Evaluation of soya bean and *Sesbania sesban* for soil fertility replenishment, increased rice yield and enhanced incomes

By

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DEDICATION

To Jesus Christ my saviour, my loved wife, Grace Muthoni Kinyanjui and our dear sons Stephen Wanjogu, Philip Gatua, Simon Peter Ngatara: to my dear mum Hanah Wambui Wanjogu and charismatic dad the late Isaiah Wanjogu Ngatara

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LIST OF ACRONYMS

AWDI	Alternate wet/dry irrigation
BNF	Biological nitrogen fixation
C/N	Carbon Nitrogen ratio
DAG	Days after germination
DAS	Days after sowing
DAT	Days after transplanting
ICIPE	International Centre for Insect Physiology and Ecology
IRRI	International rice research institute
IWMI	International water management institute
K	Potassium
LCC	Legume cover crops
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
me	Milliequivalent
MIAD	Mwea Irrigation and Agricultural Development Center
MIS	Mwea Irrigation Scheme
MC	Moisture content
MOA	Ministry of Agriculture
MOALDM	Ministry of Agriculture, Livestock Development and Marketing
NIB	National Irrigation Board
OC	Organic Carbon
P	Phosphorus
ppm	parts per million
SOM	Soil Organic Matter
SIMA	System wide Initiative on Malaria and Agriculture
TN%	Total Nitrogen (%N)
WHO	World health Organization
WUAs	Water users associations

ABSTRACT

This study focused on the development of practical agro-ecosystem measures aimed at enhancing agricultural productivity while simultaneously reducing malaria vector populations for improved household incomes in irrigated rice farming. The main strategy entailed testing alternation of rice with legumes. Soya bean (*Glycine max L.J.Marr*) and *Sesbania sesban* were tested as the preceding crops against the conventional rice-fallow and the rice-rice cultivation systems. Among the preceding crops, rice produced the highest amount of biomass followed by Soya bean varieties EAI 3600 and Duiker. However, Soya bean residue had a higher nutrient content than rice straw and fallow treatment (weeds). The fallow-rice cropping system gave the lowest preceding plants (weeds) biomass quantities followed by *Sesbania sesban.* Soya bean cultivation allowed easier working of soil for the succeeding rice crop, on the normally hard and sticky, black cotton soil. Soya bean cultivation before rice resulted in the highest soil N and P nutrient replenishment while Potassium was highest in the fallow (weeds) treatment. The Soya bean cultivation before rice saved 33% of in-organic fertilizer N. After cultivation of the subsequent rice crop, soil nutrients N, P, K and Zn content were low in all plots thus emphasizing the need to alternate rice with a legume crop to replenish soil fertility. Organic carbon was moderately available in all plots. Significant mean grain yield differences ($p<0.05$) among the test soil fertility replenishment preceding crops were obtained. Rice produced mean grain yield of 4946kg ha^{-1} while Soya bean gave an average of 2215kg ha^{-1} grain yield. Among the subsequent rice treatments, yields from Soya bean-rice cropping system were generally the highest (6307kg ha^{-1}). Rice-rice cropping system gave the lowest yield (4438kg ha^{-1}) followed by rice-fallow system (4516kg ha^{-1}). There were significant ($p<0.05$) yield differences between rice-Soya bean (4111kg ha^{-1}) and rice-rice (3167kg ha^{-1}) treatments at zero N Kg ha^{-1} level. Rice-rice treatment recorded the lowest subsequent rice grain yield at both the cropping systems and the different levels of N (3167, 4633, 5100 and 6167 kg ha^{-1} rice grain yield at 0, 40, 80, and 120 kg N ha^{-1} respectively). Soya bean-rice treatments generally gave higher subsequent rice grain yield at all N levels (4111, 5343, 5197, 6829kg ha^{-1} yield at 0, 40, 80, and 120 kg N ha^{-1} respectively). The superior performance of soya bean–rice system is attributed to averagely higher plant residue nutrient content and the increased nodulation observed in Soya beans treatments in paddy soil that could have enhanced Nitrogen-fixation resulting in improved soil fertility and hence higher yield. Malaria vector larval population densities for Anopheline species L1L2, (1^{st} instars) in Soya bean, fallow and rice treatment were 0, 2 and 4, respectively and 0, 1 and 4, respectively for L3L4, (2^{nd} instars). Hence, Soya bean-rice system resulting in modification of paddy field ecosystem leading to significant elimination of the malaria vector breeding sites unlike the rice-rice and rice-fallow systems. The reduction of mosquito larva densities would hence contribute positively to the fight against malaria disease impact. The Soya bean-rice system also resulted in production of the high protein rich soya grain that would be suitable for improvement of household nutrition and income. Adoption of Soya bean-rice cropping system would therefore cause ecosystem modification that would eventually lead to improved soil fertility, reduced malaria disease incidences and improve farmers' health. This would in turn result in allocation of uninterrupted timefor agricultural productivity and hence increase rice output and income. Partial budget, Gross margin analysis and benefit cost ratio analysis indicated multiple benefits that are associated with the Soya bean-rice cropping system. The benefits includes 16% rice grain yield increase, 1730kgha^{-1} Soya bean grain yield production and Kshs8381 ha^{-1} in inorganic N fertilizer saving. The Soya bean-rice cropping system resulted in a net income increase of Kshs 61,317. The gross margins for the preceding rice crop and Soya bean were Kshs

27,945 ha^{-1} and Kshs 47,011 ha^{-1} respectively. The benefit-cost ratio (BCR) at a price of Kshs 30 per kg of rice and Soya bean were 1.23 and 2.95 respectively. Yields were 4946Kg ha^{-1} and 2371Kg ha^{-1} for rice and Soya beans respectively. There is therefore, need to encourage farmers to rotate rice with soya bean for increased food production and income. The Soya bean cropping system should be introduced as an alternative to rice monoculture in Mwea Irrigation Scheme for increased rice production, improved incomes, improved human health, and preservation of the environment.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Global Perspective

Rice (*Oryza sativa* L.) is the leading cereal in calorie production per hectare (De Datta, 1981 and Guerra *et al*., 1998). It is one of the most important food crops in the global fight against hunger (FAOSTAT, 2002). The total annual world production of milled rice currently stands at 400 million metric tons which compares favorably well with maize and wheat. Since some percentage of both maize (67%) and wheat 25% are consumed as animal feed, rice remains the most preferred grain globally for human consumption among the three major grains (Ito, 2005). Development of rice therefore presents an opportunity to reduce the number of gravely food insecure people estimated to rise to 816 million by 2015 according to the World Food Summit (1996) and the Millennium Development Goals (MDG, 2005). Due to its importance, there are global initiatives to enhance rice research and development for the benefit of communities living particularly in sub Saharan Africa (Nguu and Aldo, 2006; IRRI, 2008b).

Rice is mainly cultivated under irrigated and rain-fed ecosystems (De Datta, 1981 and Guerra *et al*., 1998). Irrigated rice grows in controlled flooded fields. Rain-fed rice is cultivated under rainfall or irrigation supplemented environment. Rice is cultivated one to three times in a year depending on climatic and environmental conditions especially soil fertility, temperature and moisture. The plant performs well in abundant water and temperatures of 16 ^{0}C minimum and 26-35 ^{0}C maximum during reproductive stage. In Asian countries, rice has been cultivated in rotation with other crops such as wheat and legumes. However, there are several challenges facing the rice sector globally (Lacey and Lacey, 1990; Nguu and Aldo, 2006; IRRI, 2008b).

There has been limited expansion of land under rice and a decline in rice yield growth rate. This has been attributed to increasing scarcity of global water resources for agriculture, expansion of urban and industrial sectors in Asia where land is already limited and the high costs of developing new lands that are suited for rice production in Sub-Saharan Africa and Latin America. The average growth rate of rice yield was 3.68% per year in the early 1980s, but decreased to 0.74% per year in the late 1990s. This was due to limited returns with regard to yield potential of the high yielding varieties, declining productivity in intensive rice production systems, pressures from abiotic and biotic stresses, low returns in developing countries, increasing production costs in industrialized countries, and increasing public concern for the protection of environmental resources (Nguu and Aldo, 2006).

