation 2.5 and it is assumed that crop mixes are the same which is not the case in most small scale irrigation schemes. Hence the formula cannot be used to compare farmers within the same scheme in such cases.

Most scientist (Sammis and Wu, 1986; Singh *et al.*, 1987; Doorenbos and Kassam, 1979) report water use efficiency in terms of crop harvest i.e.:

$$MUE=\frac{K}{M} \qquad [2.6]$$

where MUE, is the water use efficiency in Kg/m^3 ; K is the yield harvested in Kg, and, M is the applied water in m^3. This enables the comparison of the effects of different water application regimes on yields enabling the choice of the most efficient one. Doorenbos and Kassam (1979) further suggested the use of water use efficiency of crops as a criteria for selecting the optimum cropping pattern in irrigation schemes.

2.4 SCHEME WATER REQUIREMENTS

2.4.1 Irrigation requirements

According to Doorenbos and pruit(1977), net irrigation requirements are computed using the field water balance. It is expressed as:

$$I_n = ET_{crop} - [P_e + G_e + W_b] \qquad [2.7]$$

Where, I_n is the net irrigation requirement in mm, ET_{crop} is the crop evapotranspiration in mm, P_e is the effective rainfall in mm, G_e is the ground water contribution in mm, and W_b is the stored soil water in mm at the beggining of the irrigation period in mm. Determination of ground water contribution requires detailed experiments while stored soil water is normally estimated based on previous crops and periods of a preceding fallow or dry season period(Smith, 1992).

Due to losses in conveyance and application of water, an efficiency factor is normally incooperated in the computation of project irrigation supply.

Project irrigation supply is expressed as;

$$V = \frac{10}{E_p} \Sigma_i [A * I_n] \qquad [2.8]$$

Where, V is the project irrigation supply requirements in m^3/month, E_p is the project efficiency, A is the acreage under a given crop in ha, I_n is the net irrigation requirements of a given crop in mm/month, and 10 a factor of conversion from mm/month to m^3/month.

For initial planning, the capacity of the water delivery system can be obtained from the supply required during the month of peak water use(Doorenbos and Pruit, 1977).

2.4.2 Effective rainfall

Since not all the rainfall is available to the crop, there is a need to estimate the amount of rainfall that is effective. Detailed methods of predicting effective rainfall are given by Dastane (1975). In irrigation planning the evapotranspiration/precipitation method is normally used to estimate the effective rainfall. In this method the relationship between monthly effective rainfall and mean monthly rainfall is given for different computed values of monthly average crop evapotranspiration(Table 7.16 in Annex 7.5). However, the method does not account for soil infiltration rates and rainfall intensity.

2.4.2 Field irrigation scheduling

The irrigation water supply requirements at the field level are determined by the depth and interval of irrigation. Accurate irrigation depth and timing are critical for optimal crop growth. Irrigation depth and interval data are obtained from a soil water balance which is determined by the available soil water, the fraction of available soil water permitting optimal crop growth and rooting depth (Doorenbos and pruit,1977). Based on a monthly soil water balance, Doorenbos and Pruit proposed the graphical method of developing irrigation schedules. A scheduling programme based on a daily soil water balance was proposed by Smith (1992) and is incooperated in the FAO package CROPWAT. Details on irrigation scheduling are given by Doorenbos and Pruit(1977), Raes *et al*,(1988) and Smith(1992).

2.4.3 Available river flow

To be able to meet the irrigation requirements of the selected crops or cropping pattern, the irrigation system capacity should be based on the peak irrigation requirements. However, in most cases the capacity of the irrigation system is constrained by the amount of water that can be abstracted for irrigation purposes. Hence this factor should be considered when developing cropping patterns.

For proper irrigation planning hydrological data is required. Since peak irrigation period coincides with low river flows, these flows are used for planning purposes. Data for 15-20 years are normally used with one reading every year or month(Chow, 1969). Probability analysis is used to determine the non-exceedence of hydrological events. For irrigation schemes a probability of 20% is used so that in 4 out of every

5 years there is sufficient water in the irrigation scheme. Estimation of probabilities for low flows can be done using the ranking order where the plotting position is determined using empirical methods like the California method, Hazen and Weibul formulas. The weibul formula is commonly used since it has more statistical justification(Chow, 1969). The formula is expressed as;

$$P[x \geq x_m] = \frac{m}{[n+1]} \qquad [2.9]$$

Where, $P(x > x_m)$ is the exceedence probability of the m^{th} largest value, x_m for a large number of values n, m is the rank value in a list ordered by descending magnitude and n is the total number of values to be plotted.

3. METHODOLOGY

3.1 SITE DESCRIPTION

3.1.1 location

Sagana Irrigation Scheme is located 30 Km North of Karatina town in Ruguru Location, Mathira Division, Nyeri District, Central Province of Kenya (Fig. 3.1). The scheme lies on the lower footslope of Mt. Kenya at an altitude between 1770 and 1905 meters and covers a gross area of 500 ha.

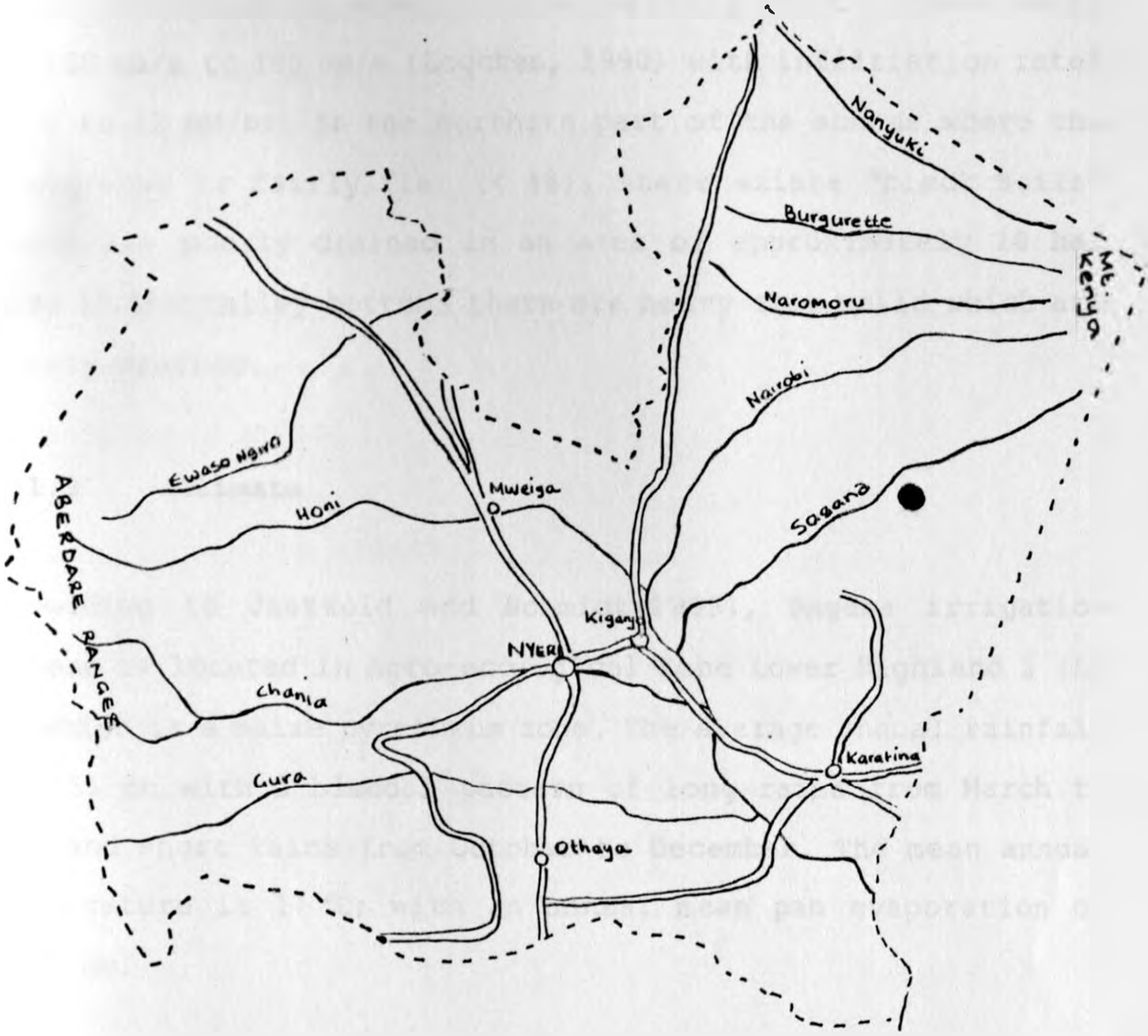
3.1.2 Topography and soils

The scheme is situated on four ridges with valleys to each side. The topography is steep and varies widely between farms with the difference between the highest and lowest part of the scheme being 140 meters. The slopes vary between 0.3% and 30% and this variation in slope can be found within most farms. The average slopes is estimated at 10%.

The soils in the scheme are of three types (Logchem, 1990) viz:

i) Soils on volcanic footridges which are well drained extremely deep, dark reddish to dark brown friable and slightly smeary clay with acid humic top soil (ando-humic Nitisols and humic Andosols); and

ii) Soils on mountains which are well drained, dark reddish brown to dark brown, very friable and smeary clay-loam/clay (humic Andosols).



● Sagana Irrigation Scheme Scale 1:500,000

o Towns

≈ Roads

— Rivers

Fig 3.1:Location of Sagana Irrigation Scheme.

The above soils have a depth greater than 1 meter, hence there is no restriction to the root development of most irrigated crops. The range of water holding capacity for the above soils is 100 mm/m to 180 mm/m (Logchem, 1990) with infiltration rates of 8 to 12 mm/hr. In the northern part of the scheme where the topography is fairly flat (< 4%), there exists "black soils" which are poorly drained in an area of approximately 10 ha. Also in the valley bottoms there are heavy clay soils which are poorly drained.

3.1.3 Climate

According to Jaetzold and Schmidt(1983), Sagana irrigation scheme is located in Agro-ecological zone Lower Highland 2 (LH 2) which is a maize pyrethrum zone. The average annual rainfall is 851 mm with a bimodal pattern of long rains from March to May and short rains from October to December. The mean annual temperature is 17 °C; with an annual mean pan evaporation of 1367 mm.

3.1.4 Background information

The Sagana Irrigation Scheme was initiated in 1984 as a self-help irrigation project after the droughts between 1974 and 1984.

The Ministry of Water Development provided various sizes of pipes which were not adequate to cover the whole scheme area as designed. This together with lack of finance to purchase more pipes resulted in inadequate and unequal water distribution in many parts of the scheme. In 1986 financial assistance was sought from an NGO (Terra Nuova) and together with the Ministries of Agriculture and Water Development new designs for the water supply and distribution system were made on the basis of which funds amounting to Kenya shillings 8 million were availed for the project's rehabilitation. The aim was to provide equal water supply to all areas of Sagana Irrigation Scheme.

3.1.5 Farming system

According to Terra Nuova (1990), changes observed with the implementation of the irrigation scheme include:

- i) a shift from food crops to cash crops;
- ii) a few land transactions; and
- iii) an appreciation in the value of land.

Allocation of water to various crop production enterprises is dependant on economic returns and farmers priorities. Currently irrigation is mainly for horticultural crops. The main food crops consist of maize, irish potatoes, and beans. Cash crops consist of a variety of horticultural crops which mainly comprise of French beans, cabbages, capsicums, onions, and carrots. In areas which are poorly drained land use is restricted to grazing during the dry period and cultivation of crops such as "arrow roots" which can withstand water logging.

3.1.6 Irrigation system

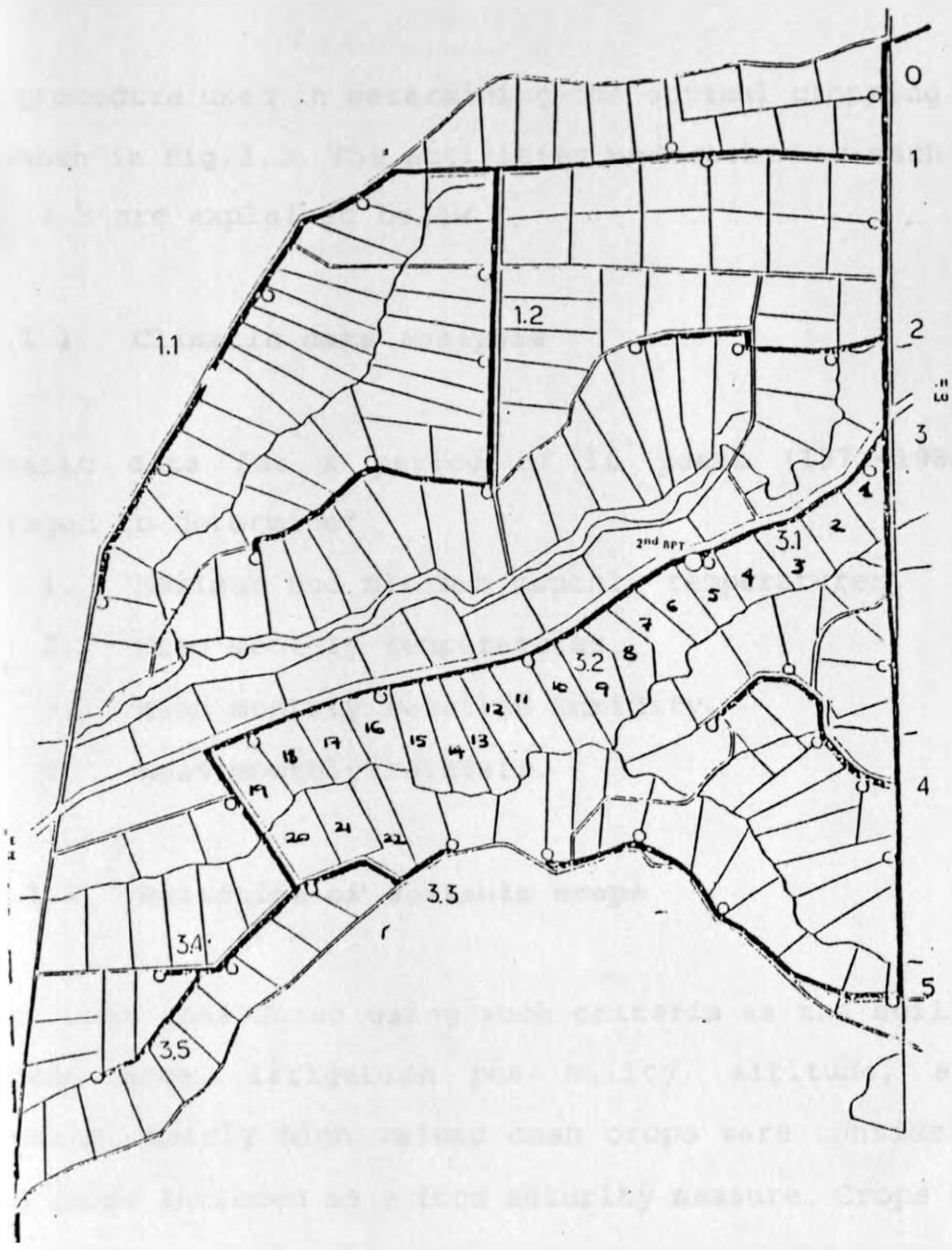
Irrigation water is from River Sagana. The water supply is via a gravity temporary weir and a 355 mm diameter UPVc pipeline 1.4 km long anchored by GI pipes in sections where the pipeline crosses gulleys. Supply to the farms is through UPVc pipe distributaries ranging from 200 to 75 mm diameter. Hydrant assemblies have been installed at the farm level to regulate pressure and flow. The design flow of the main irrigation system (110 l/sec) was originally based on providing 180 irrigation plots with 0.6 litres/sec each. It was assumed that 1 acre will be irrigated at each plot. However, due to subdivision there are currently a total of 280 farmers irrigation plots each of 1 acrea. The flow rate per farmer is hence 0.39 l/sec. Since the amount of water available for abstraction is fixed, farmers have to consider water management options that will ensure equitable water distribution and adequate water delivery at the farm level. Though suggestions have been made to instal flow limiting devices at each farm inlet by Terra Nuova (1992), a more sustainable solution will be to present the options of on-demand or rotation irrigation at the farm level.

Two factors which will affect the design and hydraulic system are:

i) variation in topography at the farm level; and

ii) land subdivision still going on at the farm level.

Due to the varied topography Gichuki (1992), recommended the need of having specific plot or hydrant pipe sizes and sprinkler types. To resolve the issue of land subdivision, Terra Nuova (1992) suggested that new members shall receive their water supply on an aerial pro rata basis. However, it is noted that the on-demand system which is the present practise can be adopted at the present level of land subdivision. From the foregoing it can be seen that there is a wide choice of water management options that can be advanced to the farmers, hence it will be better to provide the farmers with these alternatives to choose from.



Distributaries

o Hydrant

1-20 Farm number

Fig 3.2: Distribution system for Sagana Irrigation Scheme.

3.2 OPTIMAL CROPPING SYSTEM FOR SAGANA IRRIGATION SCHEME.

3.2.1 Determining the optimal cropping pattern

The procedure used in determining the optimal cropping pattern is shown in Fig.3.3. The activities undertaken at each step in Fig. 3.3 are explained below.

3.2.1.1 Climatic data analysis

Climatic data for a period of 16 years (1971-1986) were averaged to determine:

1. Maximum and minimum monthly temperatures.
2. Mean monthly temperatures.
3. Mean monthly relative humidity.
4. Mean monthly rainfall.

3.2.1.2 Selection of suitable crops

Crops were considered using such criteria as the soils in the project area, irrigation possibility, altitude, and crop rotation. Mainly high valued cash crops were considered with food crops included as a food security measure. Crops selected were those whose climatic requirements were met by the prevailing climatic conditions. The crops selected were then fitted into recommended crop rotations.