The irrigated rice environments have been associated with water borne diseases particularly Malaria, which negatively affect the human health and income resulting in decline in cultivated rice area (Lacey and Lacey, 1990; Mutero *et al.*, 2003; Jacob *et al.*, 2007). Among these diseases, Malaria causes high morbidity and mortality leading to enormous cumulative human suffering and economic damage. Its impact is especially noticeable in rice growing areas, where disease incidence is high at a time of the year when labour demand for agricultural work is at peak (WHO, 1998).

To address these challenges research and subsequent dissemination of the findings is of paramount importance. This is possible by developing and promoting rice integrated crop management (RICM) systems for improving productivity and reducing the production cost per unit of output. The need for a sustainable increase in rice production is a global issue. The evaluation of alternative crops to rice may provide a chance to improve food security, alleviate poverty and preserve the environment for the billions of people for whom "*Rice is Life*" (Nguu and Aldo, 2006)

1.2 Rice Demand in Africa

Rice consumption has increased in Africa progressively, thus creating a surge in importation. Projected deficit for rice by the year 2010 is 19 million tons in Africa (Thomson and Metz, 1997). The situation has been aggravated by several factors, particularly the 2007-2008 world food crisis that tripled rice prices in many African countries (IRRI, 2008a), increased rate of rice consumption over other cereals, burgeoning global population and climatic change. All these created a sudden rise in rice demand against a stagnant production and supply.

1.3 National Rice Requirement and Production

Rice output in Kenya is estimated at 85,000t per annum against the demand of 300,000t per annum. The 215,000t rice deficit is imported at a cost of Kshs7 billion (MOA 2009; USDA, 2008: Kore *et al.*, 2007; The Standard, 2005). The rate of increase in rice consumption is higher (>12%) than for other cereals (wheat 4%, maize 3%). This is attributed to progressive change in eating habits and ease of cooking that has favoured rice above other cereals. The increase in consumption rate requires to be met with a corresponding increase in rice production area and yield per unit area.

Most of the rice cultivated in Kenya is under irrigation (92%) and the rest is under rain-fed system (NIB, 1994). The main method of establishment is transplanting or direct seeding in puddle well leveled fields. The highest yields have been realized from irrigated rice systems.

Rain-fed rice is cultivated in upland or lowland areas mainly relying on rainfall water (Guerra *et al*., 1998). Rain fed rice has average grain yield of 1.5t ha^{-1} (NIB, 1996). However, in the recent years there has been development of the New Rice for Africa (NERICA) whose adaptability trials in various parts of the country recorded yields of 5-6t ha^{-1} (AICAD, 2006). The main varieties cultivated are the irrigated aromatic and non-aromatic types. The Kenya Pishori, an aromatic variety selected from Basmati lines, is highly prized for its aroma, good grain and cooking quality. Kenya is a net importer of non aromatic polished rice, and is hence highly vulnerable to global market trends (FAO, 2004) that have seen the production of aromatic rice increase at the expense of the high yielding non-aromatic varieties.

1.4 National Rice Production Challenges

In Kenya, rice production challenges vary with production, cropping and farming systems across the country. There has been a general decline in rice yields and area under rice, limited irrigation water supply, lack of alternative crops production package, emergence of diseases particularly rice blast and rice yellow mottle virus while weeds and vertebrates (especially birds and rats) have been threat to rice production, (FAO 2004, MOA 2009). The escalating costs of fuel and agricultural inputs lack of capital and credit facilities discourage expansion of rice production. These coupled with lack of adequate skills and knowledge on rice crop management and weak research – extension – farmer linkages as well as the threat to human health by water borne diseases in irrigated rice production, hamper rice output. The imported rice prices, whose production is usually highly subsidized, also create unfair competition to locally produced non-aromatic rice despite their high yielding ability (FAO, 2004).

1.5 Rice production in Mwea

Mwea is the main rice growing area of Kenya producing 73% of the total paddy rice in the country (NIB, 1994). The main planting method is transplanting. Average rice yield under irrigation is 3.5 t/ha for aromatic varieties and 5-6.5 t/ha for non-aromatic varieties (Kaluli and Gatharia, 1991; NIB, 1998).

1.6 Rice Monoculture system and double cropping in Mwea

Monoculture system is practiced in Mwea where rice is grown once a year followed by a long fallow period before the next rice crop. Double cropping is the cultivation of two rice crops continuously per year. The irrigated rice yield worsens when double cropping is practiced (Kuria, 2004). Farmers attempt to improve income through double cropping has not been viable (Kabutha and Mutero, 2002; Kuria, 2004 and 2007) because of progressive decline in yield as the system is repeated year after year. It was observed that a single crop of rice in a year was eventually more or equal in yield than a double crop (Kuria, 2004). Consequently, the Mwea rice farmers generally produce one rice crop per year, leaving the land uncropped for the rest of the year, a factor that has contributed to increased poverty in the community. There lacks an alternative cropping system that would allow intensive cultivation without depleting soil fertility and enhancing malaria and other water borne diseases. Development of feasible soil fertility replenishment strategies would enhance crop intensification and encourage intensive cropping for improved yields and household incomes.

1.7 Soil fertility maintenance options

In rice fields, large amounts of crop residue are burned or removed after harvest (Nguyen *et al.*, 1994; Smil, 1999). These results in loss of organic matter and nutrients causing atmospheric pollution due to emissions of toxic and greenhouse gases such as CO, CO_2, and CH_4, which pose a threat to human health and the ecosystem (Khera, 1993; Beri *et al.*, 1995). On the other hand crop residue is a vital natural resource for conserving and sustaining soil productivity. It is the primary substrate for replenishment of soil organic matter (SOM). Upon mineralization, crop residue supplies essential plant nutrients (Walters *et al.*, 1992). Additionally, residue incorporation can improve physical and biological conditions of the soil and prevent soil degradation (Nyborg *et al.*, 1995). The benefits of sequestering soil organic Carbon (SOC) to sustain crop productivity by applying organic amendments and crop residue and including legumes in crop rotations have been well documented in the temperate regions (Banik and Bagchi, 1995; Niang *et al.*, 1996).

N-fixing legumes are valuable in soil fertility restoration in crop rotations and as alley crops (Meyer, 1987). Used as green manure or cover crops, legumes offer a potential option to farmers for maintaining soil fertility at minimal costs (Buresh *et al.*, 1993; Yadvinder-Singh *et al.*, 1993). Legumes contribute mineral N to the soil and also supply the soil with P, K and soil organic matter (Bhandari, 2002). Some green manure legumes are also rich in protein and are nutritious for livestock and humans.

1.8 Crop residue use in Kenya

Although many green manure studies have been conducted with rice in Asia (Buresh *et al.*, 1993; Yadvinder-Singh *et al.*, 1993), few studies have looked at comparative effects of crop residue management with or without fertilizer N and legume green manure on crop yields and SOC in paddy fields of Mwea Kenya. Yield increases are often achieved through the use of N fertilizers, in combination with improved varieties. Encouraged by yield response, farmers increase fertilizer N rates to often excessive levels, while applying insufficient amounts of fertilizer P and K. The tendency by farmers to remove rice straw (which contains large amounts of K averaging 14.5 in straw kg t^{-1} of grain yield) combined with the amount of P and K removed through grain harvest aggravate the situation. The amount of N, Pand K nutrients removed from the soil through rice straw and grain harvest is estimated at 17.5, 3 and 17 kg t^{-1} of grain yield (Dobermann and Fairhurst, 2000). This results in an unbalanced supply of nutrients to the crop. Incorporation of crop residues holds potential to restore soil fertility (Witt *et al.*, 2007).

1.9 Agronomic Factors that limit crop production

In the year 2007, inorganic fertilizers accounted for approximately 20% of the cost of producing rice that totaled to Kshs123,500 ha^{-1}, hence taking up a major portion of farmers' returns. The recommended rates are 108-120kgN ha^{-1}, P-60kg P_2O_5 ha^{-1} and K at 50 kg K_2O ha^{-1} (Wanjogu *et al.*, 1995). This necessitates the need to seek for alternative strategies of maintaining soil fertility at lower cost to boost rice production and increase income for wealth creation in line with the national polices in vision 2030. The non-aromatic rice income averages to Kshs180,000 ha^{-1} annually (Author observation).

1.10 Economic and social impact of Soya beans

Soya bean is a leguminous crop of great economic and social importance worldwide. It provides about 64 percent of the world's oilseed meal supply and is the major source of oil, accounting for about 28 percent of total production (USDA, 2000). For countries with surplus Soya bean production, the crop represents an important source of foreign currency, for example in Brazil and Argentina in Latin America. In Argentina, the Soya bean contributes more than 50 percent of the export currency (Ploper, 1997). In Brazil the Soya bean industry generates US$ 24.5 billion in income yearly and about US$ 5.7 billion in foreign exchange (Duque, 1999; Feedstuffs, 1999). In some developing countries, especially in rural areas, Soya bean represents the best protein source available for improving the nutritional value of traditional foods (Bressani, 1974; Verma *et al.*, 1987; Seralathan *et al.*, 1987; Akpapunam *et al.*, 1996; Seralathan and Thirumaran, 1998). The crop has also revolutionized some developing countries rural economy by raising the living standards of Soya bean farmers, especially the women and children (Paroda, 1999).

Soya bean root nodules host rhizobium bactera that fix the atmospheric Nitrogen to a form that it uses effectively (Cattelan and Hungria, 1993). While the soil is the primary source of N for many crops, Soya bean can obtain 65-85% of its needs through Nitrogen fixation. A portion of the fixed N is ploughed back into the soil in form of Soya bean residue. It is used by succeeding crops to meet its N needs to replace part of chemical N fertilizer.

The introduction of Soya bean crop to several countries has led to a shift in their cropping systems from a mono-crop (post-rainy wheat or other crop) to a Soya bean-wheat or Soya bean-other crop system. This cropping system change resulted in an enhancement in the cropping intensity and an increase in the unit area profitability from land use (Paroda, 1999). Soya bean crop is seen to be useful for the sustainability of the major cereal based cropping systems in the developed world. It is, therefore, necessary to investigate the technical and economic viability of a Soya bean-rice cropping system in the Mwea irrigated rice fields.

1.11 Soya bean Requirements and Production in Kenya

1.11.1 Soya bean Requirements

Kenyas annual demand for Soya beans is estimated at 21,500 metric tons (Table 1.1) (Kuria 2006; Paul Appleby. 2001). About 75% of this is imported from Uganda, USA and Europe while domestic production is 5,000 metric tons (25%). The Soya bean demand in Kenya are therefore far beyond production (Table 1.1).

Table 1.1: Annual soya bean demand for various uses in Kenya in year 2001

Use	Soya bean requirement (Tons)
Soya bean Oil Extracts	12,000
Animal Feed	4,000
Corn soya blend (CSB)	4,500
Other Food Uses	1,000
Total	21,500

Source: Mbaabu, 2001

Thus there is high market potential for Soya beans, which has remained untapped. The country's dependence on imports is attributed to a multitude of factors. Production and consumption of Soya beans is limited by lack of awareness and a non-supportive policy environment. Other factors set in hindering rapid development of the Soya bean industry, the chief among them being lack of access to seed and crop production package and recommended varieties, lack of market information and institutional capacity to facilitate marketing of farmers' produce, and lack of competitiveness of the crop in high and medium potential areas.

1.11.2 Soya bean Production in Kenya

In Kenya, Soya beans have been produced mainly in Western Kenya, notably in Busia and Bungoma. However, the crop is, relatively new in farming systems in many parts of the country (Kuria, 2006). Domestic production of Soya bean in Kenya has been low due to support at policy level, lack of Soya bean market until the early 1990's, lack of adequate marketing organizations and information (Ephanto, 1994). In addition to these, lack of awareness on utilization of Soya bean at the household level and introduction of soybeans in farming systems without an accompaniment of crop production husbandry package were constraints. In view of the foregoing it was found necessary to evaluate soybean-rice cropping system in MweaKenya.

1.12 Irrigated rice production and human health

Rice cultivation has traditionally been associated with vector-borne diseases, especially malaria n and Japanese encephalitis (Lacey and Lacey 1990). Vector-borne diseases are among the major public health concerns and obstacles to socioeconomic development of developing countries, particularly in the tropics, with malaria alone causing an estimated 1.5 – 2.7 million deaths and 300 – 500 million health cases per year (Lacey and Lacey 1990; Mwangangi *et al.*, 2006a).

In the rural areas malaria frequently strikes at the time of the year when there is the highest demand for agricultural labour (Greenwood *et al.*, 1987). The toll it exerts is not only in terms of the physical, financial and emotional pain it inflicts on the individual family but also by its macroeconomic impact (Republic of Kenya, 2001). At the domestic level, malaria is directly responsible for massive losses of work time such that in Kenya, an estimated 170 million working days are lost each year as result of the disease. Disrupted education and the effects of repeated bouts of the disease also caused delayed child development (Republic of Kenya, 2001). The health sector is heavily burdened by the cost of drugs and treatment since malaria accounts for 30% of all outpatient illnesses, 19% of all hospital admissions of which 5.1% die from complications of the disease (Mwangangi *et al.*, 2006; Mutero *et al.*, 2000; Republic of Kenya, 2001).

Mwea Irrigation scheme is not an exception to the threat posed by the disease. The continuous presence of standing water in rice-rice (double rice cropping) system, provide breeding habitat for malaria vector and other water borne diseases of which repercussions reduce the hours spent in rice production. Flood irrigation during rice cultivation has long been associated with an increase in number of disease vectors and corresponding increase in health burden due to malaria, other vectors and water-borne diseases. In the Mwea irrigation scheme, rice growing requires standing irrigation water almost throughout the crop cycle (Wanjogu *et al.*, 1995). The *Anopheles gambiae* and the *Anopheles funestus* are the primary vectors of malaria in Mwea rice irrigation scheme (Mutero *et al.*, 2000). The distribution and abundance of mosquito larvae results from availability of oviposition sites, the oviposition preferences of females and the ability of the immatures to tolerate and develop after the eggs are laid (Ijumba *et al.*, 2002).

The malaria epidemic undermines the productivity of agricultural resources in the region. The resultant high medical bills aggravated by lack of alternative sources of income drain the single season rice-generated income leaving farmers in a vicious cycle of poverty (Lacey and Lacey, 1990; Mwangangi *et al.*, 2006; Mutero *et al.*, 2000).

A study on economic analysis of rice production systems in Mwea Irrigation Scheme (Mutero, *et al.*, 2003) pointed out that rice double cropping is technically inefficient in use of production resources. The study pointed at the importance of further research to search for an agricultural intervention strategy that would directly intervene on malaria through vector control and indirectly via income improvement of the community. Research on alternating rice cultivation with a dry land legume crop was considered as the agricultural intervention of choice for further research. The underlying findings are part of the studies that were designed and conducted to investigate the agronomic and socio-economic feasibility of rice-Soya beans cropping system in Mwea.

1.13 PROBLEM STATEMENT

In Mwea rice fields, soil fertility has declined over time due to land use practices that encourage nutrient harvest without replacement. Such include; continuous rice cultivation, nutrient extraction through crop harvest, residue removal for sale and inadequate nutrient replacement. Crop residues are either taken away from the field, burnt or grazed denying the soil organic matter, essential macro and micro nutrients such as N, P, K, Zn, Si, Mg, and B estimated at 7, 1, 14.5, 0.05, 65, 3.5 and 0.015kg t^{-1} of rice grain harvested respectively (Dobermann and Fairhurst, 2000). The removal of soil nutrients without replacement result into decline in soil fertility, crop performance, rice grain yield and income. This eventually translates to reduced crop, land, water and agricultural labour productivity impacting negatively on food security. The prevailing over dependence on imported in-organic fertilizers reduces the profit margin of rice since in-organic fertilizers contribute over 20% of rice production cost in Mwea

The high costs of inorganic fertilizers render them to being either inadequately applied or not applied at all. The consequences are low rice yields per unit area and meager farmers' income that have led to slow expansion of area under rice production. The costly inputs contribute to the high prices of the locally produced rice making it uncompetitive to the imported rice (FAO, 2004). The consequence has been a progressive decline in rice output over the years with resultant national rice deficit of 250% (MOA, 2009). The prevailing rice deficit is met through imports at an estimated annual cost of Kshs7 billion. Additionally, 75% of the raw Soya bean consumed in Kenya is imported at a cost of Kshs613 million. The importation of rice, Soya bean and inorganic fertilizers all together depletes the much needed foreign exchange reserves.

Irrigated rice farming is also hampered by water borne diseases traditionally associated with irrigated rice environments. Infections from these diseases reduce the productivity of the agricultural inputs and particularly labour through loss of work time and diversion of a large proportion of farm income into settling medical bills. The most important among these diseases is malaria whose vector is increased by flooded rice farming. Various surveys carried out in Mwea ranked malaria high as a cause of morbidity and as the community priority health problem (Mutero *et al.*, 2003).