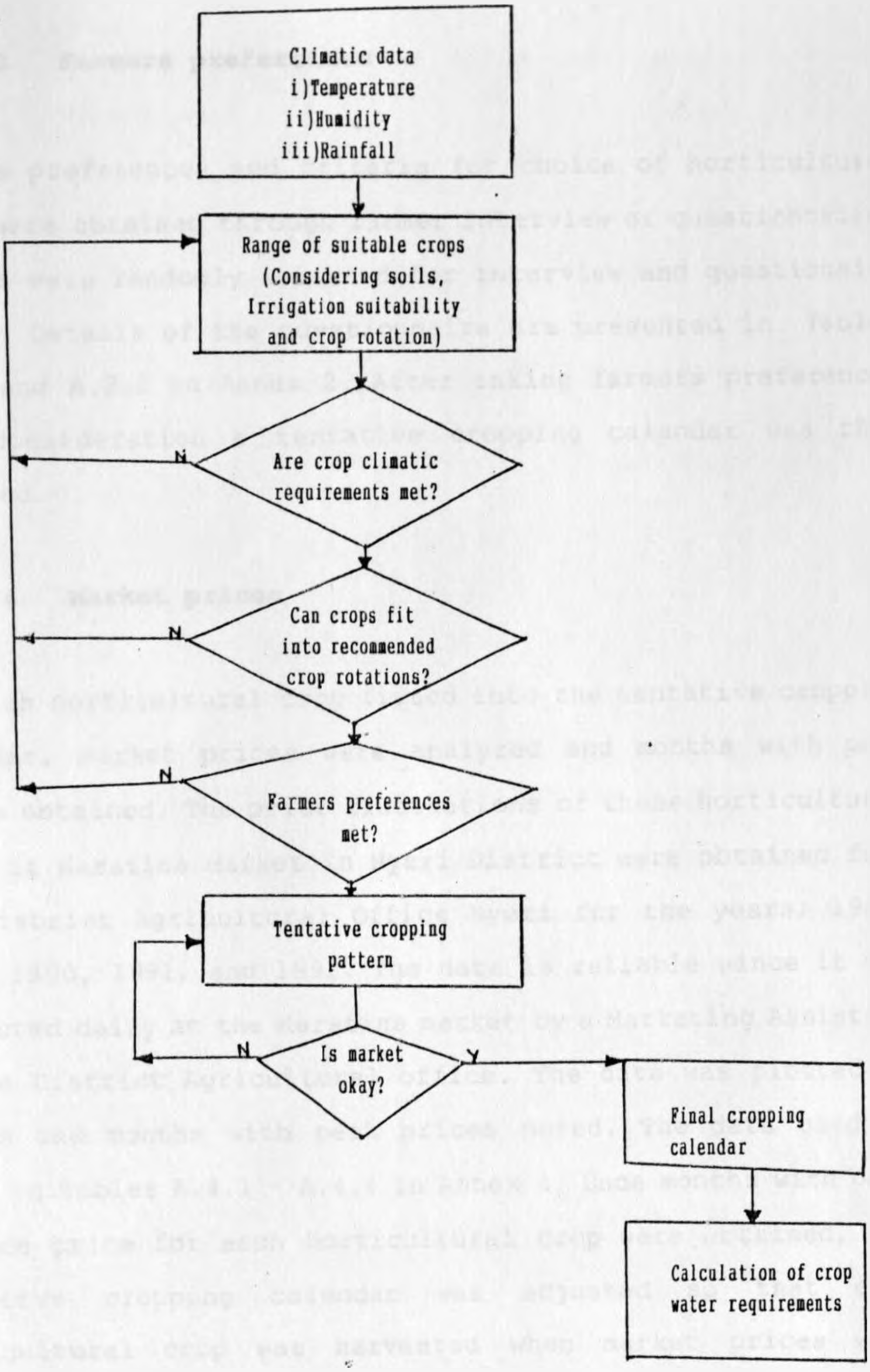


Fig 3.3: Determination of optimal cropping pattern and crop water requirements.

3.2.1.3 Farmers preferences

Farmers preferences and criteria for choice of horticultural crops were obtained through farmer interview or questionnaire. Farmers were randomly selected for interview and questionaire study. Details of the questionnaire are presented in Tables A.2.1 and A.2.2 in Annex 2. After taking farmers preferences into consideration a tentative cropping calendar was then prepared.

3.2.1.4 Market prices

For each horticultural crop fitted into the tentative cropping calendar, market prices were analyzed and months with peak prices obtained. The price fluctuations of these horticultural crops at Karatina Market in Nyeri District were obtained from the District Agricultural Office Nyeri for the years; 1985, 1986, 1990, 1991, and 1992. The data is reliable since it was collected daily at the Karatina market by a Marketing Assistant in the District Agricultural office. The data was plotted on graphs and months with peak prices noted. The data used is given in Tables A.4.1 - A.4.4 in Annex 4. Once months with peak produce price for each horticultural crop were obtained, the tentative cropping calendar was adjusted so that each horticultural crop was harvested when market prices were highest. This was taken as the final (optimal) cropping pattern.

3.2.2. Determining crop water requirements and irrigation scheduling

To compute crop water requirements for the final cropping pattern the FAO package CROPWAT was used. Sixteen years data (1971-1986) was averaged to determine:

i) Maximum and minimum monthly temperatures.

ii) Mean monthly relative humidity.

iii) Mean monthly windrun.

iv) Mean monthly sunshine hours.

These were used in the package CROPWAT to determine values of reference crop evapotranspiration in mm/month for each month. Data used is presented in Table A.5.1 in Annex 5. Cropwater requirements for the optimal cropping pattern were also determined using CROPWAT.

An irrigation schedule for crops in the optimal cropping pattern was developed using the FAO package CROPWAT. Steps in developing the irrigation schedule were as follows:

(a) The readily available soil water (Sa) was taken from Table A.1.3 in Annex 1 at a value of 96 mm/m.

(b) The rooting depth (D) for each crop at different stages was obtained from Doorenbos and Pruit (1977).

(c) The soil water depletion fraction (P) for each crop was obtained from Doorenbos and Kassam (1979).

(d) On a daily basis the soil water balance was computed by CROPWAT as:

$$SMD_i = SMD_{i-1} + ETa - P_e - Irr_{Appl} + RO + DP \qquad [3.1]$$

where, SMD_i is soil moisture depletion at day i(mm), ETa is the actual evapotranspiration(mm), P_e is the effective rainfall(mm), Irr_{Appl} is the irrigation depth(mm), RO is the runoff(mm) and DP the deep percolation(mm).

For crops in the optimal cropping pattern the results are shown in Tables A.11.1 - A.11.8 (Annex 11).

3.3 RESPONSE OF FRENCH BEANS TO DIFFERENT WATER APPLICATION DEPTHS AND FERTILIZERS RATES

3.3.1 Experimental site description

3.3.1.1 Location

The experimental site is situated within Sagana Irrigation Scheme (Farm number 1 in Fig.3.2). The location of the experimental site is shown in Figure 3.4. The experiment was conducted during the 1993 growing season. The selection of crop and experimental site were based on the following facts:

1. French beans is currently the most important cash crop at Sagana Irrigation Scheme.
2. Preceding crops and fertilizer treatments in the plots were uniform.

3.3.1.2 Soil texture

Soil particle size distribution was determined using the sieve analysis and hydrometer method(Nelson, 1983).

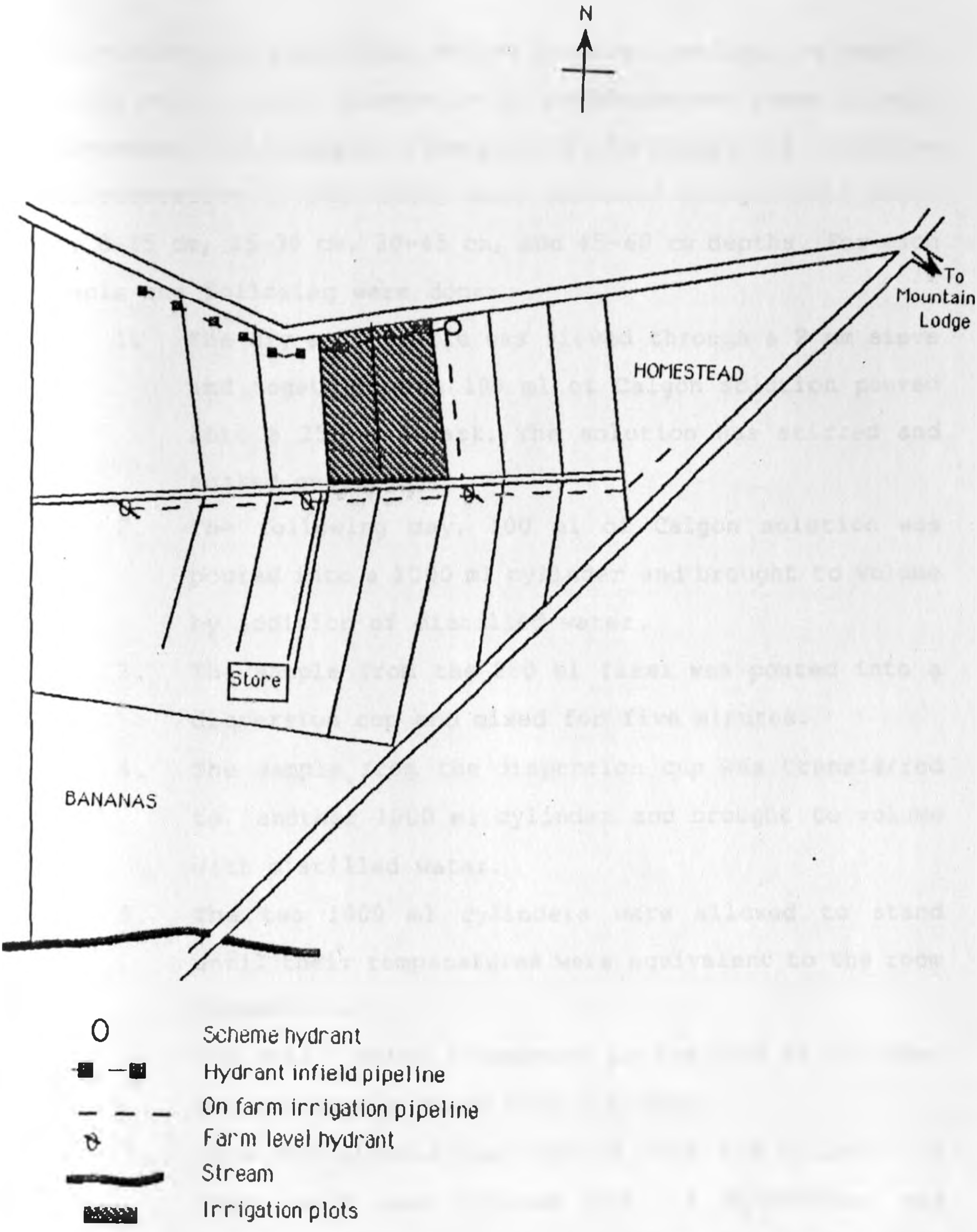


Fig 3.4: Location of experimental plots.

The shaking and hydrometer method involved reading the density of the soil - water suspension at predetermined times using a hydrometer. Soil samples from plot G23 in Figure 3.6 (taken as representative of the field) were obtained using a soil auger at; 0-15 cm, 15-30 cm, 30-45 cm, and 45-60 cm depths. For each sample the following were done:

1. The dry soil sample was sieved through a 2 mm sieve and together with 100 ml of Calgon solution poured into a 250 ml flask. The solution was stirred and soaked overnight.
2. The following day, 100 ml of Calgon solution was poured into a 1000 ml cylinder and brought to volume by addition of distilled water.
3. The sample from the 250 ml flask was poured into a dispersion cup and mixed for five minutes.
4. The sample from the dispersion cup was transferred to another 1000 ml cylinder and brought to volume with distilled water.
5. The two 1000 ml cylinders were allowed to stand until their temperatures were equivalent to the room temperature.
6. The soil - water suspension in the 1000 ml cylinder was thoroughly mixed with a plunger.
7. Once the plunger was removed from the cylinder, a stop watch was started and a hydrometer was inserted into the soil - water suspension. The hydrometer was read 40 seconds after the start of the stop watch and then removed from the cylinder.

A temperature reading of the soil - water suspension was then taken.

8. A hydrometer and temperature reading of the Calgon solution in the other 1000 ml cylinder were then taken.
9. Steps 7 and 8 were repeated 2 hours after the start of the stop watch.
10. The hydrometer readings were corrected for temperature by adding 0.11 for every degree over 20°C and subtracting 0.11 for every degree below 20°C
11. The corrected Calgon readings were then subtracted from the corrected soil suspension readings.

Using the final corrected values the following calculation were done:

(a) 100 - 40 second reading = % sand

(b) 40 second reading - 2 hours reading = % silt

(c) 2 hour reading = % clay

The density of the solution at the predetermined times is proportional to the sand, silt, and clay remaining in suspension. The results for the soil samples are in Table A.1.3 in Annex 1.

3.3.1.3 Soil water retention

Moisture retention was determined using the pressure chamber(Richards, 1949). Undisturbed (core samples) soil samples from plot G23 (see Figure 3.6) were obtained at; 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm depths in triplicates. For each sample the following was done:

1. The sample was weighed so as to be able to calculate the bulk density. This was done by dividing the weight of the oven dried soil with the volume of the core ring.
2. Each sample was fastened with cheesecloth on one end and placed around a large tray.
3. Water was added in the tray until about half-way to the top of the sample rings. The samples were left in the tray over night.
4. The saturated samples were weighed and then placed on a pre-soaked ceramic plate of 0.2 bar.
5. The plate (with samples) was then placed in the pressure chamber and the pressure in the chamber adjusted to 0.2 bar.
6. The samples were allowed to reach equilibrium after 4 days and then weighed.
7. The samples were then placed on a pre-soaked 15 bar ceramic plate and steps 5-6 repeated.

The water content at each pressure was determined by weighing the soil samples before and after equilibrium and the results are in Table A.1.2 in Annex 1.

3.3.1.4 Topography

The topography at the experimental site was estimated using a clinometer. The slope was estimated at 0.4%.

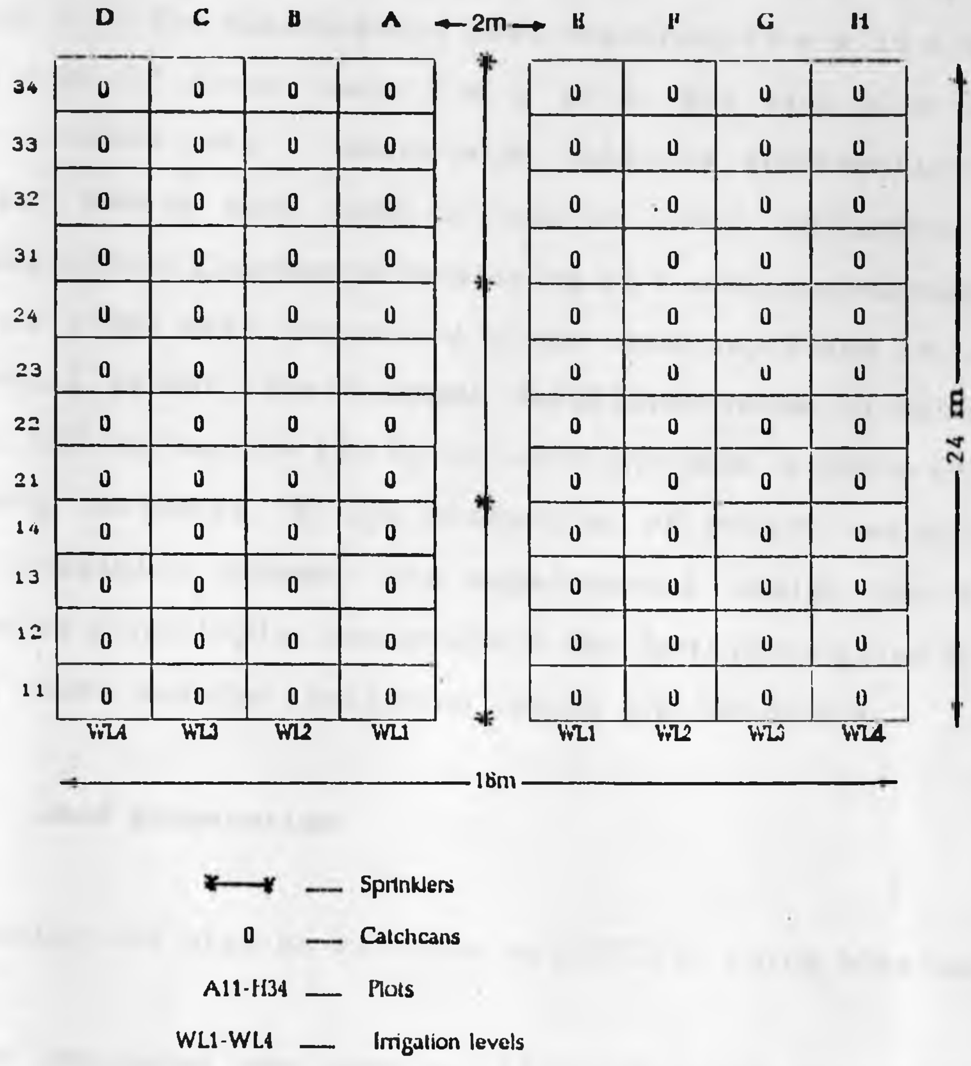


Fig 3.5: Experimental layout.

3.3.1.5 Experimental layout

The irrigation system layout and experimental plots are shown in Figure 3.6. The experimental area measuring 24 m x 16 m was divided into 12 plots (each 2 m x 16 m) and each plot was further divided into 2 metre wide subplots representing 4 irrigation levels with each irrigation level replicated 3 times. Fertilizer treatments consisting of 4 levels of Nitrogen fertilizer (CAN) were randomized within each replicate in the experimental layout. The Nitrogen fertilizer rates (0 kg/ha, 80 kg/ha, 120 kg/ha, and 160 kg/ha) were the same as those used by farmers currently in the production of French beans at Sagana Irrigation Scheme. The experimental design can be described as a split-plot design where the fertilizer rates are the main plots and the irrigation levels the sub-plots.

3.3.1.6 Land preparation

Land clearing and digging was done on 23/12/92 using hoes and folks.

The first harrowing was done on 27/12/92 using folks(hand tools) with the second harrowing being done on 18/1/93. Ridges at a spacing of 60 cm were made on 29/1/93.

3.3.1.7 Planting and pre-irrigation

French beans were planted in the ridges at a spacing of 15 cm and a depth of about 8 cm. Diammonium phosphate fertilizer

(DAP) was applied at each hole in the ridge at the rate of 2 gms/hole. The seeding rate used was 40 kg/ha derived from current farmers practices. Following emergence of seedlings on 8/2/92, the plant population was 42 plants/subplot. To ensure uniform soil moisture availability, irrigation was applied for a period of 2 hours on 1/3/92 and 1 hour on 4/3/92 using Lego sprinklers at a sprinkler spacing of 12 m * 12 m and operating at a pressure of 2.0 bars. On 2/3/92 the four fertilizer treatments consisting of 4 levels of Nitrogen (0 kg/ha, 80 kg/ha, 120 kg/ha, and 160 kg/ha) were randomized and side dressed to a depth of about 5 cm in the experimental plot.

3.3.1.8 Plant protection

Weeding was done manually on 15/2/93, 8/3/93, 29/3/93, and 19/4/93."Diazinon" at the rate of 0.5 l/ha was applied on 11/2/93 and 19/2/93 for the control of Beanfly and Bean aphid pests."Dithane M.45" at the rate of 0.625 kg/ha was applied on 13/2/93, 26/2/93, 12/3/93, 26/3/93, 10/4/93 and 24/4/93 for the control of blight, while Copperoxide was applied at the rate of 1.5 kg/ha on 19/2/93, 5/3/93, 19/3/93, and 16/4/93 for the control of leafrust. As a broad spectrum control of pests "Brigade" was applied on 1/3/93 and 22/3/93 at the rate of 0.5 l/ha.

3.3.1.9 Irrigation water application and irrigation scheduling

The sprinkler system used in this study can be described as a line source irrigation system (Figure 3.6). Following field trials at spacings of 8 m, four sprinklers at a spacing of 8 meters were used, these were lego S33 Ap type and were operated at a pressure of 2 bars. Flow in the irrigation mainline was controlled by means of a gate value. Irrigation depth was based on the available soil water at plot E21 and was taken as the depth of water collected in each catch can in the subplots. Irrigation scheduling was done according to the soil water balance sheet in Table A.7 in Annex 7.

Fig 3.6: Experimental plot with operating sprinklers

Crop evapotranspiration (ET_c) in the soil water balance sheet was calculated using the formula:

$$ET_c = K_c \times E_{pan} \times K_p \qquad [3.2]$$

where E_{pan} is the class A pan evaporation in mm measured daily at Sagana State Lodge meteorological station, K_c the crop coefficient derived from Fig A.7 in Annex 7, and K_p the pan coefficient taken as 0.7 due to the following conditions (Doorenbos and Pruit,1977):

i) pan was sited in a dry fallow area and windward distance of dry fallow was 100m;

ii) relative humidity ranged from 50% to 80%; and

iii) wind speed was < 175 km/day.

The soil water balance on a particular day was determined as below:

$$S_i = S_{i-1} - ET_{ci} + R_i + I_i \qquad [3.3]$$

Where; S_i is the soil water balance on day i in the soil water balance sheet in Table A.7(Annex 7); S_{i-1} is the soil water balance on day i-1; ET_{cr} is the crop evapotranspiration determined using equation 3.2 on day i; R_i is the effective rainfall on day i; and I_i is the irrigation depth on day i.

During the initial 28 days of growth the rooting depth of French beans was estimated at 20cm and using the total available soil water at different soil depths (Table A.1.3 in

Annex 1), the total available soil water over the rooting depth was (97 mm/m x 0.15 m + 96 mm/m x 0.05 m) 19.2 mm . Using an allowable depletion of 45%, irrigation was carried out whenever the soil water balance was depleted to a value of 10.6 mm in plot E21 (Fig.3.6). From day 29 to 90 the average rooting depth was estimated as 0.3 cm and the total available soil water was (97 mm/m x 0.15 m + 96 mm/m x 0.15 m) 28.5 mm, and allowing a depletion of 45%, irrigation was applied whenever the soil water balance was depleted to a value of 15.7mm .

3.3.2 Data collection

3.3.2.1 Soil moisture determination

Gravimetric soil samples using a soil auger (3 replicates) were taken at; 0-15 cm, 30-45 cm, and 90-105 cm depths. The samples were taken from subplots; E21, F13, G23, and H23 in Figure 3.6 on the following dates: 1/2/93, 13/3/93, 15/3/93, 3/3/93, 30/4/93, and 6/4/93. The samples were weighed and then ovendried at 105°c for 24 hours before being weighed again to determined the moisture content.

3.3.2.2 Crop height

In each subplot the average height of 10 marked plants in the centre row of crops was determined using a tape measure. Measurements were done on; 6/3/93, 12/3/93, 26/3/93, and 4/4/93. Changes in height with time were plotted on graphs and are shown in Fig 4.4.

3.3.2.3 Crop cover

In each subplot crop cover was estimated using the meter stick method. This was done by placing the meter stick at right angles between three rows of crop and noting the number of graduations on the meter stick covered by the crop shadows. Measurements were done on; 7/3/93, 22/3/93, and 6/4/93. Crop cover trends with time were plotted on graphs and are shown in Fig 4.5.

3.3.2.4 Irrigation depth measurement

The irrigation depth in each plot was calculated by noting the volume of water collected in catchcans placed at the center of each plot. The catchcan diameter used was 8 cm. There was minimal interference from crop cover as the crop height was not high and any obstruction to the catchcans was removed before an irrigation event. The irrigation depth was calculated by dividing the volume of water collected with the cross-sectional area of the catchcans. The irrigation depth was determined after every irrigation on the following dates: 14/3/93, 19/3/93, 24/3/93, 5/4/93, 13/4/93, and 22/4/93.
The information on irrigation depth is shown in Table A.8.1 in Annex 8.

3.3.2.5 Crop yield

The middle row of crops in each subplot was harvested for yields. The yields were determined by weighing them on a weighing scale. The yields in each plot were adjusted to a plant density of 42 plants/4m^2. Yields were determined on; 5/4/93, 7/4/93, 9/4/93, 12/4/93, 14/4/93, 16/4/93, 19/4/93, 23/4/93, 26/4/93, 28/4/93, and 30/4/93. At each irrigation level and fertilizer rate, crop yields (kg/ha) were analyzed using analysis of variance for a split plot design. Equation 2.4 was used to determine the yield response factor K_y.

Crop water use (ET_c) was estimated as:

$$ET_c = I + R - D \pm \Delta M \qquad [3.4]$$

where, ET_c is the crop evapotranspiration in mm, I the irrigation depth (mm), R the effective rainfall(mm), D the deep drainage(mm), and ΔM the change in soil moisture storage (mm) over the root depth. Deep drainage was computed from the soil water balance sheet in Table A.7 in Annex 7 and was taken as the amount excess of the total available soil water following an irrigation or rainfall event.

Crops in plots A11 to D34 were destroyed by gazelles at the flowering stage, hence data from these plots was not included in the analysis.

4. RESULTS AND DISCUSSION

4.1 DEVELOPMENT OF OPTIMAL CROPPING SYSTEM FOR SAGANA IRRIGATION SCHEME

4.1.1 Climatic data

Averaged climatic data for Sagana State Lodge meteorological station is shown in Fig.4.1.

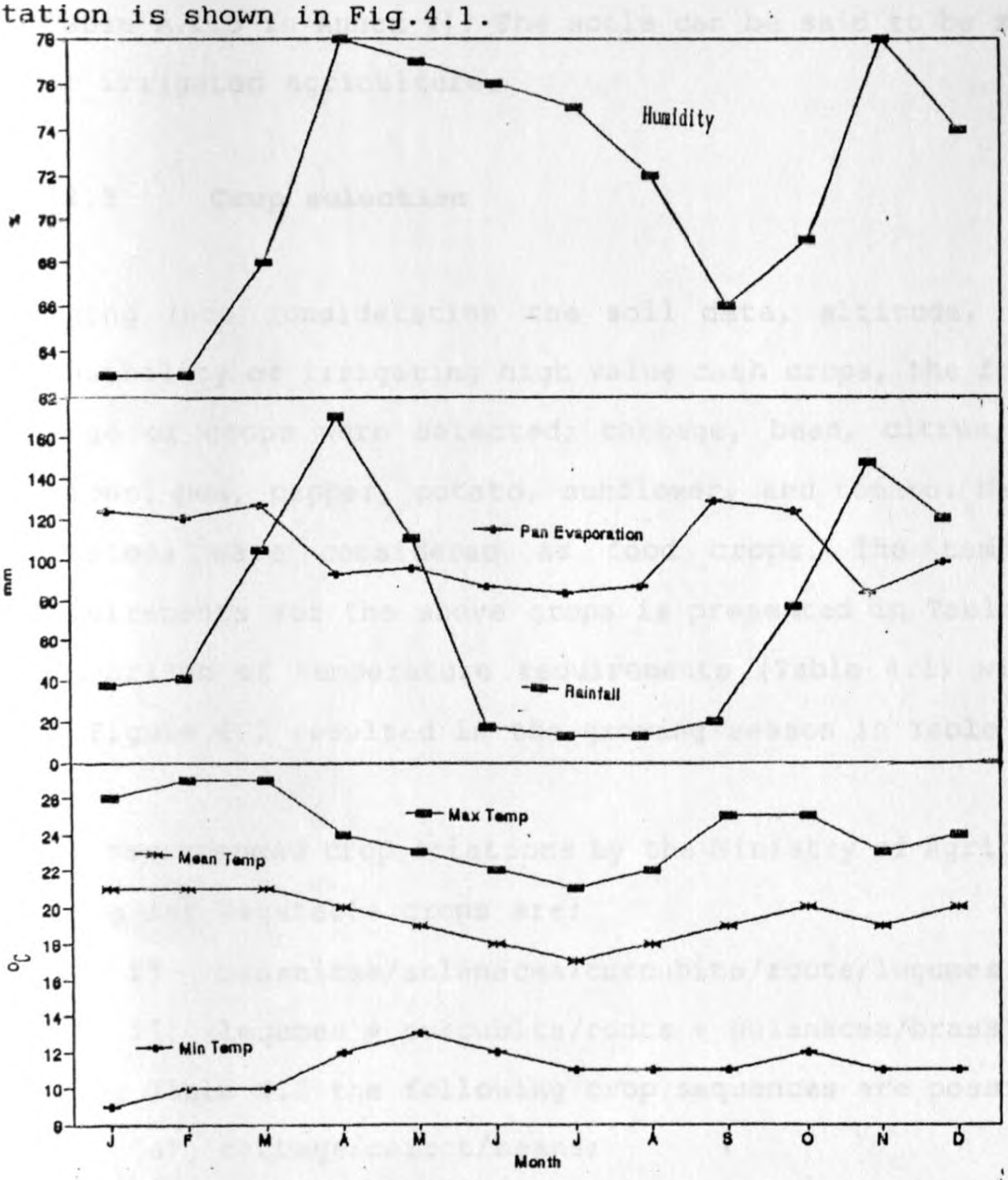


Fig 4.1: Averaged Climatic data for Sagana State Lodge meteorological station(1971 - 1986)

4.1.2 Soil data

A preliminary soil tests report (Logchem, 1990) showed a pH range of 6.2 to 8.6 for soils of Sagana Irrigation Scheme. Texture analysis showed that the soils are clay (Table A.1.4 in Annex 1) with the total available soil water being 96 mm/m (Table A.1.3 in Annex 1). The soils can be said to be suitable for irrigated agriculture.

4.1.3 Crop selection

Taking into consideration the soil data, altitude, and the possibility of irrigating high value cash crops, the following range of crops were selected; cabbage, bean, citrus, maize, onions, pea, pepper, potato, sunflower, and tomato. Maize and potatoes were considered as food crops. The temperature requirements for the above crops is presented in Table 4.1. Comparison of temperature requirements (Table 4.1) with data in Figure 4.1 resulted in the growing season in Table 4.2.

The recommended crop rotations by the Ministry of Agriculture, Kenya for Vegetable crops are:

i) brassicae/solanacea/curcubits/roots/legumes; and

ii) legumes + curcubits/roots + solanacea/brassicae.

Using Table 4.2 the following crop sequences are possible:

(a) cabbage/carrot/beans;

(b) pea/onions/cabbage;

(c) beans/maize/pepper; and

(d) sunflower/potato/fallow.

Table 4.1 : Temperature requirements for selected crops.

Crop	Temp °C (range)	Temp °C (optimum)
Cabbage	10	10-34
Bean	10-34	15-20
Citrus	13-38	23-30
Maize	10-40	24-30
Onion	10-25	15-20
Pea	10-23	17
Pepper		15-27
Potato	10-30	18-20
Sunflower		18-25
Tomato	10-30	18-25
Carrot	5-30	15-20

Source: Doorenbos and Pruit,1977.

Table 4.2: Growing season for selected crops

Crop	Growing season
Cabbage	Jan-Dec
Bean	Jan-Dec
Maize	Jan-Dec
Onion	Apr-Dec
Pea	May-Aug
Pepper	Jan-Dec
Potato	Apr-Dec
Sunflower	Aug-Dec
Tomato	Aug-Dec
Carrot	Jan-Dec

4.1.4 Farmers preferences and responses based on questionnaire

The questionnaire (Annex 2) administered to determine farmers preferences as far as horticultural crops are concerned gave the results shown in Table 4.3.

Table 4.3 Farmers preferences

Crop	% of farmers growing the crop
French beans	73
Cabbages	44
Carrots	30
Capsicum	12
Onion	5

As far as French beans are concerned, 67% of the farmers growing the crop planted during the months of November and December. The sole purpose of growing the crop was marketing. Majority of the farmers (47%) noted January, February, and March as months with peak prices for French beans. Months with water shortages were noted as January, February, March, August, September, and October. This is due to the high demand of irrigation water due to little rainfall.

Most farmers (67%) plant cabbage in the months of October and December. The main purpose of growing this crop is marketing. According to farmers, no well defined month for peak price existed.

The carrot crop is planted during November and December by 69% of the farmers. Marketing is the main purpose of growing the crop and peak prices were between February and August.

Capsicum planting dates were scattered between January and July with peak prices ranging from March to July.

Onions are planted in May and August for the sole purpose of marketing. According to farmers, peak produce prices are realized between July and September.

From the foregoing discussion, it is apparent that horticultural crops are planted at Sagana Irrigation Scheme for the sole purpose of marketing. Apart from French beans, peak prices fluctuate and farmers use their past experiences in timing the market. Though market information is available at the District Agricultural Office it does not reach the farmers. There is a need for proper planning of the cropping patterns so as to ensure high returns to the farmers. Also farmers if given the choice will not irrigate at night due to the inconveniences caused to them.

4.1.5 Tentative Cropping Calendar

Taking into consideration farmers preferences the following cropping calendar were made:

(a) French beans/cabbages/carrots.

(b) Cabbage/onions/capsicums.

(c) French beans/maize/fallow.

(d) Potato/carrot/fallow.

4.1.6 Market prices

Market prices (monthly averages) of horticultural crops in the tentative cropping calendar were plotted and fluctuations noted (Fig 4.2). The export season for french beans is normally from November to March. Months with peak produce prices were noted as shown in Table 4.4

Table 4.4: Months with peak produce prices

Crop	Months with peak prices
Onion	May, Sept
Cabbage	March, April, May
Carrot	Feb, March, April, May
Capsicum	March, Sept
French beans	Jan, Feb, March

4.1.6 Optimal cropping pattern

The tentative cropping pattern was adjusted so that horticultural crops were harvested when prices were highest (Table 4.4), resulting in the final (optimal) cropping pattern (Fig 4.3). The distribution of crops in the cropping pattern is shown in Table 4.5 with the total acreage of 280 (112 ha) not being exceeded at any one time.