Due to deterioration of soil fertility and human health, attempts to boost rice production through cultivation of two continuous rice crops per year has not been feasible (Mutero *et al.,* 2000; Kuria, 2004). The study region lack feasible strategies to replenish soil fertility and reduce inorganic fertilizer use, increase rice/Soya bean production and reduce malaria vector for improved community health and household's income. Farmers have relied on one rice crop per year whose income is not able to support the needs of the family round the year. Farmers are therefore forced by the prevailing circumstances to borrow money at high interest rates or rent out their paddy fields, a factor that has made rice farmers revolve in a vicious cycle of poverty. Additionally there lacks documented research findings that can be used to guide in decision making and further research for interventions to enhance crop intensification in Mwea irrigated rice ecosystem.

1.14 OBJECTIVES

1.14.1 Broad objectives

To increase rice yields by improving soil fertility through soil nutrient pool build up using Soya bean (*Glycine max*), *Sesbania sesban* and rice straw

1.14.2 Specific objectives

a) Investigate the effect of rice-legume rotation on the levels of N, P, K and soil organic C in Mwea paddy soils

b) Investigate the effects of the rice-legume rotation on plant growth and rice grain yield in Mwea.

c) Evaluate the effects of rice-legume cropping system in improving farmer's income in Mwea.

1.15 HYPOTHESIS

a) Rice–legume rotations significantly increase paddy soil NPK and OC.

b) Rice–legume cropping system significantly increase rice yield

c) Rice–legume cropping systems increase income

1.16 JUSTIFICATION

The role of agriculture in economic development has been recognized for years both globally and nationally. Expected increases in agricultural demand associated with population growth and rising per-capita incomes will require continuing increases in agricultural productivity. Agricultural productivity, defined as the ratio of its output to its input, varies due to differences in production technology, the setting in which production occurs, the efficiency of the production process among other factors. Rice is progressively forming an important part of the diet for the majority of Kenyans. The annual consumption is increasing at a rate of 12% as compared to 4% for wheat and 1% for maize, which is the main staple food. This is attributed to progressive change in eating habits. The national rice consumption is estimated at 300,000 metric tons per year compared to an annual production range of 45,000 to 80,000 metric tons (MOA, 2009). The deficit is met through imports which contribute to depletion of the national foreign currency. Promotion of rice production will therefore improve food security, increase smallholder farmers' income and contribute to employment creation in rural areas as well as reduce the rice import bill. To achieve this, there is need for an improved farming system that could reduce the period that rice fields remain flooded, restore soil fertility, increase grain yield and generate higher income for Mwea rice farmers. There are various challenges that have faced the rice farmers discouraging crop intensification. The intensification of agriculture consists in increasing the yield of harvested material per hectare of land used. There lacks information on the returns to the resource use, associated benefits and costs of the second rice crop as compared to a break-crop of Soya bean. Although the effects of legumes on upland soils have been extensively studied (Palm *et al.*, 1997; Gachene *et al.*, 1999; Nnadi *et al.*,1993), there are no documented research findings on use of legumes as alternative sources of soil fertility replenishment for the vertisols of Mwea thereby creating a knowledge gap. On the other hand, local nitrogen fixation legume and cereal research has not addressed paddy soils (vertisols) for rice production enhancement but focus mainly on upland soils. Observational evaluation of legumes in Mwea highlighted the possibility of legume cultivation on paddy fields (Ephanto, 1995; Tsuruuchi and Waiyaki, 1995). However, the study did not continue due to farmers' unrest in Mwea Irrigation Scheme in 1998 (Kabutha and Mutero, 2002). The feasibility of introducinglegume-rice cropping system in Mwea can help farmers participate in achieving sustainable rice grain yield for sustainable food and income generation. It is therefore important to test various legumes to determine the sutable one for Mwea paddy fields. Rice irrigation ecosystems are known to habour malaria and other water borne disease vectors (Lacey, L. A., and C.M. Lacey, 1990). There is need to determine the agro-economic effects of integrating legume into the rice farming system on grain yield, income and malaria vector breeding habitat in Mwea. The war on malaria was largely won in Europe and in the US due to improvements in standards of living (Mutero *et al.*, 2000 and 2003). General development was the engine of the anti-malaria war machine in Europe and the United States, and it remains the most potent weapon against the disease to date (Bruce-Chwatt, 1993). The findings from this study are expected to address the Mwea vertisols legume research gap and the outstanding challenge of enhancing crop intensification for increased crop production and income. The rocketing global food prices as well as the looming threat from food crisis encouraged by biofuel production calls for urgent action. The findings from this study will add knowledge to scientific clientele and be useful in irrigated Schemes production policy and decision making

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice production systems

For nearly half of the world's population (2.7 billion people), rice is the staple food, providing 35-60 % of the calories consumed (Guerra *et al.*, 1998). More than 75% of the world's rice is produced in irrigated rice lands, which are predominantly found in Asia. Rice is a semi-aquatic annual grass, which thrives and yields best when flooded for two-thirds or all of its life cycle (De Datta, 1981; Labrada, 1996). Rice production systems are thus classified according to availability of water as: Irrigated, Rain-fed, Flood-prone or Deep water. According to establishment method, rice is either transplanted as 8 to 35 days old seedling into puddled soils, broadcast or drill-seeded into dry soil or broadcast as pre-germinated seeds onto wet (puddled) soil (De Datta, 1981). Globally, 53% of cultivated rice is irrigated, 27% lowland rain fed, 12% upland rice and 8% deep water rice (Labrada, 1996).

2.2 Rice production in Kenya

Rice production in Kenya occurs under small-scale type of farming and in three systems (MOA, 2009). The first system of production is through irrigation in NIB schemes, namely Mwea, Ahero, West Kano and Bunyala Irrigation Schemes. In total, the schemes produce about 85% of Kenya's rice mainly from irrigated land. The yields average about 4.5t/ha for Basmati varieties and 6.5t/ha for non-aromatic varieties such as BW 196 and IR2793 (Kaluli and Gatharia, 1991). The second system of production is under rainfed condition and supplement irrigation which is mainly concentrated in Nyanza, Western and coastal provinces. This is carried out by smallholder farmers mainly on marshy lands and valley bottoms which get waterlogged during the long rain season (Kore *et al.*, 2007). These smallholder rainfed rice farmers operates no more than one hectare of land each and achieve paddy yield of 1.7t/ha. The third system is under smallholder schemes that are organized under water users associations (MOA, 2004). The schemes were initiated by the irrigation and drainage branch of the Ministry of Agriculture but have now been left to the individual associations to manage, operate and maintain. A similar organization uniting farmers under water users associations (WUAs) have been adopted by NIB to enhance irrigation water and infrastructure management (NIB corporate plan, 2002-2007).

2.3 Crop rotation (Alternation) and its effects on crop yields

Crop rotation is a planned order of specific crops planted on the same field. Crop rotation also means that succeeding crops are of a different genus, species, subspecies, or variety than the previous crop (Peel, 1998). Examples are barley after wheat and grain crops after legumes (Robinson *et al.*, 1979). The planned rotation sequence may be for a two- or three-year or longer period. Some of the general purposes of rotations are to improve or maintain soil fertility, reduce erosion, reduce the build-up of pests, spread the workload, reduce risk of weather damage, reduce reliance on agricultural chemicals, and increase net profits (Tanaka *et al.*, 1998).

An evaluation of traditional cropping systems in Africa shows that crop rotations involving legume and cereal monocultures is by far more sustainable than inter-cropping, the most dominant cultural practice in the continent (Dakora and Keya, 1997). The research indicated that achieving sustainable yields in sub Saharan Africa would require a deeper understanding of how fixed N in legume residues is managed in the soil environment in addition to expanding the use of neglected African food legumes. Among different legume cover crop management(LCC) strategies, incorporation gives higher yields of maize where the legume cover crop is incorporated *in situ* than where residues are mulched or removed (Fischler, 1997; Kirungu,1998). Findings from gross margin analysis at Nakuru Kenya by Gichuru (2001) indicated that chickpea (*Cicer arietinum* L.) and common beans (*Phaseolus vulgaris* L.) are profitable short-rains season activities and that maize/wheat in rotation with dolichos (*Lablab purpureus* L. Sweet), common beans and chickpea without use of inorganic nitrogen application increased yield. Optimized legume production for farm enterprises show working capital and march labour resources as inefficient. Based on a 20% cut-off criterion for income differential between optimal and existing farm plans, a legume-cereal double cropping was shown to contribute significantly to smallholder farm income in Nakuru district. The study recommends that the legume-maize/wheat rotation is profitable with chickpea, common beans, and dolichos as the legumes.