Table 4.5: Distribution of crops in optimal cropping pattern

Crop	Ha	Cropped Area%	Planting date	Harvesting date
French beans	56	50	1-15th Nov	Jan-Feb
Capsicum	28	25	15th Nov	15th Mar
Carrots	28	25	1st Dec	28th Feb
Cabbages	28	25	1st Feb	30th April
Onion	28	25	1st Apr	30th Aug
Maize	28	25	Ist Apr	30th Aug
Potato	28	25	15th Apr	30th Aug

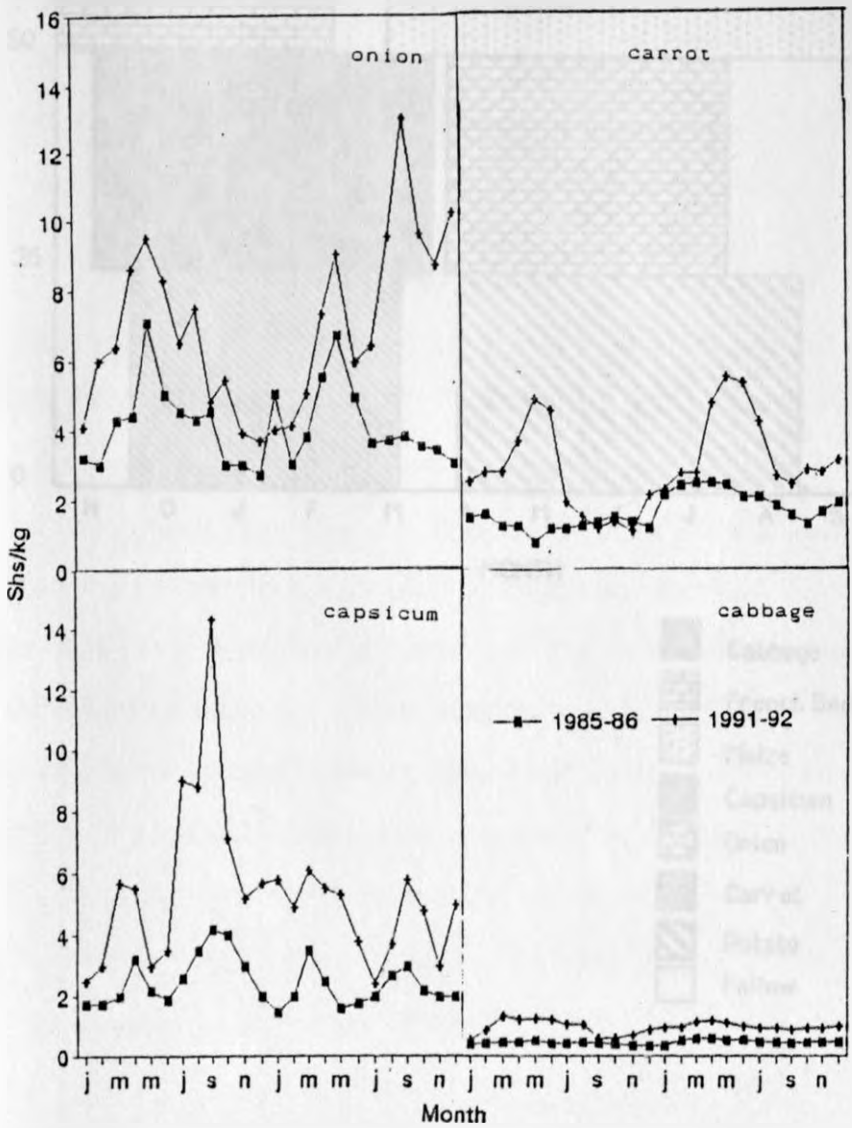


Fig.4.2: Average prices for horticultural crops(Karatina market)
Source (DAO, Nyeri)

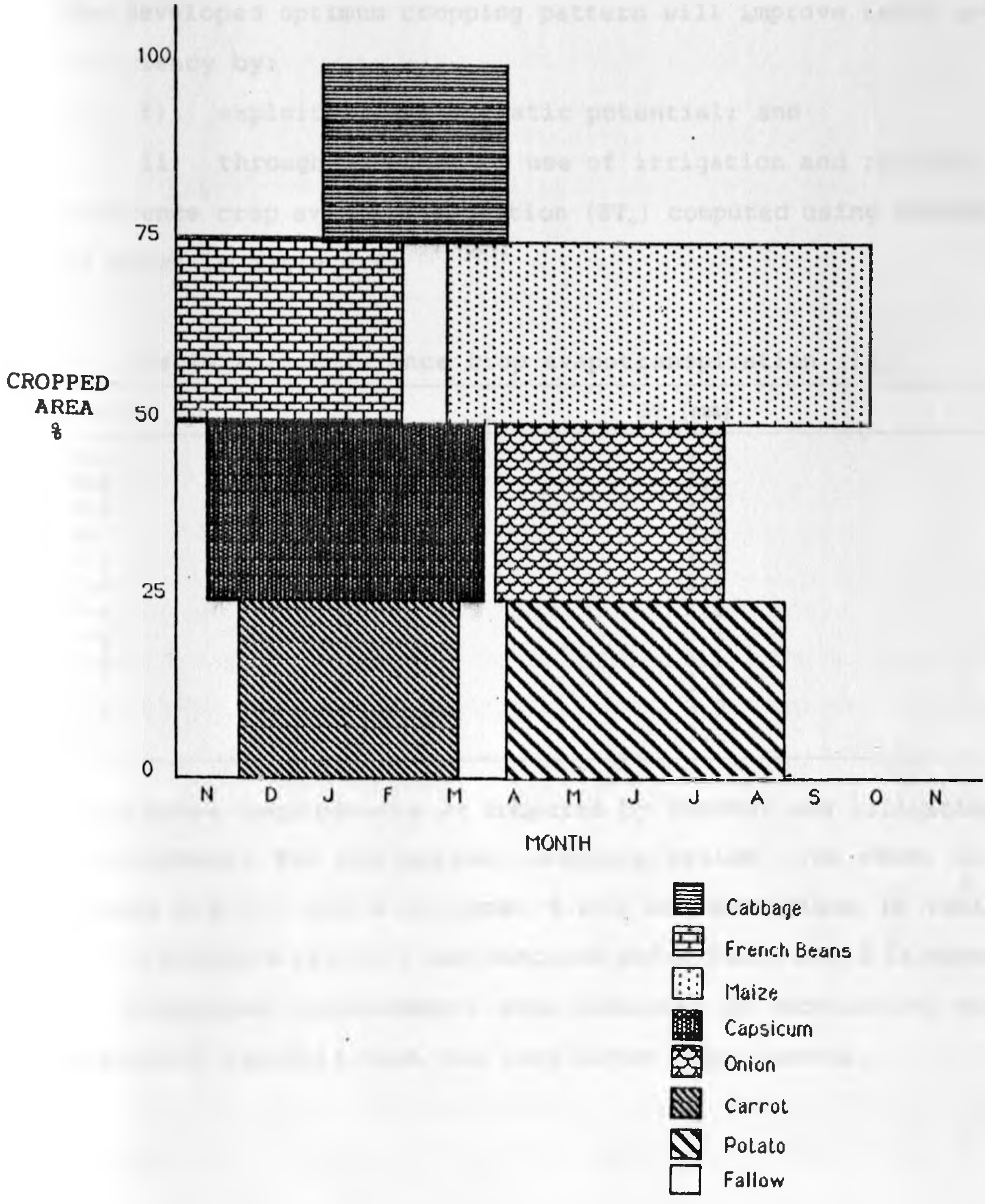


Fig 4.3: Optimal cropping pattern.

The developed optimum cropping pattern will improve water use efficiency by:

i) exploiting the climatic potential; and

ii) through conjunctive use of irrigation and rainfall.

Reference crop evapotranspiration (ET_o) computed using CROPWAT is shown in Table 4.6.

Table 4.6: Reference crop evapotranspiration (ET_o)

Month	ET_o(mm)
Jan	3.6
Feb	3.9
Mar	3.9
Apr	3.3
May	3.3
Jun	3.0
Jul	2.8
Aug	3.1
Sep	3.6
Oct	3.7
Nov	3.2
Dec	3.2

Crop water requirements as computed by CROPWAT and irrigation requirements for the optimal cropping system are shown in Tables A.6.1 - A.6.9 in Annex 6 and are summarised in Table 4.7. Effective rainfall was computed using Table A.5.3 in Annex 5. Irrigation requirements were obtained by subtracting the effective rainfall from the crop water requirements.

Table 4.7: Crop water requirement, effective rainfall and irrigation requirement

Month	Crop water requirements(mm)	Effective rainfall(mm)	Irrigation water requirements(mm)
Jan	114	40	74
Feb	94	34	60
Mar	44	38	6
Apr	60	48	12
May	55	50	5
Jun	70	12	58
Jul	68	11	57
Aug	51	8	43
Sep	0	0	0
Oct	0	0	0
Nov	23	20	3
Dec	78	66	12

To convert the irrigation requirements in Table 4.7 to equivalent discharge, equation 2.8 was used . The irrigation efficiency was taken as 75%. A factor of 0.0009 was introduced to convert m^3/month to l/sec based on the following assumptions:

i) only daytime(12 hours)irrigation is practised; and

ii) farmers irrigate 6 out of every 7 days.

The monthly irrigation requirements in equivalent discharge are shown in Table 4.8 together with the permitted abstraction of 110 l/sec. From the analysis of low flows for river Sagana(Table A.3.1 in Annex 3), a low flow of 320 l/sec is expected, hence the permitted abstraction of 110 l/sec should be available at most times.

Table 4.8: Monthly irrigation requirements and permitted abstraction for Sagana irrigation scheme.

Month	Irrigation requirements(l/sec)	Permitted abstraction(l/sec)
Jan	99	110
Feb	81	110
Mar	4	110
Apr	16	110
May	5	110
Jun	58	110
Jul	57	110
Aug	43	110
Sep	-	110
Oct	-	110
Nov	3	110
Dec	16	110

From Table 4.8, peak irrigation requirements will occur during the months of January and February. Hence there is a need for an irrigation schedule for the optimal cropping system. An irrigation schedule will promote water use efficiency which is one of the objectives of the study. The irrigation schedules for the optimal cropping pattern were developed using the FAO package CROPWAT and are shown in Tables A.11.1-A.11.8 in Annex 11. From the irrigation schedules, the highest gross irrigation depth during the peak irrigation month of January is 62.5mm. It will be difficult to achieve this depth of irrigation with on-demand irrigation due to the low flow rate per farmer(0.39 l/sec). Hence rotational irrigation is recommended for crops under the optimal cropping system.

4.2 RESPONSE OF FRENCH BEANS TO DIFFERENT WATER APPLICATION DEPTHS AND FERTILIZERS RATES

4.2.1 Rainfall and irrigation

The amount of water applied at each irrigation level is shown in Table 4.9.

Table 4.9: Amount of water applied

Date	Rainfall (mm)	Irrigation depth applied (mm) Level 1	Level 2	Level 3	Level 4
3/2	9.4				
8/2	7.4				
12/2	2.2				
14/2	1.4				
19/2	7.6				
24/2	13.0				
1/3	pre-irrigation	20	20	20	20
4/3	"	10	10	10	10
6/3	3.4				
7/3	1.8				
8/3	8				
14/3		14	8.6	5.5	2.3
19/3		10.7	6.6	3.7	1.4
24/3		20.6	14	8.7	4.7
27/3	2.0				
29/3	13				
31/3	3.4				
1/4	1.0				
5/4		19.6	13.8	8.8	4.7
8/4	4.1				
13/4		14.6	9.2	5.8	2.3
15/4	3.2				
20/4	1.0				
22/4		11.6	8.2	5.8	2.7
28/4	1.8				
29/4	6.2				
Total	89.9	121.1	90.4	68.3	48.1
Total water applied		211	180.3	158.2	138

The applied irrigation water forms the irrigation levels while the irrigation levels together with rainfall forms the water levels.

4.2.2 Crop height and crop cover

Crop height increased at all water levels with increased fertilizer rates (Fig.4.4). Crop cover also increased with increasing water levels and fertilizer rates (Fig.4.5).

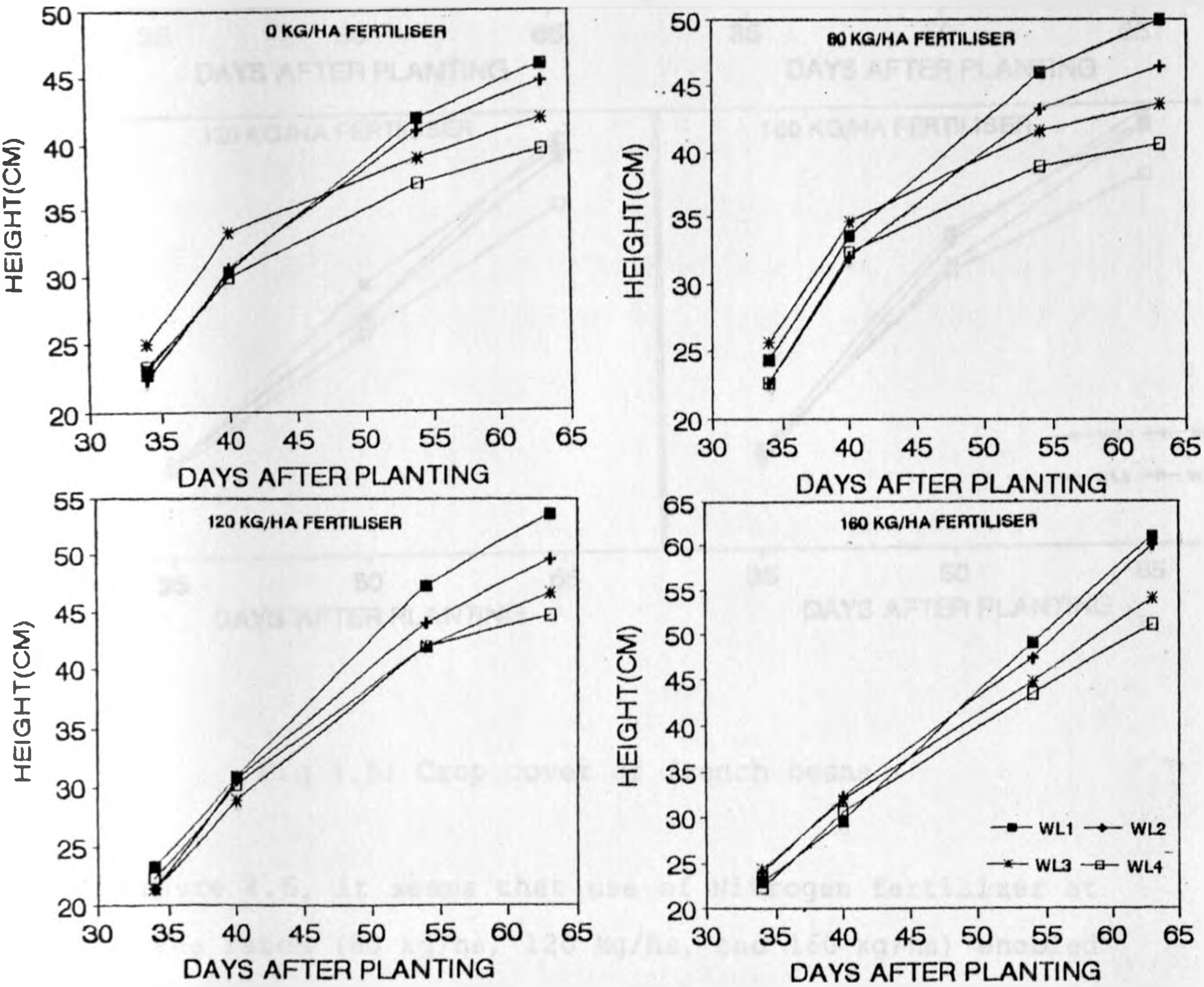


Fig 4.4: Crop height of french beans

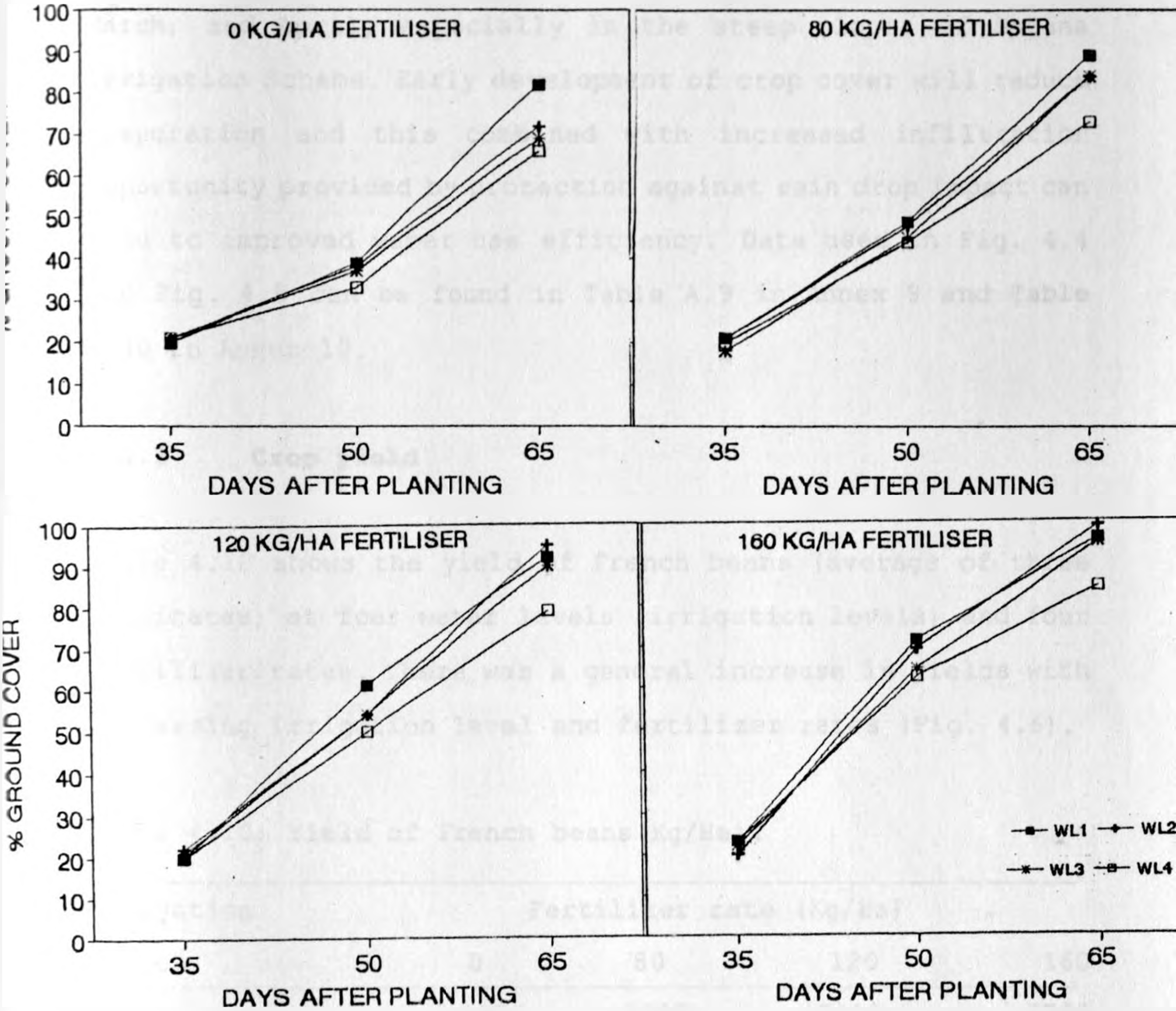


Fig 4.5: Crop cover of french beans

From Figure 4.5, it seems that use of Nitrogen fertilizer at any of the rates (80 kg/ha, 120 kg/ha, and 160 kg/ha) enabled the crop cover to reach and surpass the critical 40% stage by the 50th day. This will be critical for providing protection against erosion by rainfall during the months of December, March, and April, especially in the steep slopes of Sagana Irrigation Scheme. Early development of crop cover will reduce evaporation and this combined with increased infiltration opportunity provided by protection against rain drop impact can lead to improved water use efficiency. Data used in Fig. 4.4 and Fig. 4.5 can be found in Table A.9 in Annex 9 and Table A.10 in Annex 10.