Azolla spp was tested as a source of soil-N replenishment in Ahero paddy fields indicating positive potential of green manure use as a source of soil N, for rice production (NIB, 1985). Legume cultivation in paddy fields has not been feasible in Mwea despite several attempts to do so (Ephanto, 1995).

One immediate economic benefit of crop rotations is improved yields. For example, sunflower yields over eight years at Crookston, Minnesota (Robinson *et al.*, 1979) were often significantly greater in rotation with other crops than when continuous sunflower was grown. Wheat yields were also greater with rotation than continuous wheat in an eight-year study (Miller, 1984) conducted with different crops at Fargo. A study at the Agriculture Research Service at Mandan has shown that increased hard red spring wheat yields can be expected when an alternative crop is included in the rotation (Tanaka *et al.*, 1998).

Rotating with a different crop such as wheat on barley ground usually results in higher grain yields when compared to continuous cropping of wheat. Greater benefits are usually obtained by rotating two distinctly unrelated crops, such as a cereal seeded into land where the previous crop was a legume or other herbaceous dicot such as flax or sunflower (Peel, 1998). Many of the reasons for the beneficial effects of rotations are not completely understood. However, some of the more important beneficial effects that can be obtained from a well planned crop rotation are:

- Reduced insect and disease problems
- Beneficial residual herbicide carryover
- Improved soil fertility
- Improvements in soil tilth and aggregate stability
- Soil water management
- Reduction of soil erosion
- Reduction of allelopathic or phytotoxic effects

Pest control is often an important reason for crop rotation. Rotations can be used to prevent or partially control several pests and reduce the reliance on chemical and mechanical control (Peel, 1998). A combination of crop rotation and pesticides is often more effective in reducing pest populations to economic levels than pesticides alone. Pesticides that provide economical control are not available for pests such as white mold in potato, dry bean, and sunflower, and crop rotations are the only feasible control method for reducing the impact of *Sclerotinia*. Crop rotation must be used to reduce the buildup of insect, disease and weed pests.

2.3.1 Disease control

Crop rotation has tremendous potential for reducing and often preventing the transmission of disease. Disease pressures change with changing environmental conditions. Crop rotation, in combination with cultural practices plus necessary fungicides, is the most desirable method of disease control (Peel, 1998). Common diseases controlled by crop rotation are *Fusarium*, root rot and stem rot.

2.3.2 Insect control

Some insect pests can be controlled entirely or in part by rotations. In addition, insect populations may become greater within a region where only one or two crops are continuously grown in contrast to a region where several crops are grown in rotation. Insects such as corn borer, sunflower seed and stem weevil and many others readily migrate to nearby or distant fields. Therefore, only partial control can be obtained by rotation. Increasing field isolation from fields seeded to the same crop the previous year will often increase the effectiveness of crop rotation as an insect control method (Peel, 1998).

2.3.3 Weed control

Rotations can be used to cause shifts in weed populations. Populations of certain weed species can be suppressed by competition from the crop raised or by the selective use of herbicides. Wild mustard populations can be reduced by selective treatment of small grain crops such as millet grown in rotation with row crops. Grass weed populations, which are often problem in small grains crops, can be reduced by the use of the appropriate herbicide in the previous row crop (Peel, 1998).

2.3.4 Soil nitrogen

Legumes in the rotation can be used to increase the available soil nitrogen (Karanja *et al*., 1997). Symbiotic nitrogen-fixing bacteria called rhizobia form nodules on the roots of legume plants and convert or fix atmospheric nitrogen to organic nitrogen. The amount of nitrogen fixed varies with species, available soil nitrogen, and many other factors. Fixed nitrogen not removed from the land by harvest becomes available to succeeding crops as the legume tissues undergo microbial decomposition. When the legume crop is seeded, rhizobia inoculum should always be applied to the seed to ensure the most productive commercial strains are available to form nodules and that inoculating bacteria are always present (Karanja *et al.*, 1997). Even though indigenous bacteria may be present in the soil, research shows improved commercial strains of rhizobia have more capacity to fix nitrogen (Zollinger, 1998).

Legumes have the capacity to fix large amounts of nitrogen by the rhizobium hosted in the root nodules. Research in Minnesota (Heichel *et al.*, 1981) indicated that alfalfa fixed an average of 78kg ha^{-1} of nitrogen annually during the first two years of production. However, only a portion of the nitrogen fixed is available to the next crop because much is removed in the harvested alfalfa.

2.3.5 Soil tilth and structure

Many farmers who rotate crops comment on the improvement in tilth or friability of soil following Soya bean or other row crops. In a Colorado study involving corn, sugarbeet, and barley planted on succeeding years, soil aggregate stability was increased from 67 to 76% when three years of alfalfa cropping were added to the rotation (Schumaker *et al.*, 1967). Increased aggregate stability reduces the tendency of the soil to puddle or crust, increases rate of water infiltration under certain conditions, and may also reduce wind erosion.

2.3.6 Soil moisture

Crop rotation can lead to greater overall efficiency in soil water utilization. Shallow rooted crops deplete soil water about 90cm deep (Peel, 1998). In contrast, sunflower, safflower, corn and sugar beet are deep-rooted crops which can deplete soil water to depths of 170cm. Therefore, deep-rooted crops such as sunflower following shallow rooted crops can take advantage of the extra reserve of deep moisture and also any nitrogen which was position wise unavailable to a shallow-rooted crop.

Alfalfa and sweet clover, also deep-rooted crops, can be used to dry up saline seeps and other wet areas. Depletion of soil water in saline areas prevents the accumulation of salts on the surface, permits movement of the salts downward by leaching, and allows re-cropping to a cash crop such as wheat. Alfalfa or sweet clover should be seeded on the upslope recharge area to use and remove soil water as deeply as possible from the soil profile, reducing lateral flow of water and salts into the saline seep discharge area (Black *et al.*, 1981).

2.3.7 Allelopathy - Phytotoxicity

The reasons for improved yields due to crop rotations are not completely understood. Research has attempted to reveal some of the unknown factors (Miller, 1982). Terms such as phytotoxicity, allelopathy and autotoxicity are coming into common usage. Phytotoxicity, a general term, is defined as chemical that is toxic to plant growth whether it is derived from plant products or synthetic (herbicide or other pesticide residues). Allelopathy refers to plant material or chemicals derived from these materials which inhibit the germination, growth or development of another species. Autotoxicity refers to plant material which inhibits the germination, growth and development of the same species.

Legumes such as alfalfa, while often beneficial to non-related species, exhibit autotoxic effects to alfalfa seedlings. Older stands caused greater inhibition of new seedlings. Miller, (1982) observed that one year out of alfalfa was sufficient to nullify the detrimental effects of the alfalfa.

2.3.8 Reduced risk

Crop rotations add diversity to farm operations and can help reduce risk, provide income stability, spread labour requirements, help control pests, and may add to efficient machinery use (Peel, 1998). Maintaining some flexibility within rotations to take advantage of price changes can help increase returns.

2.4 Legume Cultivation

N_2-fixing legumes are valuable in soil fertility improvement offering a potential option to farmers for minimizing production costs (Peoples *et al.*, 1995). Legumes contribute mineral N P, K and organic matter to the soil (Fujita *et al.*, 1992). Legume relay crops have numerous advantages which include improved soil productivity through increased soil organic matter (SOM) content, improved soil physical and microbial properties, suppression of weeds and pests, and erosion control. Their contribution of fixed N to the soil and succeeding crops reduces the need for inorganic fertilizers (Palm *et al.*, 1997).