4.2.3 Crop yield

Table 4.10 shows the yield of French beans (average of three replicates) at four water levels (irrigation levels) and four fertilizer rates. There was a general increase in yields with increasing irrigation level and fertilizer rates (Fig. 4.6).

Table 4.10: Yield of French beans(Kg/Ha).

Irrigation	Fertilizer rate (Kg/Ha)			
level	0	80	120	160
1	5175	5325	5625	5775
2	4800	5175	5267	5400
3	4575	5025	5025	5175
4	3900	4200	4500	4650

Analysis of variance for a split-plot design (Table 4.11) showed no significant interaction between water level and fertilizer at the 5% level. This implies that water levels and fertilizer rates used in the experiment did not have significant effects in combination. This could be attributed to the amount of rainfall during the study period and/or adequate organic matter in the soils.

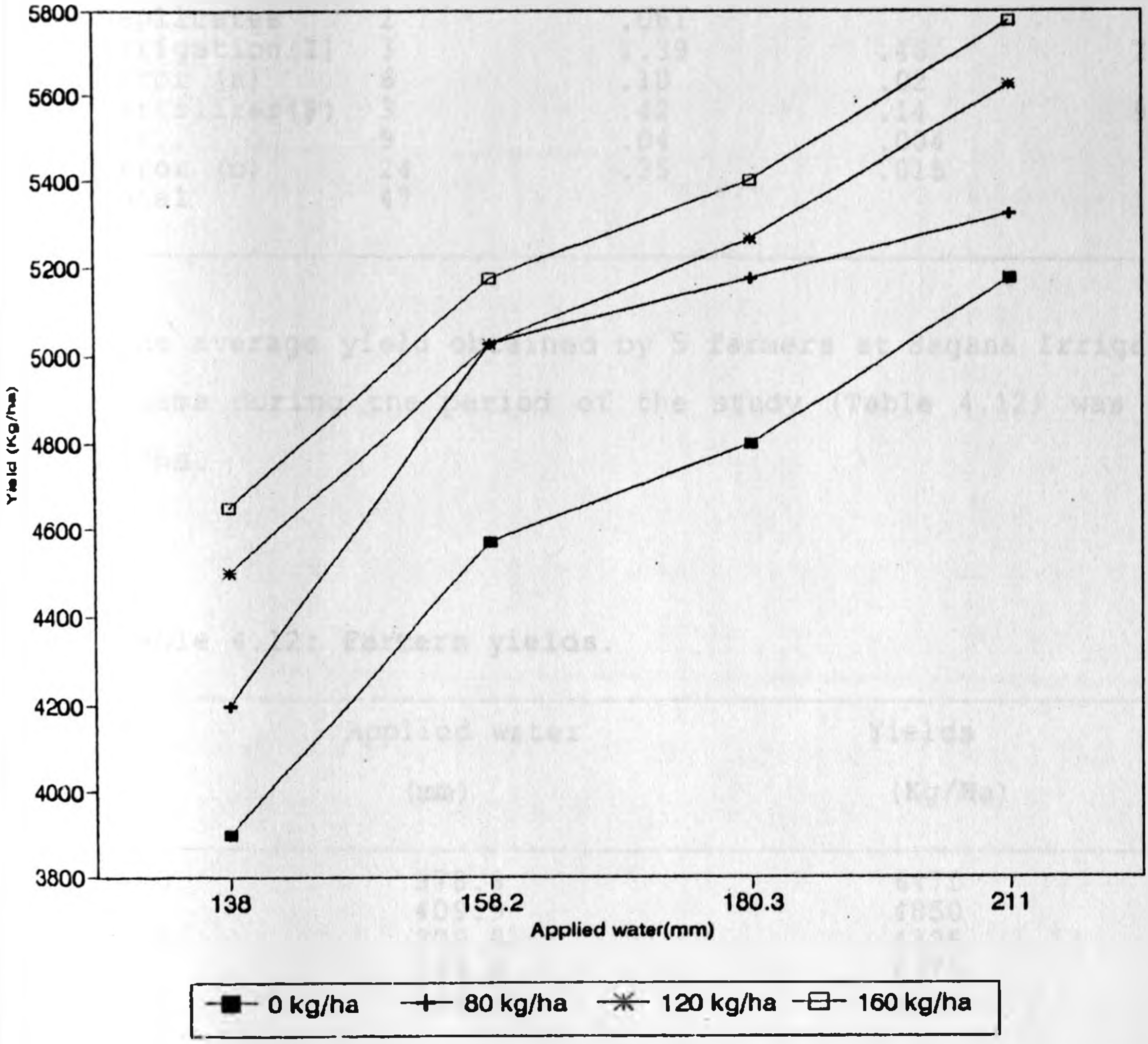


Fig 4.6: Crop yield at different water levels and fertilizer rates.

Table 4.11: Analysis of variance for crop yields.

Source	Degrees of freedom	Sum of squares	Mean square	F
Replicates	2	.061		
Irrigation(I)	3	1.39	.46	23
Error (a)	6	.10	.02	
Fertilizer(F)	3	.42	.14	9.31
I*F	9	.04	.004	.27
Error (b)	24	.35	.015	
Total	47			

The average yield obtained by 5 farmers at Sagana Irrigation Scheme during the period of the study (Table 4.12) was 4865 Kg/ha.

Table 4.12: Farmers yields.

Plot No	Applied water (mm)	Yields (Kg/Ha)
143	378.9	6475
1	409.9	4850
385	329.9	4325
72	349.9	4375
94	389.9	4300

Though the level of production of French beans at Sagana Irrigation Scheme seems satisfactory compared to national figures, the applied water seem excessive. This could be due to lack of appropriate knowledge on water management.

4.2.4 Soil moisture content

Changes in soil moisture content at planting time and harvesting time are shown in Table 4.13. This data is utilised in computing the seasonal evapotranspiration.

Table 4.13: Changes in soil moisture storage

Depth (cm)	Moisture content (mm) 1/2/93	Moisture content(mm) 30/4/93	Change in soil moisture (mm)
0 - 15	63	56.6	6.4
15 - 30	58.8	51	7.8
30 - 45	63.5	61.2	2.3
90 - 105	36.4	37.3	0.9

Over the rooting depth (0 - 30 cm) the change in soil moisture over the growing season was 14.2 mm. At depths of 90 - 105 cm the change in moisture content remained nearly constant. For individual rainstorm and irrigation events, using the soil water balance sheet (Table A.7 in Annex 7) and assuming that there was no water lost to deep drainage due to irrigation at the other water levels, the amount of water lost to deep drainage was 45.3 mm at water level 1, while at other water levels deep drainage due to rainfall was 25.8 mm.

4.2.5 Yield response to water and fertilizer

Crop evapotranspiration (ET_c) was estimated according to equation 3.4. The results are shown in Table 4.14.
The maximum estimated evapotranspiration at water level 1 was 179.9 mm, almost the same as that in the soil water balance sheet (Table A.7 in Annex 7) of 172.5 mm.

Table 4.14: Crop evapotranspiration

Water level	Irrigation (mm)	Rainfall (mm)	Deep drainage (mm)	Change in soil moisture (mm)	ET_c (mm)
1	121.1	89.9	45.3	14.2	179.9
2	90.4	89.9	25.8	14.2	168.7
3	68.3	89.9	25.8	14.2	146.6
4	48.1	89.9	25.8	14.2	126.4

Using data in Table A.8.2 (Annex 8), at each fertiliser level the highest yield was taken as Y_m and the highest evapotranspiration level taken as ET_m. The relationship between actual evapotranspiration and potential evapotranspiration (ET_a/ET_m) and actual yield versus maximum yield (Y_a/Y_m) was then computed and found to be linear as below:

i) at 160 kg/ha; $R^2 = 0.82$;

ii) at 180 kg/ha; $R^2 = 0.89$;

iii) at 80 kg/ha; $R^2 = 0.71$; and

iv) at no fertilizer; $R^2 = 0.56$.

This justified the calculation of the yield response factor (K_y). To compute the yield response factor in equation 2.4, the value of ET_{max} and Ymax for water level 1 were used as references(179.9 mm of 5775 kg/ha). Crop evapotranspiration (ET_c) values from Table 4.13 and yield values from Table 4.10, were used in computed K_y values as shown in Table 4.15.

Table 4.15: Computed yield response (K_y) values.

Water	Fertilizer rate (Kg/Ha)			
level	0	80	120	160
2	2.70	1.67	1.41	1.04
3	1.12	0.70	0.70	0.56
4	1.09	0.91	0.74	0.65

There was variation in K_y values as seen from Table 4.15 with the average being 1.1, which nears those reported by Doorenbos and Kassam (1979) of 1.0 - 1.15. The wide scatter in K_y values can be attributed to the complex interaction of plant, soil, water, and fertilizer relationships. The point at which extra inputs of water and fertilizer causes a decline in yields was not reached in this experiment.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions were drawn from this study:

1. Adoption of the designed optimal cropping system can improve water use efficiency at Sagana Irrigation Scheme by exploiting the climatic potential and through conjunctive use of irrigation and rainfall.
2. Irrigation water requirements for the optimal cropping system computed using the FAO package CROPWAT had a peak cropwater requirement of 114 mm during the month of January. To minimize the risk of crop stress and increase water use efficiency an irrigation schedule for crops in the optimal cropping system was developed using the FAO package CROPWAT.
3. In assessing the yield response of French beans, an average yield response factor (K_y) of 1.1 was determined.
4. Increasing amounts of Nitrogen fertilizer at the same water level had a positive effect on the yields of French beans, hence increasing water use efficiency. Nitrogen fertilizer enhanced early development of crop cover which can lead to improved infiltration and reduced evaporation further increasing water use efficiency.
5. The maximum seasonal evapotranspiration for French beans was 179.9 mm.

6. The point at which water becomes limiting and fertilizer applications do not increase yields of French beans was not reached in this experiment.

5.2 RECOMMENDATIONS

To be able to further improve irrigation water use the following recommendations were made:

1. Rotational irrigation as opposed to on-demand irrigation should be adopted for the optimal cropping system.
2. The current field application efficiency at Sagana Irrigation Scheme should be determined.
3.. The water delivery performance of the new irrigation system should be monitored regularly so as to be able to adjust the design flows and pressures to cater for changing cropping systems.
4. Further experiments involving yield response to fertilizer for other irrigated crops should be conducted at Sagana Irrigation Scheme.

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ANNEXES

Annex 1: Soil data

Table A.1.1 Soil test report for Sagana Irrigation Scheme

Field Designation	Plot 162	Plot 156	Plot 175	Plot 103	Plot 120	Plot 23	Plot 80	Plot 52
Lab. No./90	2527	2528	2529	2531	2531	2532	2533	2534
Depth .. CM..	10-20	25-35	10-20	10-20	10-17	20-30	10-20	20-30
Ph	8.6	6.8	6.2	6.2	6.2	6.3	6.5	6.9
Na m.e %	0.43	0.28	0.50	0.60	0.40	0.36	1.10	1.64
K.m.e %	0.64	0.18	0.98	1.04	0.78	0.44	3.20	4.90
Ca m.e %	24.5	8.6	17.0	17.9	20.0	8.8	51.0	8.6
Mg m.e %	2.8	1.7	3.0	3.8	3.0	2.6	6.1	3.0
Mn m.e %	1.25	0.90	0.58	1.20	0.88	0.66	1.22	0.72
C%	2.79	0.66	2.48	3.17	4.28	1.24	5.19	0.27
E.C.mmhos/cm	0.4							

source(Logchem, 1990)

Table A.1.2 Field capacity, permanent wilting point and bulk density.

Replicate	Depth (cm)	% W			B.D (gm/cm³)
		0.001 bar	0.2 bar	15 bar	
I	0 - 15	55	39.5	29.8	0.94
II	0 -15	46.8	37.5	26.9	1.0
III	0 -15	46.2	38.0	28.5	0.99
I	15 - 30	53	39	29.6	0.96
II	15 - 30	54	38.0	30	1.03
III	15 - 30	55.3	39	28.9	1.01
I	30 - 45	63	39	31	0.89
II	30 -45	41.7	38	28.5	1.05
III	30 - 45	45.3	39	28.5	1.02
I	45 - 60	49.5	39.8	27.9	0.97
II	45 - 60	53.4	38.0	27	0.94
III	45 - 60	50	37.5	29	1.01

Table A.1.3: Total available soil moisture

Depth (cm)	Available moisture(volume%)
0-15	9.7
15-30	9.3
30-45	9.2
45-50	10

Table A.1.4: Texture analysis

Depth (cm)	% sand	% silt	% clay	Texture grade
0-15	18	26	56	clay
0-15	16	26	58	clay
15-30	16	18	66	clay
15-30	16	18	66	clay
30-45	14	26	60	clay
30-45	16	18	66	clay
45-60	15	22	63	clay
45-60	16	22	62	clay

Annex 2: Questionnaire and list of farmers

Questionnaire

Name of farmer..Plot No...
Village..
Crop..
Variety..

	season 1	Season 2
Planting date		
Date of first irrigation		
Harvesting period		

1. Purpose of growing crop

   (a) Subsistence
   (b) Marketing
   (c) Subsistence and marketing
   (d) Others(specify)..

2. (a) During which months do you get the highest prices for the crop?
   ....

   (b) Do you plant according to these prices?
   No Yes

   (c) If Yes (explain how)..

3. (a) During which months are pests and disease incidence highest:
   ....
   ....

   (b) How does this influence your planting date?

   ....

4. (a) In which months do you experience labour shortage most?

   ....

   (b) How do you solve the problem of labour shortage?
   ....

5. (a) During which months do you experience severe water shortages?
   ....

   (b) How do you solve the problem of water shortage?
   (i) Night irrigation
   (ii) Under irrigating the crop
   (iii) Irrigate water sensitive crops first
   (iv) Irrigate only crops with very high economic value
   (v) Others (specify)
   ....

6. Indicate below crops previously grown on this piece of land and crops you intend to grow next.

Past season		Future season	
Crop	Season	Crop	Season
1.			
2.			
3.			

7. During which months do you experience severe capital constraints?

....

8. What yields did you get last season from the crop?

Season.......................................Yield...

9. How much did you (or do intend to) invest in the current crop?

Cash...Kshs.