Some legumes are rich nutritious source of protein for human and livestock (Smith and Huyer, 1987). Legumes are used to improve soil fertility for increased yields of cereal crops (Giller *et* *al*., 1997). Meyer (1987) reported that wheat grain yield following a green manure sweet clover crop were 96% higher than continuous wheat yields and 9% higher than following fallow when unfertilized and, 31 and 10% higher respectively, when fertilized with 56 kg Nha^{-1}. Morris *et al*., (1986) reports that a fast growing tropical legume can accumulate more than 80 kg N ha^{-1} in 45 days and that rice yield responses exceeding 2t ha^{-1} are possible from green manure incorporated soils. According to Buresh *et al*., (1993) weeds (fallow) and legume crops before rice can reduce soil-N loss by assimilating Nitrate - Plant N and then recycling this N through incorporated plant residues where it is rapidly mineralized and used by rice. Backer *et al*., (1994) observed that synchronizing soil N supply with N demand by incorporating residues with suitable chemical composition may not immediately increase rice grain yields, but improves long term soil fertility. Ladha *et al*., (1996) found proportions of N fixed by Legume cover crops (LCC) to range from 50 to 100%.

In other rice growing regions of the world, legumes have been evaluated for their potential to enhance paddy soils fertility (Walters *et al*., 1992; Nyborg *et al*., 1995). Dual cropping of *Azolla microphylla* with rice enhanced soil available N status and rice grain yield necessitating a skip of second N topdressing at 30 days after transplanting (DAT) [Vendan *et a*l., 1999]. In India, *Sesbania rostrata* contributed to higher yields of rice (Singh *et al*., 1999). Its incorporation increased soil organic carbon (SOC) content, available N and available P significantly compared with mineral fertility treatment. According to Geriek (1999) *Azolla mexican* when applied to experimental fields in Turkey increased total soil N by 38-56% and contributed to total soil organic matter. In India, 45 day old S*esbania aculeata* (daincha) at 12 ton ha^{-1} was incorporated *in situ* 3 days before rice transplanting against farm yard manure and C*rotalaria juncea* and alongside 50%, 75% and 199% recommended dose of inorganic N fertilizers (Hemalatha *et al*., 1999). This improved rice quality by increased optimum cooking time, lowered gruel loss, and improved total amylose and crude protein contents. *Sesbania aculenta* improved quality characters of rice best. Incorporation of daincha at 12 ton ha^{-1} and application of 50% of recommended inorganic N plus *Azospirillum* inoculation improved the rice quality (Cattelan and Hungria, 1993).

2.5 Soya bean residues

Toomsan *et al*, (1995) observed that returning of Soya bean and groundnut stover to the soil improved rice growth and grain yield. Banik and Bagchi (1995) found that inter-cropping of rice and Soya bean gave the best returns. Soya bean hosts *Bradyrhizobium japonicum* strains in its root nodules, which fix atmospheric N. The association can fix over 100 kg N ha^{-1} per season and frequently triple this amount in upland ecology (Gardener *et al.*, 1985).

2.6 *Sesbania spp* residues

Sesbania aculeate and urea increased soil fertility and N recovery efficiency which was reflected by improved rice growth and increase in grain yield (Hussain *et al.*, 1995). In an experiment by Ladha *et al.*, (1995) *Sesbania rostrata* could be substituted for 35-90 kg of applied N. According to Ndoye *et al.*, (1993) *Sesbania rostrata* increased rice yield from 1.7 to 4 t ha^{-1} with no application of N–fertilizer in Senegal. Gurung and Sherchan, (1993) in Nepal found out that rice responded better than maize to incorporated green manure of *Sesbania aculeata*. The grain and straw yields of rice were significantly higher from all green manure treatments than the control (no green manure). Transplanting rice immediately after incorporation of green manure was more beneficial than allowing time for the decomposition of the green manure. *Sesbania sesban* can be used for short term (<6 months) and medium term (6-12 months) fallows for restoration of soil fertility in nutrient depleted soils (Niang *et al.*, 1996). In a single year, the pruning of

Sesbania sesban can provide to a hectare of cereal crop, up to 448 kg N, 314 Kg P, 125 Kg K, 114 Kg Ca and 27.3 Kg Mg (Dakora and Keya, 1997).

2.7 Effect of legumes cultivation on N losses from soil

During the dry season, a large amount of mineral N can accumulate in the surface soil horizons in un-cropped paddy fields due to mineralization of organic N in the soil. This can amount to between 30 and 90 kg N ha^{-1} and is largely present in the form of nitrate (Brush *et al.*, 1989). This nitrate can easily be lost by leaching or denitrification when the soil is flooded. More than 95% of ^{15}N labelled Nitrate fertilizer was lost from the soil after only nine days of flooding. It is likely that a green manure crop growing before the soil is flooded would absorb much of this mineral and help reduce N losses from the soil (George *et al.*, 1990). In this way green manure can be highly beneficial compared to fertilizer N.

2.8 Matching N release with crop N demand

Decomposition of shoots of forage legumes or prunings of legume trees can be rapid. Several reports suggest that 40% or more of the N in legume shoot material can be released in less than two weeks after addition to the soil (Cornforth and Davis, 1968; Wilson et *al.*, 1986; Palm *et* al., 1988). This means that the N may be released before the crop growth stage that can take full advantage of it. The synchronisation of nutrient release from organic matter with optimum timing for uptake by crops is a major challenge for research (Woomer and Ingram, 1990).

2.9 Residue management

An evaluation of traditional cropping systems in Africa shows that crop rotations involving legume and cereal monocultures is by far more sustainable than inter-cropping, the most dominant cultural practice in the continent (Dakora and Keya, 1997). These researchers indicated that achieving sustainable yields in sub Saharan Africa would require a deeper understanding of how fixed N in legume residues is managed in the soil environment in addition to expanding the use of neglected African food legumes. Among different legume cover crop management strategies, incorporation gives higher yields of maize where the legume cover crop is incorporated *in situ* than where residues are mulched or removed (Fischler, 1997; Kirungu,1998).

2.10 Biological Nitrogen fixation (BNF)

The cost of heavy use of chemical fertilizers in agriculture is a global concern. Sustainability considerations mandate that alternatives to Nitrogen fertilizer must urgently be sought (Bohlool *et al.*, 1992). Biological Nitrogen Fixation (BNF), a microbiological process which converts atmospheric Nitrogen into a plant useable form, offers this alternative. Nitrogen fixing systems offer economically attractive and ecologically sound means of reducing inorganic fertilizer inputs and improving internal resources. Symbiotic systems such as that of legumes and *Rhizobium* can be a major source of N in most cropping systems.

Biological Nitrogen fixation (BNF), is mediated by the enzyme complex nitrogenase, which consists of an Fe protein and an Mo-Fe protein (Gardener *et al.*, 1985). Requirements for high nitrogenase activity include (1) an O_2 free environment; (2) low level of available substrate N, such as ammonia; and (3) high levels of available C to energize the system and protect nitrogenase against O_2 inactivation. A *Rhizobium* species generally can colonize and infect a number of legume species (cross-inoculation), but certain *Rhizobium* species are specific such as *R. japonicum* to Soya bean (Cattelan and Hungria, 1993). Strains of *Rhizobium* vary widely in effectiveness, ranging from no fixation to effective fixation (Gardener *et al.*, 1985). Many of the soils under farm conditions in East Africa are severely depleted in nutrients and would result in reduced performance and N-fixation (Gachene *et al.,* 1999). *Rhizobia* can persist heterotrophically in soil for many years without an intervening host-legume crop. Soil levels of Ca, P and K aid in *Rhizobium* survival, nitrogenase activity, and enzyme activity associated with nitrogenase. Inoculation can be beneficial to establishment and N_2 fixation of new seedlings of legumes in areas where the crops have not been grown previously or where *Rhizobium* populations may have been severely reduced by adverse soil conditions (Gardener *et al.*, 1985; Cattelan and Hungria, 1993). Other soils lack suitable strains of *Rhizobia* that may enhance BNF. Inoculation of legume seed with the compatible *Rhizobium* strain and application of required nutrient such as P enhances the effectiveness of the LCC. A study by Karanja *et al.*, (1997) in which they looked at the effects of inoculation and N and P fertilization on nodulation, indicated that legume nodulation increased only with P application. Most of the legume screening network (LSN) results indicates that there were no significant differences between the performance of inoculated and uninoculated in terms of effective nodules and biomass production (Mureithi *et al.*, 1998). Angaw (1992) indicated that some *Rhizobium* enhances N fixation even under waterlogged conditions. In most studies involving trials with P, maximum dry matter (DM) yields were obtained at P application rates of 20-40kg P ha^{-1} (Nnadi *et al.*, 1993 and Karanja *et al.,* 1997).