Labour(hired)...Kshs

Labour(self)...Mondays

Table A.2.1 List of farmers

Name of farmer	Member No.	Village	Farm size	Irrigated plot
Gatua Nguri	228	Kamuya	6 acres	1/4 acre
Mambo Mwaniki	54	Kamuya	"	3/8 acre
Samuel Kariuki	251	Inono	"	1/8 acre
Gichohi Karere	123	Karia	"	3/8 acre
Mwaniki Kagwe	168	Wamwaki	"	1/4 acre
Charles K. Githae	160	Wamunyoro	"	1/8 acre
Ithiru Nguru	185	Wamunyoro	"	1/4 acre
Mishek Murage	223	Kamuya	"	3/8 acre
John Gichuki	43	Karia	"	1/2 acre
Erastus Mwai	23	Mutaga	"	1/4 acre
Kareithi	46	Wamwaki	"	3/8 acre
Amos Mwangi	79	Mutaga	"	1/8 acre
Kamango Kariuki	55	Wamunyoro	"	1/4 acre
Lydia Gathoni Ngechu	18	Inono	"	1/4 acre
Kinyua Kiambati	234	Wamwaki	"	1/4 acre
Gathara Munyiri	92	Wamunyoro	"	1/4 acre
Joel Kabugwa	28	Mutaga	"	1/4 acre
Muchiri Kinaichu	58	Iganjo	"	1/4 acre
Moses Gichohi	232	Kahiti	"	1/2 acre
John Ndegwa	81	Wamwaki	"	1/2 acre
Warui Kamiri	86	Miteroini	"	1/2 acre
Martha Gachagua	19	Wamunyoro	"	1 acre
Gathiga Chege	50	Inono	"	1/4 acre
Mwaniki Njeraini	33	Karia	"	1/2 acre
Mathenge Kanyi	131	Wamwaki	"	1/2 acre
John Macharia	39	Inono	"	1/8 acre
Michael Kabia	6	Inono	"	1/4 acre
Theuri	249	Wamunyoro	"	1/4 acre
Muthami Kagoca	83	Miteroini	"	3/8 acre
Kagiri Kanyoro	4	Iganjo	"	1/2 acre
Karapa Gichuru	88	Inono	"	1/4 acre
Joseph Maina Kariuki	146	Karia	"	1/4 acre
Christopher Kariuki Gatundu	186	Karia	"	1/2 acre
Kareithi	78	Wamwaki	"	1/4 acre
Gathogo Githendia	167	Kamuya	"	1/4 acre
Wairimu Gathumbi	63	Wamunyoro	"	1/2 acre
Muriuki Kabia	44	Inono	"	1/4 acre
Wangereria Muya	102	Kahiti	"	1/2 acre
Ndegwa Githungo	29	Miteroini	"	3/8 acre
Francis Ngatia	44	Inono	"	1/2 acre
Kabiru Ndua	24	Kahiti	"	1/4 acre

Table A.2.2: Crops grown by interviewed farmers

Crop	No of farmers growing crop
French beans	30
Cabbage	18
Carrots	12
Capsicum	5
Onion	2
Maize	40
Potato	8

Annex 3: River flow data

Table A.3.1 Analysis of low flows for River Sagana(RGS 4AA01)

Rank	Year	Flow (L/sec)	Plotting position (R/n+1)	%
1	1948	230	0.036	3.6
2	1949	249	0.071	7.1
3	1960	273	0.107	10.7
4	1971	289	0.143	14.3
5	1974	290	0.179	17.9
6	1953	301	0.214	21.4
7	1954	308	0.25	25
8	1952	312	0.286	28.6
9	1968	314	0.321	32.1
10	1976	316	0.357	35.7
11	1975	320	0.393	39.3
12	1958	337	0.429	42.9
13	1965	355	0.464	46.4
14	1963	364	0.5	50
15	1969	367	0.536	53.6
16	1950	369	0.571	57.1
17	1961	371	0.607	60.7
18	1951	376	0.643	64.3
19	1955	392	0.679	67.9
20	1967	397	0.714	71.4
21	1957	421	0.75	75
22	1956	442	0.786	78.6
23	1962	500	0.821	82.1
24	1959	503	0.857	85.7
25	1970	528	0.893	89.3
26	1966	538	0.923	92.3
27	1964	551	0.964	96.4

Table A.3.2 Monthly low flows for river Sagana (Litres/sec)

Rank	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	349	230	249	114	995	476	347	273	314	605	724	600
2	375	264	289	1146	1267	559	392	312	337	650	726	611
3	385	277	290	1156	1291	597	396	355	367	655	805	618
4	394	301	299	1158	1356	610	442	367	365	660	840	637
5	412	308	316	1162	1456	701	546	438	376	731	938	660
6	426	320	341	1176	1546	706	524	459	384	738	1022	692
7	427	340	398	1345	1724	727	527	475	421	752	1044	778
8	431	369	455	1407	1775	750	538	490	430	764	1107	793
9	438	371	485	1500	1781	776	590	500	451	795	1133	796
10	440	391	557	1554	1785	783	605	503	488	821	1148	805
11	442	397	565	1563	1798	845	618	507	521	899	1163	807
12	449	424	575	1566	1869	848	635	545	522	904	1294	866
13	480	530	576	1583	1891	972	665	562	528	976	1413	895
14	540	532	587	1528	1996	1004	699	563	540	1036	1429	927
15	607	537	605	1616	1997	1013	713	569	551	1056	1458	972
16	639	589	686	1720	2061	1031	745	579	561	1094	1484	1143
17	644	636	906	1893	2114	1147	749	583	580	1107	1540	1190
18	723	729	917	2079	2131	1169	752	654	623	1129	1571	1230
19	903	743	1048	2350	2154	1173	801	667	701	1191	1579	1222
20	912	746	1077	2158	2422	1222	848	679	738	1348	1594	1340
21	951	768	1136	2716	2453	1242	911	686	790	1414	1686	1424
22	954	775	1159	2815	2547	1245	969	713	791	1683	1708	1452
23	1088	957	1202	2828	2700	1350	976	741	864	1243	1745	1516
24	1148	969	1303	2895	2709	1355	1002	784	877	1486	1771	1846
25	1218	990	1682	3274	2786	1448	1143	806	907	1442	1812	1944
26	1259	1142	1880	3314	2855	1480	1209	819	912	3885	2469	2808
27	2055	1476	1890	4197	3504	1632	1217	1045	1126	5562	2770	5558

Annex 4: Crop market prices (for horticultural produce, Karatina Market)

Table A.4.1 Average monthly prices for onions

Year	Price	J	F	M	A	M	J	J	A	S	O	N	D
1985	Kshs/	3	3	4.3	4.4	7.1	5	4.5	4.3	4.5	3	3	2.7
1986	kg	2.5	3	3.8	5.5	6.7	4.9	3.6	3.7	3.8	3.5	3.4	3
1990	.	5	5	4.3	4.5	7.1	7.1	8.0	11.0	12.0	11.6	9.0	8.0
1991	.	6.2	6	6.4	8.6	9.5	8.3	6.5	7.5	4.8	5.4	3.9	3.7
1992		4.1	4.1	5	7.3	9	5.9	6.4	9.5	13	9.6	8.7	10.2

Table A.4.2 Average monthly prices for Capsicums

Year	Price	J	F	M	A	M	J	J	A	S	O	N	D
1985	Kshs/kg	1.76	1.76	2	3.2	2.2	1.9	2.6	3.5	4.2	4	3	2
1986	.	1.5	2	3.5	2.5	1.6	1.8	2	2.7	3	2.2	2	2
1990	.	3.6	3.6	4	5	3.5	4.6	5	5.4	5	4.8	3.6	3.6
1991	.	2.5	3	5.7	5.5	3	3.5	9	8.8	14.3	7.1	5.2	5.7
1992	.	5.8	4.9	6.1	5.5	5.3	3.8	2.4	3.7	5.8	4.8	3	5

Table A.4.3 Average monthly prices for Cabbages

Year	Price	J	F	M	A	M	J	J	A	S	O	N	D
1985	Shs/kg	0.38	0.4	0.46	0.46	0.5	0.42	0.40	0.46	0.42	0.38	0.3	0.33
1986	.	0.33	0.5	0.56	0.58	0.5	0.54	0.43	0.43	0.42	0.46	0.5	0.46
1990	.	0.5	1.0	0.92	0.92	1.17	0.96	0.63	0.63	0.63	0.53	0.4	0.33
1991	.	0.54	0.83	1.36	1.23	1.28	1.25	1.06	1.06	0.58	0.6	0.7	0.87
1992	.	0.96	0.98	1.19	1.2	1.13	1.01	0.94	0.94	0.88	0.95	0.9	1.0

Table A.4.4 Average monthly prices for Carrots

Year	Price	J	F	M	A	M	J	J	A	S	O	N	D
1985	Shs/kg	1.8	1.9	1.5	1.5	0.9	1.4	1.4	1.5	1.6	1.8	1.6	1.4
1986	.	2.5	2.8	2.9	2.9	2.8	2.4	2.4	2.1	1.8	1.5	1.9	2.2
1990	.	1.7	2.4	2.3	2.3	2.7	2.5	2.6	2.6	3.0	2.5	2.7	2.5
1991	.	3.0	3.3	3.3	4.3	5.7	5.3	2.3	1.8	1.4	1.6	1.3	2.5
1992	.	2.7	3.2	3.2	5.5	6.4	6.2	4.9	3.1	2.8	3.3	3.2	3.6

Source (DAO, Nyeri)

Annex 5: Climatic Data for Sagana Meteorological Station

Table A.5.1 Monthly Temperature, Humidity, sunshine hours, and windrun for the years 1971 - 1986.

Month	Max Temp °C	Min Temp °C	Humidity %	Sunshine hours	Wind speed Km/day
Jan 71-80	25	8.8	64	7.6	54
Feb "	26.2	9	62	8.2	65
Mar "	26.3	9.8	64	7.5	68
Apr "	24.2	12.3	74	6.1	68
May "	22.8	13.1	74	7.1	84
Jun "	21.8	11.8	73	5.5	84
Jun "	21.1	11.4	75	3.2	90
Aug "	21.7	11.3	71	4.4	94
Sep "	24.2	11.5	64	6.0	107
Oct "	24.9	12	65	7.2	105
Nov "	23.4	11.2	72	6.6	106
Dec "	24.3	9.3	69	7.6	49
Jan 81-	26.3	8.9	66	7.1	52
86	27.7	9.6	64	7.3	55
Feb "	27.1	9.8	69	6.8	64
Mar "	24.2	12.8	79	5.3	57
Apr "	23.2	13.2	78	6.1	68
May "	22.1	11.6	77	6.1	70
Jun "	21.1	11.3	76	5.3	73
Jul "	22.4	11.2	73	5.3	83
Aug "	24.3	11.5	67	5.9	92
Sep "	24.6	11.6	69	5.8	78
Oct "	23.2	11	79	4.8	41
Nov "	24.3	10.7	76	5.4	39
Dec "					

Source (MoTC, Nairobi)

Table A.5.2 : Rainfall and Pan Evaporation data for Sagana Meteorological Station(1971-1986)

Month	Rainfall(mm)	Evap(mm)
Jan	55	123
Feb	8	119
Mar	8	134
Apr	142	102
May	120	111
Jun	17	99
Jul	17	94
Aug	12	109
Sep	34	139
Oct	93	128
Nov	139	100
Dec	106	109

Table A.5.3 Average monthly effective rainfall as related to average monthly ETcrop and mean monthly rainfall.

Monthly mean rainfall mm		12.5	25	37.5	50	62.5	75	87.5	100	112.5	125	137.5	150	162.5	175	187.5	200
		Average monthly effective rainfall in mm															
	25	8	16	24													
Average	50	8	17	25	32	39	46										
monthly	75	9	18	27	34	41	48	56	62	69							
ETcrop	100	9	19	28	35	43	52	59	66	73	80	87	94	100			
mm	125	10	20	30	37	46	54	62	70	76	85	92	98	107	116	120	
	150	10	21	31	39	49	57	66	74	81	89	97	104	112	119	127	133
	175	11	23	32	42	52	61	69	78	86	95	103	111	118	126	134	141
	200	11	24	33	44	54	64	73	82	91	100	109	117	125	134	142	150
	225	12	25	35	47	57	68	78	87	96	106	115	124	132	141	150	159

Source: Doorenbos and pruit, 1977.

Annex 6: Cropwater requirements computed using CROPWAT

Table A.6.1 : Cropwater requirements and effective rainfall

Climate file : Climate Station : Sagana

	ETcrop (mm/month)	Rainfall (mm/month)	Eff. Rain (mm/month)
January	114	55	40
February	94	48	34
March	44	68	38
April	60	142	48
May	55	120	50
June	70	17	12
July	68	17	11
August	51	12	8
September	-	34	-
October	-	93	-
November	23	139	20
December	78	106	66
YEAR Total	657	851	mm

Table: A.6.2 Cropwater requirements for Frenchbeans

Crop Evapotranspiration

Climate File : saga4 Climate Station: Sagana
Crop : BEANS Planting date : 1 November

Month	Dec	Stage	Coeff Kc	ETcrop mm/day	ETcrop mm/dec
Nov	1	init	0.35	1.18	11.8
Nov	2	init	0.35	1.12	11.2
Nov	3	deve	0.48	1.55	15.5
Dec	1	deve	0.75	2.40	24.0
Dec	2	deve	1.02	3.25	32.5
Dec	3	mid	1.15	3.83	38.3
Jan	1	mid	1.15	3.99	39.9
Jan	2	mid	1.15	4.14	41.4
Jan	3	late	0.92	3.42	34.2
TOTAL					248.8

Table: A.6.3 Cropwater requirements for Frenchbeans

Crop Evapotranspiration

Climate File : saga4 — Climate Station: Sagana
Crop : BEANS — Planting date : 15 November

Month	Dec	Stage	Coeff Kc	ETcrop mm/day	ETcrop mm/dec
Nov	2	init	0.35	1.12	5.6
Nov	3	init	0.35	1.12	11.2
Dec	1	in/de	0.42	1.33	13.3
Dec	2	deve	0.62	1.97	19.7
Dec	3	deve	0.88	2.94	29.4
Jan	1	de/mi	1.08	3.76	37.6
Jan	2	mid	1.15	4.14	41.4
Jan	3	mid	1.15	4.25	42.5
Feb	1	mi/lt	1.04	3.94	39.4
Feb	2	late	0.70	2.73	13.7
TOTAL					253.9

Table: A.6.4 Cropwater requirements for Capsicum

Crop Evapotranspiration

Climate File : saga4 — Climate Station: Sagana
Crop : Capsicum — Planting date : 15 November

Month	Dec	Stage	Coeff Kc	ETcrop mm/day	ETcrop mm/dec
Nov	2	init	0.75	2.40	12.0
Nov	3	init	0.75	2.40	24.0
Dec	1	init	0.75	2.40	24.0
Dec	2	in/de	0.77	2.46	24.6
Dec	3	deve	0.82	2.74	27.4
Jan	1	deve	0.89	3.10	31.0
Jan	2	deve	0.96	3.47	34.7
Jan	3	mid	1.00	3.70	37.0
Feb	1	mid	1.00	3.80	38.0
Feb	2	mid	1.00	3.90	39.0
Feb	3	mid	1.00	3.90	39.0
Mar	1	late	0.96	3.75	37.5
Mar	2	late	0.89	3.46	34.6
TOTAL					402.8

Table: A.6.5 Cropwater requirements for Carrots

Crop Evapotranspiration					
Climate File : saga4			Climate Station: Sagana		
Crop : Carrots			Planting date : 1 December		
Month	Dec	Stage	Coeff Kc	ETcrop mm/day	ETcrop mm/dec
Dec	1	init	0.75	2.40	24.0
Dec	2	in/de	0.78	2.51	25.1
Dec	3	deve	0.89	2.97	29.7
Jan	1	deve	1.03	3.57	35.7
Jan	2	mid	1.10	3.96	39.6
Jan	3	mid	1.10	4.07	40.7
Feb	1	mid	1.10	4.18	41.8
Feb	2	mi/lt	1.08	4.19	41.9
Feb	3	late	1.00	3.90	39.0
TOTAL					317.5

Table: A.6.6 Cropwater requirements for Cabbage

Crop Evapotranspiration					
Climate File : saga4			Climate Station: Sagana		
Crop : CABBAGE			Planting date : 1 February		
Month	Dec	Stage	Coeff Kc	ETcrop mm/day	ETcrop mm/dec
Feb	1	init	0.70	2.66	26.6
Feb	2	init	0.70	2.73	27.3
Feb	3	deve	0.74	2.90	29.0
Mar	1	deve	0.83	3.23	32.3
Mar	2	deve	0.91	3.57	35.7
Mar	3	de/mi	0.98	3.62	36.2
Apr	1	mid	1.00	3.50	35.0
Apr	2	mid	1.00	3.30	33.0
Apr	3	late	0.93	3.05	30.5
TOTAL					285.6

Table: A.6.7 Cropwater requirements for Onion

Crop Evapotranspiration

Climate File : saga4 Climate Station: Sagana
Crop : ONION(dry) Planting date : 1 April

Month	Dec	Stage	Coeff Kc	ETcrop mm/day	ETcrop mm/dec
Apr	1	init	0.70	2.45	24.5
Apr	2	init	0.70	2.31	23.1
Apr	3	init	0.70	2.31	23.1
May	1	deve	0.73	2.41	24.1
May	2	deve	0.79	2.62	26.2
May	3	deve	0.86	2.74	27.4
Jun	1	deve	0.92	2.85	28.5
Jun	2	mid	0.95	2.85	28.5
Jun	3	mid	0.95	2.79	27.9
Jul	1	mid	0.95	2.72	27.2
Jul	2	mid	0.95	2.66	26.6
Jul	3	mid	0.95	2.76	27.6
Aug	1	late	0.92	2.75	27.5
Aug	2	late	0.85	2.64	26.4
Aug	3	late	0.78	2.56	25.6
TOTAL					394.1

Table: A.6.8 Cropwater requirements for Maize

Crop Evapotranspiration

Climate File : saga4 Climate Station: Sagana
Crop : MAIZE Planting date : 1 April

Month	Dec	Stage	Coeff Kc	ETcrop mm/day	ETcrop mm/dec
Apr	1	init	0.40	1.40	14.0
Apr	2	init	0.40	1.32	13.2
Apr	3	in/de	0.45	1.47	14.7
May	1	deve	0.58	1.92	19.2
May	2	deve	0.77	2.52	25.2
May	3	deve	0.95	3.03	30.3
Jun	1	de/mi	1.08	3.36	33.6
Jun	2	mid	1.13	3.39	33.9
Jun	3	mid	1.13	3.31	33.1
Jul	1	mid	1.13	3.24	32.4
Jul	2	mid	1.13	3.16	31.6
Jul	3	late	1.09	3.16	31.6
Aug	1	late	1.01	3.01	30.1
Aug	2	late	0.92	2.86	28.6
TOTAL					371.7

Table: A.6.9 Cropwater requirements for Potato

Crop Evapotranspiration

Climate File : saga4					Climate Station: Sagana
Crop : POTATO					Planting date : 15 April

Month	Dec	Stage	Coeff Kc	ETcrop mm/day	ETcrop mm/dec
Apr	2	init	0.55	1.82	9.1
Apr	3	init	0.55	1.82	18.2
May	1	init	0.55	1.82	18.2
May	2	deve	0.64	2.12	21.2
May	3	deve	0.83	2.64	26.4
Jun	1	deve	1.01	3.13	31.3
Jun	2	mid	1.10	3.30	33.0
Jun	3	mid	1.10	3.23	32.3
Jul	1	mid	1.10	3.15	31.5
Jul	2	mid	1.10	3.08	30.8
Jul	3	mi/lt	1.07	3.09	30.9
Aug	1	late	0.97	2.90	29.0
Aug	2	late	0.83	2.58	25.8
Aug	3	late	0.70	2.29	11.4
TOTAL					349.0

Annex 7: Soil Water Balance Sheet (Plot E21 at Water level 1) and crop coefficient

Table A.7: Soil water balance for Plot E21

Soil type clay   Total available water
9.7 V% 0-15 cm
9.3 V% 15-30 cm
9.2 V% 30-45
10 V% 45-60 cm

Month February
Crop French Beans   Rooting Depth 0.2 m
Irrigate when balance is 10.6 mm

Date	Days after planting	Epa mm	Wind	Humidity	K_{pan}	K_{crop}	ET_{crop} (mm)	Rain (mm)	Irrig (mm)	Balance (mm)	Deep Perc (mm)
31/1	0		Light	Medium						19.2	
1/2	1	3.5		"	0.7	0.5	1.2				
2/2	2	3.5	"	"	0.7	0.5	1.2				
3/2	3	5.0	"	"	0.7	0.5	1.8			15	
4/2	4	1.9	"	"	0.7	0.5	0.7	9.4		19.2	4.5
5/2	5	3.1	"	"	0.7	0.5	1.1				
6/2	6	3.4	"	"	0.7	0.5	1.2				
7/2	7	3.5	"	"	0.7	0.5	1.2			15.7	
8/2	8	2.4	"	"	0.7	0.5	0.8	7.4		19.2	3.1
9/2	9	4.0	"	"	0.7	0.5	1.4				
10/2	10	2.5	"	"	0.7	0.5	0.9				
11/2	11	2.5	"	"	0.7	0.5	0.9				
12/2	12	2.0	"	"	0.7	0.5	0.7	2.2		16.6	
13/2	13	3.5	"	"	0.7	0.5	1.2				
14/2	14	1.5	"	"	0.7	0.5	0.5				
15/2	15	2.9	"	"	0.7	0.5	1.0	1.4		15.3	
16/2	16	3.5	"	"	0.7	0.5	1.2				
17/2	17	5.0	"	"	0.7	0.5	1.8				
18/2	18	4.0	"	"	0.7	0.5	1.4				
19/2	19	5.0	"	"	0.7	0.5	1.8	7.6		16.7	
20/2	20	3.0	"	"	0.7	0.5	1.1				
21/2	21	4.0	"	"	0.7	0.52	1.5				
22/2	22	3.0	"	"	0.7	0,53	1.1				
23/2	23	5.5	"	"	0.7	0.55	2.1			10.9	
24/2	24	3.0	"	"	0.7	0.56	1.2	13.0		19.2	3.5
25/2	25	3.1	"	"	0.7	0.57	1.2				
26/2	26	4.0	"	"	0.7	0.59	1.7				
27/2	27	5.0	"	"	0.7	0.60	2.1				
28/2	28	4.5	"	"	0.7	0.62	2.0			12.2	

Table A.7 Contd.

Month: March - April Rooting depth 0.3m
Irrigate when balance is 15.7mm

Date	Days after planting	E_{pan} (mm)	Wind	Humidity	K_{pan}	K_{crop}	ET_{crop} (mm)	Rain (mm)	Irrig (mm)	Balance (mm)	Deep Perc (mm)
1/3	29	3.0	Light	Medium	0.7	0.63	1.3		20	28.5	2.4
2/3	30	3.5	.	.	0.7	0.65	1.6				
3/3	31	4.0	.	.	0.7	0.66	1.8			25.1	
4/3	32	4.5	.	.	0.7	0.68	2.1		10	28.5	4.5
5/3	33	3.0	.	.	0.7	0.69	1.5			27	
6/3	34	3.0	.	.	0.7	0.71	1.5	3.4		28.5	.4
7/3	35	4.3	.	.	0.7	0.73	2.2	1.8		28.1	
8/3	36	1.5	.	.	0.7	0.74	0.8	8		28.5	
9/3	37	7.5	.	.	0.7	0.75	3.9			24.6	6.8
10/3	38	3.5	.	.	0.7	0.77	1.9				
11/3	39	5.5	.	.	0.7	0.78	3.0				
12/3	40	3.5	.	.	0.7	0.80	2.0				
13/3	41	4.7	.	.	0.7	0.82	2.7			15.0	
14/3	42	4.0	.	.	0.7	0.83	2.3		15.5	28.2	
15/3	43	2.5	.	.	0.7	0.84	1.5				
16/3	44	5.5	.	.	0.7	0.86	3.3				
17/3	45	4.5	.	.	0.7	0.87	2.7				
18/3	46	4.5	.	.	0.7	0.89	2.8		1	18.9	
19/3	47	4.0	.	.	0.7	0.90	2.5		10.7	27.1	
20/3	48	4.0	.	.	0.7	0.92	2.6				
21/3	49	5.0	.	.	0.7	0.93	3.3				
22/3	50	3.5	.	.	0.7	0.95	2.3				
23/3	51	2.5	.	.	0.7	0.95	1.7			17.2	
24/3	52	4.5	.	.	0.7	0.95	3.0		20.7	28.5	6.4
25/3	53	5.5	.	.	0.7	0.95	3.7				
26/3	54	4	.	.	0.7	0.95	2.7				
27/3	55	3	.	.	0.7	0.95	2.0	2.0			
28/3	56	4.5	.	.	0.7	0.95	3.0			19.1	
29/3	57	2.8	.	.	0.7	0.95	1.9	13.0		28.5	1.7
30/3	58	2.0	.	.	0.7	0.95	1.3				
31/3	59	1.9	.	.	0.7	0.95	1.3	3.4		28.5	0.8
1/4	60	2.5	.	.	0.7	0.95	1.7	1.0			
2/4	61	5.5	.	.	0.7	0.95	3.7				
3/4	62	3.5	.	.	0.7	0.95	2.3				
4/4	63	4	.	.	0.7	0.95	2.7			19.1	
5/4	64	3	.	.	0.7	0.95	2.0		19.7	28.5	8.3
6/4	65	3.5	.	.	0.7	0.95	2.3			26.2	
7/4	66	3.3	.	.	0.7	0.95	2.2				
8/4	67	1.6	.	.	0.7	0.95	1.1	4.1		27	
9/4	68	3.5	.	.	0.7	0.95	2.3				
10/4	69	6	.	.	0.7	0.95	4.0				
11/4	70	4	.	.	0.7	0.95	2.7				
12/4	71	2.4	.	.	0.7	0.95	1.6			16.4	
13/4	72	2.8	.	.	0.7	0.95	1.9		15.3	28.5	1.3
14/4	73	3.0	.	.	0.7	0.95	2.0				
15/4	74	4.2	.	.	0.7	0.95	2.8	3.2			
16/4	75	1.5	.	.	0.7	0.95	1.0				
17/4	76	3.5	.	.	0.7	0.95	2.3				
18/4	77	2.0	.	.	0.7	0.95	1.3				
19/4	78	4.5	.	.	0.7	0.95	3.0				
20/4	79	2.5	.	.	0.7	0.95	1.7	1.0			
21/4	80	2.4	.	.	0.7	0.95	1.6				
22/4	81	2.8	.	.	0.7	0.94	1.8		12.6	27.8	
23/4	82	1.2	.	.	0.7	0.93	0.8				
24/4	83	3.0	.	.	0.7	0.92	1.9				
25/4	84	3.5	.	.	0.7	0.91	2.2				
26/4	85	2.5	.	.	0.7	0.90	1.6				
27/4	86	3.5	.	.	0.7	0.89	2.2				
28/4	87	3.0	.	.	0.7	0.88	1.8	1.8			
29/4	88	5.5	.	.	0.7	0.87	3.3	6.2			
30/4	89	4.0	.	.	0.7	0.86	2.4				
1/5	90	3.5	.	.	0.7	0.85	2.1				
							172.5				

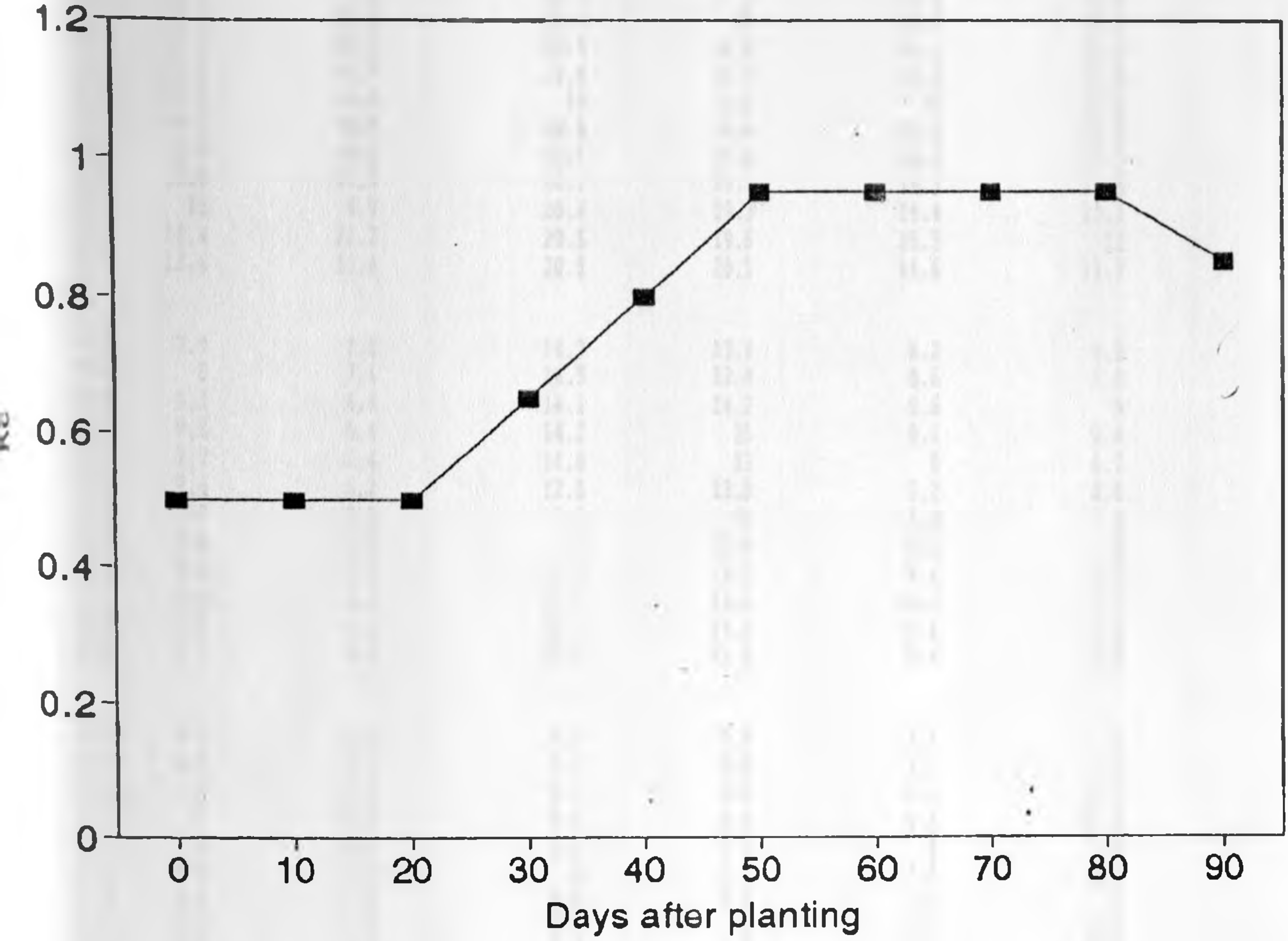

Fig A.7 Crop coefficient values for French beans

Annex 8: Crop evapotranspiration and Yields

Table A.8.1 : Depth of irrigation in individual subplots

plot	date of irrigation and depth(mm)					
	14.3.93	19.3.93	24.3.93	5.4.93	13.4.93	22.4.93
E13	12.1	10.4	20.4	19.1	13.7	10.8
E24	14.1	10.5	20.4	19.8	14.9	11.5
E31	15.3	11.9	21.3	20	15.3	12.5
E11	13.5	10.3	20.9	18.8	14.1	11.7
E21	15.5	10.7	20.9	19.7	15.3	12.6
E33	14.2	10.6	19	19.9	15	12.4
E22	13.3	10.8	20.8	19.6	13.9	10.3
E14	13.4	10.6	21.1	19.8	14.2	11.2
E34	13.6	10.9	20.7	19.5	14.5	11.4
E12	15	9.9	20.4	19.3	14.4	11.1
E23	14.4	11.2	20.6	19.6	15.3	12
E32	13.6	10.6	20.8	20.1	14.6	11.7
F13	7.9	7.2	14.2	13.4	8.2	9.2
F24	8	7.1	14.5	12.8	8.6	7.8
F31	9.2	6.1	14.1	14.2	9.8	9
F11	9.8	6.4	14.2	15	9.4	9.4
F21	7.7	6.4	14.8	13	9	6.7
F33	9.4	6.2	12.8	13.8	9.2	8.6
F14	9	6.6	13.2	14	8.8	7.8
F22	7.4	6.5	14	12.8	8.6	8
F34	8.6	7.1	15.2	13.9	9.4	8.2
F12	8.9	6.7	14.5	14.6	10.4	9.5
F23	7.8	6.3	12.6	14.4	9.6	6.6
F32	9.5	6.6	13.8	13.8	9.4	7.6
G13	9.2	6.2	6.4	5.8	3.4	9
G24	8.2	5.5	5.8	5.8	3.6	7.8
G31	8	5.8	5.2	4.6	3.6	9.2
G11	11	6.5	6.4	6.4	4.3	10.2
G21	7.8	4.6	5.8	5.6	4	7.4
G33	8.8	5.4	6	5.2	3.8	8.6
G14	8.6	6	5.8	5.9	3.5	9
G22	8.2	5	5.2	6	3.6	8.8
G34	8.4	5.8	5.4	4.1	3.4	8.6
G12	10.7	7	6.6	5.8	4	9.4
G23	8.4	6.2	5	4.2	3.6	8.6
G32	8.6	5.6	6	5.6	3.1	7.8
H13	4.6	2.4	2.6	2.2	1	5.2
H24	4.8	2.2	2.4	2.4	1.2	4
H31	4.4	2.2	3.2	2	1.6	5.6
H11	5.9	2.9	4.2	2.6	2.5	5.7
H21	5.6	2.7	3.2	2.6	1.6	5.2
H33	4.7	2.2	2.4	1.8	0.6	3.8
H14	4.2	2	2.4	2.2	1.4	5.4
H22	4.4	2.1	2.4	1.9	1.7	4.4
H34	4	1.8	2	2.5	1	4.2
H12	5	1.9	3.5	2.8	1.9	5.2
H23	4.6	2.2	2.3	2.4	1	4
H32	4.3	2.1	1.8	2.3	1.4	3.6

Table A.8.2 Crop yields and evapotranspiration at each plot

Plot	Irrigation level	Irrigation depth(mm)	Fertilizer rate (kg/ha)	Evapotranspiration (mm)	Yield kg/Ha
E13	1	116.5	160	175.3	5625
E24	1	121.2	160	180	5850
E31	1	125.9	160	184.7	5850
F13	2	90.1	160	168.4	5625
F24	2	88.8	160	167.1	5400
F31	2	92.4	160	170.7	5175
G13	3	70	160	148.3	5175
G24	3	66.7	160	145	5175
G31	3	66.4	160	144.7	5175
H13	4	48	160	126.3	4950
H24	4	47	160	125.3	4725
H31	4	45.5	160	123.8	4275
E11	1	119.3	120	178.1	5625
E21	1	124.7	120	183.5	5625
E33	1	117	120	175.8	5625
F11	2	96.2	120	174.5	5450
F21	2	85.6	120	163.9	5175
F33	2	90	120	168.3	5175
G11	3	76.6	120	154.9	5175
G21	3	65	120	143.3	4725
G33	3	67.8	120	146.1	5175
H11	4	55.8	120	134.1	4725
H21	4	50.9	120	129.2	4275
H33	4	45.8	120	124.1	4500
E22	1	118.7	80	177.5	5175
E14	1	120.3	80	179.1	5625
E34	1	124.7	80	183.5	5175
F14	2	89	80	167.3	5175
F22	2	87.3	80	165.6	5175
F34	2	92.4	80	170.7	5175
G14	3	68.8	80	147.1	5175
G22	3	66.8	80	145.1	4950
G34	3	65.7	80	144	4950
H14	4	47.6	80	125.9	4950
H22	4	46.1	80	124.4	3825
H34	4	45.1	80	123.4	3825
E12	1	120.6	0	179.4	5175
E23	1	122.6	0	181.4	5175
E32	1	121.4	0	180.2	5175
F12	2	94.5	0	172.8	4725
F23	2	87.3	0	165.6	5175
F32	2	91.2	0	169.5	4500
G12	3	74.4	0	152.3	4500
G23	3	66	0	144.3	4500
G32	3	66.7	0	145	4725
H12	4	51.6	0	129.9	3825
H23	4	46.5	0	124.8	3150
H32	4	46	0	124.3	4725

Annex 9: Crop Height

Table A.9 Crop height at each plot

Irrigation level	Fertilizer rate (Kg/ha)	Plot	Crop height (cm)			
			35th day	40th day	55th day	60th day
1	120	E11	23	28	47	55
1	0	E12	26	31	38	44
1	160	E13	23	28	49	60
1	80	E14	25	36	44	48
1	120	E21	24	31	48	56
1	80	E22	25	32	48	50
1	0	E23	23	32	45	46
1	160	E24	25	33	51	64
1	160	E31	21	28	47	59
1	0	E32	20	28	43	48
1	120	E33	23	34	47	50
1	80	E34	23	33	46	52
2	120	F1	19	24	43	52
2	0	F12	23	29	42	44
2	160	F13	26	32	52	58
2	80	F14	24	32	41	45
2	120	F21	22	34	46	51
2	80	E22	24	35	46	46
2	0	F23	23	32	40	44
2	160	F24	26	35	46	62
2	160	F31	20	30	44	60
2	0	F32	21	31	41	46
2	120	F33	23	34	43	46
2	80	F34	20	29	43	48
3	120	G11	19	25	40	48
3	0	G12	27	35	38	42
3	160	G13	25	29	43	54
3	80	G14	27	33	44	43
3	120	G21	21	27	42	48
3	80	G22	24	36	40	44
3	0	G23	23	31	39	42
3	160	G24	25	34	48	54
3	160	G31	23	33	43	54
3	0	G32	25	34	40	42
3	120	G33	24	35	44	44
3	80	G34	26	35	42	44
4	120	H11	23	28	42	46
4	0	H12	25	30	38	40
4	160	H13	26	32	45	50
4	80	H14	23	31	39	41
4	120	H21	23	31	42	46
4	80	H22	23	34	38	40
4	0	H23	22	32	37	40
4	160	H24	21	31	43	52
4	160	H31	20	29	42	51
4	0	H32	23	28	36	39
4	120	H33	21	32	42	42
4	80	H34	22	32	40	41