2.11 Soya bean, its uses and benefits

Soya bean is a leguminous plant which produces seed with high protein and oil contents. The nutritional value of soy protein is high being rich in essential amino acids. The oil is rich in the desirable polyunsaturated fatty acids especially linoleic, an essential fatty acid and lecithin, an important phospholipid that contributes to lowering of blood cholesterol. Soya beans can appropriately substitute meat and babies can be raised on soy milk enriched with Vitamin B_{12} and calcium. Soya bean can locally be prepared for household use in a variety of ways including mixing soy flour with cereal flours for porridge and as beverage. It could also be sold for industrial processing of Soya bean beef, oil, milk, and other products (Carrao and Gontijo, 1993). Soya bean is also valuable for production of a high protein seed cake which is the residue left after oil extraction and has a high nutritional value for livestock feeding (MOALDM, 1995b).

Soya bean *(Glycine max L.J.Marr)*, the 'golden bean', or the ‘gold that grows’, as is commonly referred to is of great economic importance the world over. It has enormous protein reserves and has a wide range of use in products that include animal feed, human food, and non-edible products. Compared to other oilseeds, Soya beans have the highest protein content of at least 36 per cent. Groundnuts, simsim, sunflower, and rapeseed have less than 30 per cent protein by weight. The ratio of protein in Soya bean per weight as compared to meat, milk and eggs are 2:1, 8:1 and 40:1 respectively. Soya bean is cheaper to produce than other proteins and has over 360 uses both industrial and domestic. No other protein rich food can be produced in as large quantities and as cost effectively as the Soya bean as it yields more protein per unit area of land than any other crop making it the most inexpensive source of high quality protein (MOALDM, 1995a)

The Soya bean plant is able to obtain 65-88% of its N requirement from atmospheric Nitrogen fixation. Most of these N is translocated into the seed while the rest is left in the crop residue. The plant is sometimes grown as a green manure. Soya beans help in reducing use of nitrogen fertilizer and therefore reduce cost of production and environmental pollution and degradation associated with chemical N fertilizers (Ladha et al., 1992). Soybeans, like most legumes perform nitrogen fixation by establishing a symbiotic relationship with the bacterium *Bradyrhizobium japonicum* (syn. *Rhizobium japonicum*). However, for best results an inoculum of the correct strain of bacteria should be mixed with the soybean (or any legume) seed before planting (Cattelan and Hungria, 1993)

.The introduction of Soya bean crop to several countries has led to a shift in their cropping systems from a monocrop (post-rainy wheat or other crop) to a Soya bean-wheat or Soya bean-other crop system. This cropping system change has resulted in an enhancement in the cropping intensity and resultant increase in the unit area profitability from the land use (Paroda, 1999). Soya bean crop is seen to be useful for the sustainability of the major cereal based cropping systems in the world. Among the legumes, the soybean, also classified as an oilseed, is pre-eminent for its high (38-45%) protein content as well as its high (20%) oil content. The bulk of the soybean crop is grown for oil production, with the high-protein defatted and "toasted" soy meal used as livestock feed. A smaller percentage of soybeans are used directly for human consumption (Carrao and Gontijo, 1993).

Soybeans may be boiled whole in their green pod and served with salt, under the Japanese name *edamame*. Soybean sprouts, called *kongnamul* are also used in a variety of dishes. Common forms of soy (or *soya*) include soy meal, soy flour, "soy milk", tofu, miso, natto, textured vegetable protein (TVP), which is made into a wide variety of vegetarian foods (Carrao and Gontijo, 1993). Soybeans are also the primary ingredient involved in the production of soy sauce (or *shoyu*).

2.11.1 The Soya bean Plant growth Stages

In the main production areas, Soya beans are planted in rainfall season or by irrigation. The seed germinates and the plant emerges in about two weeks. The rate of growth of the Soya bean plant depends on the amount of sunlight per day and temperatures. Soya bean is a legume and like other beans, the plant is capable of extracting nitrogen from the air through N fixation to assist in its own growth. Its deep root system makes Soya beans resistant to drought. Eventually, the plant reaches three to five feet in height. Each plant produces 60 to 80 pods, each of which usually contains two to four Soya beans (Garcia, 1993). At maturity, the lush green colour of the Soya bean plant turns yellow, the Soya beans begin to dry and the leaves begin to drop away from the pods. When the leaves have fallen and the moisture of the Soya beans has dried to less than 15 percent, the crop is harvested (Garcia, 1993).

2.12 Malaria in irrigation schemes

2.12.1 Malaria and development

Malaria affects 300-500 million people each year, resulting in the deaths of at least one million people over the same period (Mwangangi *et al.*, 2006a). More than 90% of morbidity and mortality due to malaria occurs in sub-Saharan Africa. Malaria has slowed economic growth in Africa leading to a gross domestic product level up to 32% lower than it would have been had the disease been eradicated from the continent in the early sixties. Every year 39,000 children die of malaria in Kenya (Mwangangi *et al.*, 2006a). It is the number one killer of children and women in Kenya. Malaria is also known to cause cerebral complications that lead to mental disability. On a broader scale malaria impacts negatively on development in Africa in all sectors including agriculture, as funds meant for development initiatives are channeled to combat malaria (WHO, 1998). Due to its negative effects on agriculture, it is important to evaluate the impact of any new agricultural intervention on malaria in irrigation schemes.

Up until the nineteen thirties, malaria was endemic in a wide swathe extending to several countries in southern Europe and south-eastern United States. During the next few decades, these northern countries either eradicated or effectively controlled the disease. Malaria endemicity is now restricted to a barely-changing geographic band within and around the tropics. Sub-Saharan Africa continues to be the epicenter of this deadly zone (Republic of Kenya, 2001).

The war on malaria was largely won in Europe and in the US due to improvements in standards of living (Mutero *et al.*, 2000 and 2003). General development was the engine of the anti-malaria war machine in Europe and the United States, and it remains the most potent weapon against the disease to date (Bruce-Chwatt, 1993).

2.12.2 Malaria Vector growth and development

A mosquito passes through four stages in its life cycle. The stages are the egg, larva, pupa, and adult. Eggs, larvae, and pupae must have standing water to develop. There are four larval growth stages, called "larval instars." All larval stages resemble each other, except that each stage is larger than the preceding one. The first stage hatches from the egg and the fourth stage becomes the pupa (Mutero *et al.*, 2000). The mosquito lay eggs in standing water and the larvae need about 7-10 days in a water environment to develop into adult mosquitoes (Lacey and Lacey, 1990).

2.12.3 Malaria and rice production

More than 75 percent of the world's rice is produced in irrigated rice lands, which are predominantly found in Asia (Lindsay et al. 1995). The abundant water environment in which rice grows best differentiates it from all other important crops. Rice cultivation has traditionally been associated with vector-borne diseases, especially malaria (Lacey and Lacey, 1990). The main vector of malaria in most of sub Saharan Africa, *An. gambiae s.l.*, has long been associated with rice cultivation (Grainger, 1947; Surtees, 1970; Muturi *et al.*, 2006).

Alternating crops to allow drying of rice fields was therefore tested for its mosquito control potential as far back as early twentieth century. Some dramatic results were obtained in studies in Portugal (Hill and Cambournac, 1941) and Indonesia. However, with the introduction of DDT after World War II, water management and other environmental measures to control mosquitoes were neglected. It is only since the 1980s, after the failure of the DDT-based eradication campaigns of malaria that environmental control measures have received renewed attention (WHO, 1982; Ault, 1994). A study by Forget and Lebel (2001) indicated that an ecosystem approach to human health had distinct advantages for the development of integrated and sustainable strategies for malaria reduction when compared to the traditional uni-disciplinary approaches to research. Recent local study data provided a good understanding of health problems and linkages with agriculture and lifestyles, social issues such as gender and alcoholism, and their implications for productivity (Mutero *et al.*, 2003).

Ijumba, (1997) did experiments in the Lower Moshi irrigation scheme in Tanzania with different rice varieties and different water management methods. Alternate wet/dry irrigation (AWDI) resulted in increased mosquito production compared with permanent flooding. It was concluded that the small pools that were created by drying out the fields remained highly productive for the malaria vector.

A field study was carried out in the rice irrigation scheme *Office du Niger*, Mali, to observe malaria mosquito larval development as related to differences in field irrigation practices, such as water level, irrigation application and irrigation frequency (Klinkenberg *et al.*, 2002). The results show that minor differences in water management do result in small differences in mosquito development, with respect to larval densities and species composition. The main malaria vector for the area, *An. gambiae s.l.*, developed predominantly in the first six weeks after transplanting. Due to improper drainage after harvest *An. gambiae s.l.* breeding quickly re-established on fields where small water pools remained. The study suggested a strict performance of the agricultural calendar in combination with a rotation of transplanting in large blocks.