Annex 10: Crop cover

Table A.10 **Percentage crop ground cover at each plot**

Fertilizer rate (kg/ha)	Irrigation level	Plot	% Ground cover 35th day	% Ground cover 50th day	% Ground cover 65th day
160	1	E13	25	74	95
160	1	E24	24	68	98
160	1	E31	20	70	95
160	2	F13	20	75	100
160	2	F24	22	69	100
160	2	F31	18	63	98
160	3	G13	24	72	95
160	3	G24	23	70	96
160	3	G31	20	51	93
160	4	H13	22	66	83
160	4	H24	25	60	84
160	4	H31	21	60	85
120	1	E11	19	61	93
120	1	E21	17	65	92
120	1	E33	24	58	91
120	2	F11	20	58	97
120	2	F21	24	54	97
120	2	F33	22	50	91
120	3	G11	20	53	92
120	3	G21	21	54	89
120	3	G33	19	56	90
120	4	H11	18	48	82
120	4	H21	22	52	80
120	4	H33	20	50	75
80	1	E14	21	45	88
80	1	E22	20	50	89
80	1	E34	21	53	91
80	2	F14	21	48	89
80	2	F22	23	48	79
80	2	F34	18	47	83
80	3	G14	19	46	76
80	3	G22	17	41	89
80	3	G34	19	47	86
80	4	H14	22	41	75
80	4	H22	18	45	72
80	4	H34	20	47	73
0	1	E12	21	40	84
0	1	E23	20	38	84
0	1	E32	18	40	78
0	2	F12	23	40	71
0	2	F23	19	36	70
0	2	F32	22	38	74
0	3	G12	24	37	65
0	3	G23	20	35	74
0	3	G32	19	38	68
0	4	H12	21	36	70
0	4	H23	20	32	62
0	4	H32	22	30	67

Annex 11 Irrigation schedule for the optimal cropping system

Information in the irrigation schedules presented include:

i) Number of irrigation turn(No.Irr.)

ii) Interval period(Int days).

iii) Date of irrigation turn(Date)

iv) Crop stage in which irrigation turn occurs(stage); A for initial phase, B for development stage, C for mid-season stage, and D for late season stage.

v) Depletion level(Depl) as percentage of total available soil moisture.

vi) Actual evapotranspiration rate(TX) on the day before irrigation, expressed as a percentage of potential crop evapotranspiration.

vii) Average actual evapotranspiration(ETa) calculated over the irrigation interval period, and expressed as a percentage of potential crop evapotranspiration.

iix) Deficit(Deficit), indicates the soil moisture depletion level after irrigation i.e. a zero value represents a refill to field capacity while a positive value represents an under- irrigation, equal to the amount needed to refill the root zone to field capacity.

ix) Loss is the excess water lost to deep percolation of any irrigation depth or rain exceeding refill to field capacity.

x) Net and gross irrigation depth as defined by application option.

xi) The gross depth is converted to a permanent flow(Flow) representing a continuous flow discharge to satisfy irrigation requirements over the concerned interval period.

Table A.11.1: Irrigation schedule details for French beans

```
IRRIGATION SCHEDULING          BEANS   1 November
==========================================================================
Climate Station : Sagana           Climate File        : sifmet
Crop            : BEANS            Planting date       :  1 November
Soil            : claysag          Available Soilmoist : 96 mm/m.
                                   Initial   Soilmoist : 0 mm/m.
Irrigation Options selected  :
  Timing      : Irrigation applied at 100 % Readily Available Moist.
  Application : Irrigation up to Field Capacity.

Field Application Efficiency 75 %
==========================================================================
```

No. Irr.	Int days	Date	Stage -	Deplet %	TX %	ETA %	NetGift mm	Deficit mm	Loss mm	Gr.Gift mm	Flow L/s/ha
1	1	1 Nov	A	100	-0	-0	30.2	0.0	0.0	40.2	4.66
2	10	11 Nov	A	48	99	100	21.0	0.0	0.0	28.0	0.32
3	16	27 Nov	B	47	100	100	30.3	0.0	0.0	40.4	0.29
4	20	17 Dec	B	48	100	100	44.6	0.0	0.0	59.5	0.34
5	19	6 Jan	C	46	100	100	43.9	0.0	0.0	58.5	0.36
6	16	22 Jan	D	49	100	100	46.9	0.0	0.0	62.5	0.45
	9	1 Feb	D	18	100	100					

Table A.11.2: Irrigation schedule details for French beans

IRRIGATION SCHEDULING BEANS 15 November

Climate Station : Sagana
Crop : BEANS
Soil : Claysag

Climate File : sifmet
Planting date : 15 November
Available Soilmoist : 96 mm/m.
Initial Soilmoist : 0 mm/m.

Irrigation Options selected :
Timing : Irrigation applied at 100 % Readily Available Moist.
Application : Irrigation up to Field Capacity.

Field Application Efficiency 75 %

No. Irr.	Int days	Date	Stage -	Deplet %	TX %	ETA %	NetGift mm	Deficit mm	Loss mm	Gr.Gift mm	Flow L/s/ha
1	1	16 Nov	A	100	-0	-0	30.2	0.0	0.0	40.2	4.66
2	15	1 Dec	A	46	100	100	23.1	0.0	0.0	30.8	0.24
3	26	27 Dec	B	46	100	100	39.6	0.0	0.0	52.8	0.23
4	18	15 Jan	C	46	100	100	44.2	0.0	0.0	58.9	0.38
5	15	1 Feb	C	46	100	100	43.9	0.0	0.0	58.6	0.45
	16	16 Feb	D	37	100	100					

Table A.11.3: Irrigation schedule details for Capsicum

IRRIGATION SCHEDULING Capsicums 15 November

Climate Station : Sagana Climate File : sifmet
Crop : Capsicum Planting date : 15 November
Soil : Claysag Available Soilmoist : 96 mm/m.
Initial Soilmoist : 0 mm/m.

Irrigation Options selected :
Timing : Irrigation applied at 100 % Readily Available Moist.
Application : Irrigation up to Field Capacity.

Field Application Efficiency 75 %

No. Irr.	Int days	Date	Stage -	Deplet %	TI %	ETA %	NetGift mm	Deficit mm	Loss mm	Gr.Gift mm	Flow L/s/ha
1	1	16 Nov	A	100	-0	-0	24.8	0.0	0.0	33.1	3.83
2	3	19 Nov	A	24	100	100	6.4	0.0	0.0	8.6	0.33
3	2	21 Nov	A	22	100	100	6.4	0.0	0.0	8.6	0.50
4	2	23 Nov	A	21	100	100	6.4	0.0	0.0	8.6	0.50
5	3	26 Nov	A	28	99	100	9.3	0.0	0.0	12.4	0.48
6	4	1 Dec	A	25	100	100	9.2	0.0	0.0	12.3	0.35
7	3	3 Dec	A	24	100	100	9.2	0.0	0.0	12.3	0.47
8	3	6 Dec	A	21	100	100	8.6	0.0	0.0	11.4	0.44
9	5	11 Dec	A	24	100	100	10.9	0.0	0.0	14.5	0.34
10	6	17 Dec	B	21	100	100	10.5	0.0	0.0	14.1	0.27
11	5	22 Dec	B	24	100	100	12.8	0.0	0.0	17.1	0.40
12	11	3 Jan	B	29	100	100	18.5	0.0	0.0	24.6	0.26
13	9	12 Jan	B	29	100	100	20.5	0.0	0.0	27.3	0.35
14	10	22 Jan	C	33	100	100	25.0	0.0	0.0	33.4	0.39
15	9	1 Feb	C	30	100	100	23.4	0.0	0.0	31.2	0.40
16	10	11 Feb	C	34	100	100	26.1	0.0	0.0	34.8	0.40
17	9	20 Feb	C	31	100	100	23.8	0.0	0.0	31.7	0.41
18	9	29 Feb	C	30	100	100	23.3	0.0	0.0	31.1	0.40
19	12	11 Mar	D	43	100	100	32.7	0.0	0.0	43.6	0.42
	10	21 Mar	D	24	100	100					

Table A.11.4: Irrigation schedule details for Cabbage

IRRIGATION SCHEDULING CABBAGE 1 February

Climate Station : Sagana
Crop : CABBAGE
Soil : Claysag

Climate File : sifmet
Planting date : 1 February
Available Soilmoist : 96 mm/m.
Initial Soilmoist : 0 mm/m.

Irrigation Options selected :
Timing : Irrigation applied at 100 % Readily Available Moist.
Application : Irrigation up to Field Capacity.

Field Application Efficiency 75 %

No. Irr.	Int days	Date	Stage -	Deplet %	TX %	ETA %	NetGift mm	Deficit mm	Loss mm	Gr.Gift mm	Flow L/s/ha
1	1	1 Feb	A	100	-0	-0	24.4	0.0	0.0	32.6	3.77
2	6	7 Feb	A	47	100	100	12.6	0.0	0.0	16.8	0.32
3	4	11 Feb	A	42	100	100	12.0	0.0	0.0	16.0	0.46
4	6	17 Feb	A	40	100	100	12.6	0.0	0.0	16.8	0.32
5	5	22 Feb	B	44	100	100	14.8	0.0	0.0	19.7	0.46
6	8	1 Mar	B	40	100	100	14.9	0.0	0.0	19.9	0.29
7	7	7 Mar	B	42	100	100	17.0	0.0	0.0	22.7	0.38
8	6	13 Mar	D	48	100	100	20.4	0.0	0.0	27.2	0.52
9	7	20 Mar	B	41	100	100	18.6	0.0	0.0	24.8	0.41
10	10	1 Apr	C	47	100	100	22.4	0.0	0.0	29.9	0.35
11	10	10 Apr	C	42	100	100	20.1	0.0	0.0	26.8	0.31
12	11	21 Apr	D	42	100	100	20.1	0.0	0.0	26.7	0.28
	10	1 May	D	28	100	100					

Table A.11.5: Irrigation schedule details for Carrots

IRRIGATION SCHEDULING CARROTS 1 December

Climate Station : Sagana
Crop : CARROTS
Soil : Claysag

Climate File : sifmet
Planting date : 1 December
Available Soilmoist : 96 mm/m.
Initial Soilmoist : 0 mm/m.

Irrigation Options selected :
Timing : Irrigation applied at 100 % Readily Available Moist.
Application : Irrigation up to Field Capacity.

Field Application Efficiency 75 %

No. Irr.	Int days	Date	Stage -	Deplet %	TX %	ETA %	NetGift mm	Deficit mm	Loss mm	Gr.Gift mm	Flow L/s/ha
1	1	1 Dec	A	100	-0	-0	25.1	0.0	0.0	33.5	3.87
2	5	6 Dec	A	34	100	100	10.3	0.0	0.0	13.8	0.32
3	5	11 Dec	A	37	100	100	13.1	0.0	0.0	17.5	0.41
4	10	21 Dec	B	35	100	100	16.4	0.0	0.0	21.8	0.25
5	12	3 Jan	B	45	100	100	27.1	0.0	0.0	36.2	0.35
6	13	16 Jan	C	51	100	100	34.0	0.0	0.0	45.3	0.40
7	11	27 Jan	C	51	100	100	34.0	0.0	0.0	45.4	0.48
8	9	6 Feb	C	47	100	100	31.3	0.0	0.0	41.7	0.54
9	10	16 Feb	D	48	100	100	32.0	0.0	0.0	42.7	0.49
10	11	27 Feb	D	51	100	100	34.0	0.0	0.0	45.3	0.48
	4	1 Mar	D	17	100	100					

Table A.11.6: Irrigation schedule details for Onion

IRRIGATION SCHEDULING ONION(dry) 1 April

Climate Station : Sagana   Climate File : sifmet
Crop : ONION(dry)   Planting date : 1 April
Soil : Claysag   Available Soilmoist : 96 mm/m.
Initial Soilmoist : 0 mm/m.

Irrigation Options selected :
Timing : Irrigation applied at 100 % Readily Available Moist.
Application : Irrigation up to Field Capacity.

Field Application Efficiency 75 %

No. Irr.	Int days	Date	Stage -	Deplet %	TX %	ETA %	NetGift mm	Deficit mm	Loss mm	Gr.Gift mm	Flow L/s/ha
1	1	1 Apr	A	100	-0	-0	29.2	0.0	0.0	39.0	4.51
2	6	7 Apr	A	36	100	100	11.4	0.0	0.0	15.2	0.29
3	4	11 Apr	A	32	100	100	10.7	0.0	0.0	14.3	0.41
4	10	21 Apr	A	33	100	100	12.2	0.0	0.0	16.3	0.19
5	11	2 May	B	34	100	100	14.3	0.0	0.0	19.0	0.20
6	11	13 May	B	35	100	100	16.2	0.0	0.0	21.6	0.23
7	10	23 May	B	35	100	100	17.7	0.0	0.0	23.6	0.27
8	9	2 Jun	B	34	100	100	18.3	0.0	0.0	24.4	0.31
9	9	11 Jun	C	33	100	100	18.8	0.0	0.0	25.1	0.32
10	8	19 Jun	C	34	100	100	19.8	0.0	0.0	26.4	0.38
11	7	26 Jun	C	31	100	100	18.0	0.0	0.0	23.9	0.40
12	7	3 Jul	C	31	100	100	17.7	0.0	0.0	23.6	0.39
13	7	10 Jul	C	30	100	100	17.3	0.0	0.0	23.1	0.38
14	8	18 Jul	C	31	100	100	17.6	0.0	0.0	23.5	0.34
15	7	25 Jul	C	30	100	100	17.4	0.0	0.0	23.2	0.38
16	8	3 Aug	D	35	100	100	20.4	0.0	0.0	27.1	0.39
17	10	13 Aug	D	45	100	100	25.7	0.0	0.0	34.2	0.40
18	14	27 Aug	D	59	100	100	34.1	0.0	0.0	45.5	0.38
	4	1 Sep	D	13	100	100					

Table A.11.7: Irrigation schedule details for Potato

IRRIGATION SCHEDULING POTATO 15 April

Climate Station	: Sagana	Climate File	: sifmet
Crop	: POTATO	Planting date	: 15 April
Soil	: Claysag	Available Soilmoist	: 96 mm/m.
		Initial Soilmoist	: 0 mm/m.

Irrigation Options selected :
Timing : Irrigation applied at 100 % Readily Available Moist.
Application : Irrigation up to Field Capacity.

Field Application Efficiency 75 %

No. Irr.	Int days	Date	Stage -	Deplet %	TX %	ETA %	NetGift mm	Deficit mm	Loss mm	Gr.Gift mm	Flow L/s/ha
1	1	16 Apr	A	100	-0	-0	29.3	0.0	0.0	39.1	4.53
2	5	21 Apr	A	28	100	100	9.0	0.0	0.0	11.9	0.28
3	11	2 May	A	30	100	100	11.3	0.0	0.0	15.1	0.16
4	11	13 May	B	29	100	100	12.7	0.0	0.0	16.9	0.18
5	10	23 May	B	29	100	100	14.3	0.0	0.0	19.0	0.22
6	9	2 Jun	B	34	100	100	18.2	0.0	0.0	24.2	0.31
7	8	10 Jun	B	31	100	100	17.9	0.0	0.0	23.9	0.35
8	6	16 Jun	C	32	100	100	18.3	0.0	0.0	24.4	0.47
9	6	22 Jun	C	32	100	100	18.2	0.0	0.0	24.2	0.47
10	7	29 Jun	C	34	100	100	19.4	0.0	0.0	25.8	0.43
11	7	6 Jul	C	35	100	100	20.4	0.0	0.0	27.2	0.45
12	7	13 Jul	C	35	100	100	20.1	0.0	0.0	26.8	0.44
13	7	20 Jul	C	34	100	100	19.7	0.0	0.0	26.3	0.43
14	7	27 Jul	D	35	100	100	20.0	0.0	0.0	26.6	0.44
15	8	5 Aug	D	39	100	100	22.3	0.0	0.0	29.7	0.43
16	11	16 Aug	D	47	100	100	27.2	0.0	0.0	36.2	0.38
	10	26 Aug	D	34	100	100					

Table A.11.8: Irrigation schedule details for Maize

IRRIGATION SCHEDULING MAIZE 1 April

Climate Station : Sagana
Crop : MAIZE
Soil : Claysag

Climate File : sifmet
Planting date : 1 April
Available Soilmoist : 96 mm/m.
Initial Soilmoist : 0 mm/m.

Irrigation Options selected :
Timing : Irrigation applied at 100 % Readily Available Moist.
Application : Irrigation up to Field Capacity.

Field Application Efficiency 75 %

No. Irr.	Int days	Date	Stage -	Deplet %	TX %	ETA %	NetGift mm	Deficit mm	Loss mm	Gr.Gift mm	Flow L/s/ha
1	1	1 Apr	A	100	-0	-0	29.5	0.0	0.0	39.4	4.56
2	46	17 May	B	63	100	100	39.7	0.0	0.0	53.0	0.13
3	20	7 Jun	C	62	100	100	47.4	0.0	0.0	63.2	0.37
4	16	23 Jun	C	61	100	100	47.0	0.0	0.0	62.6	0.45
5	16	9 Jul	C	62	100	100	47.3	0.0	0.0	63.1	0.46
6	17	26 Jul	D	63	100	100	48.5	0.0	0.0	64.6	0.44
7	17	13 Aug	D	61	100	100	46.7	0.0	0.0	62.2	0.42
	8	21 Aug	D	24	100	100					