2.12.4 Malaria vector study in Kenya

In an experimental fields in the Mwea rice irrigation scheme in Kenya in 1998, higher numbers of *An. arabiensis* 1^{st} instar larvae were found in alternate wet/dry irrigation (AWDI) fields than in continuously flooded fields, indicating that the AWDI water regime provided the most attractive environment for egg laying (Mutero *et al.*, 2000). However, the ratio between the 4^{th} and 1^{st} instar larvae for AWDI fields was only 0.08, indicating very low survival rates. In contrast, the 4^{th} / 1^{st}- instar ratio for the non-AWDI fields ranged between 0.27 and 0.68, suggesting much higher survival under flooded water management regimes.

Malaria was perceived by the community as a priority health problem in Mwea (Mutero, *et al.*, 2003). Many households were willing to use preventive measures but were unable to do so due to poverty.

A study on economic analysis of rice production systems in Mwea Irrigation Scheme (Mutero *et al.*, 2000) pointed out that rice double cropping is technically inefficient as regards the use of production resources. The findings highlighted the need for a farming system that could reduce the time that paddies are wet.

Various observations were made regarding the prevailing farming systems, their possible links with malaria and the socio-economic status of the local community (Mutero *et al.*, 2003). The findings indicated presence of malaria risks associated with farming practices (high vector population due to prolonged flooding in paddies); poor soil fertility and structure due to continuous mono-cropping of rice; food insecurity and poor nutrition (based on rice staple) and apparent lack of grain legume cultivation; low use of agricultural productivity resources (land labour, water and capital) during off-season for rice and finally, poverty leading to poor access in health seeking (preventive and curative).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site Description

This research was carried out in Mwea Irrigation Agricultural Development (MIAD) Center situated 100 km NE of Nairobi at 37° 20'E and 0°, 41'S. Mwea is located at 1159 m above sea level and stretches between latitude 0°37'S and 0°45S and longitudes 37°14'E and 37°26'E. It has a mean minimum and maximum temperature of 17 °C and 26 °C, respectively. Relative humidity varies from 52–67%. The annual average solar radiation is 573 cal. cm/day. It rises above 600 cal. cm/day in January-May and September-November. It falls below 500 cal. cm/day during the June - August and December periods (NIB, 1996). It receives mean annual rainfall of 940 mm in two seasons. The site lies in Agro-Ecological Zone (AEZ) L that has high agricultural potential with dark deep vertisols with average pH of 6.8 (Jaetzold and Schimdt, 1982). The soils are low in Organic Carbon (OC), Nitrogen (N), Phosphorus (P) and Potassium (K). N, P and K are added from inorganic sources. Mwea is the main rice producing area of Kenya. National census of 2009 showed that, the Mwea irrigation scheme has approximately 268,990 persons in 47,073,000 households. The Mwea rice irrigation scheme is located in the west central region of Mwea Division and covers an area of about 23,640 ha (Plate 3.1). More than 75% of the scheme area is used for rice cultivation. The remaining area is used for horticulture and subsistence farming, grazing and community activities.

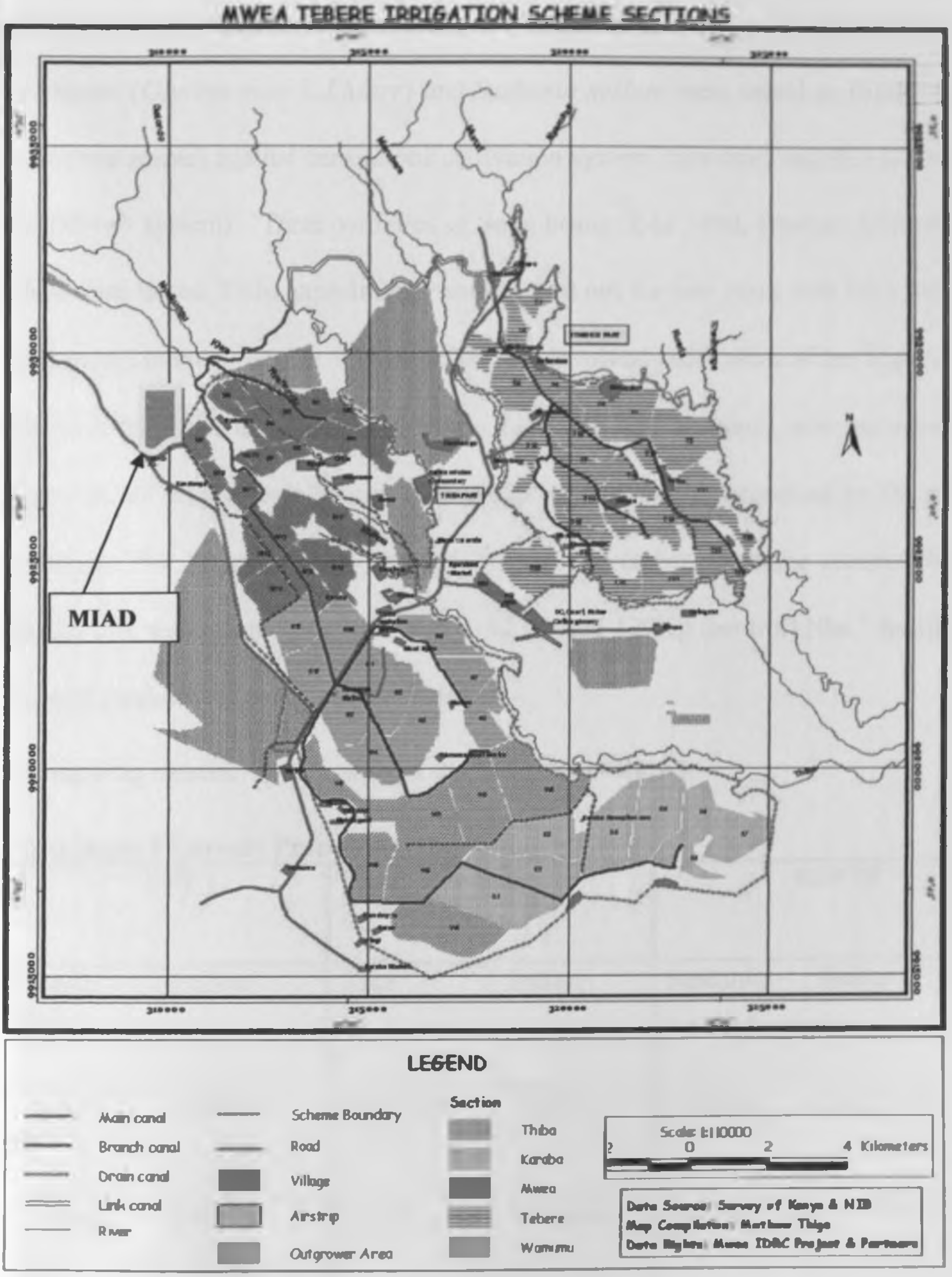


Plate 1.1: Mwea Irrigation Scheme showing the site of research study

3.2 Experimental Design, Treatments and Variables

Soya beans (*Glycine max L.J.Marr*) and *Sesbania sesban* were tested as follow-up crop to the rice (*Oryza sativa*) against continuous cultivation system (rice-rice) and rice followed by fallow (rice-fallow) systems. Three varieties of Soya beans: EAI 3600, Bossier, Duiker and *Sesbania sesban* were tested. Field experiments were carried out for two years each with two seasons. The first season covered October to May 2004 and involved cultivation of the legume crop against fallow control in a randomized complete block design. *Sesbania* was incorporated as green manure at 50 days after planting. Soya bean residue was incorporated in the soil after grain harvesting. The second season covered June to November when the commercial rice variety NIBAM 108 was planted in all plots at 0, 40, 80 and 120Kg (control) Nha^{-1} fertilizer levels in a Split plot randomized complete block design.

The cropping seasons were organized and laid out as follows;

Experiment I Layout: Preceding crop testing

REP I		REP II		REP III	
Sesbania sesban	Fallow	Rice	Fallow	Sesbania	Bosier
EAI 3600	Bosier	EAI 3600	Duicker	Duicker	EAI 3600
Rice	Duicker	Bosier	Sesbania	Fallow	Rice

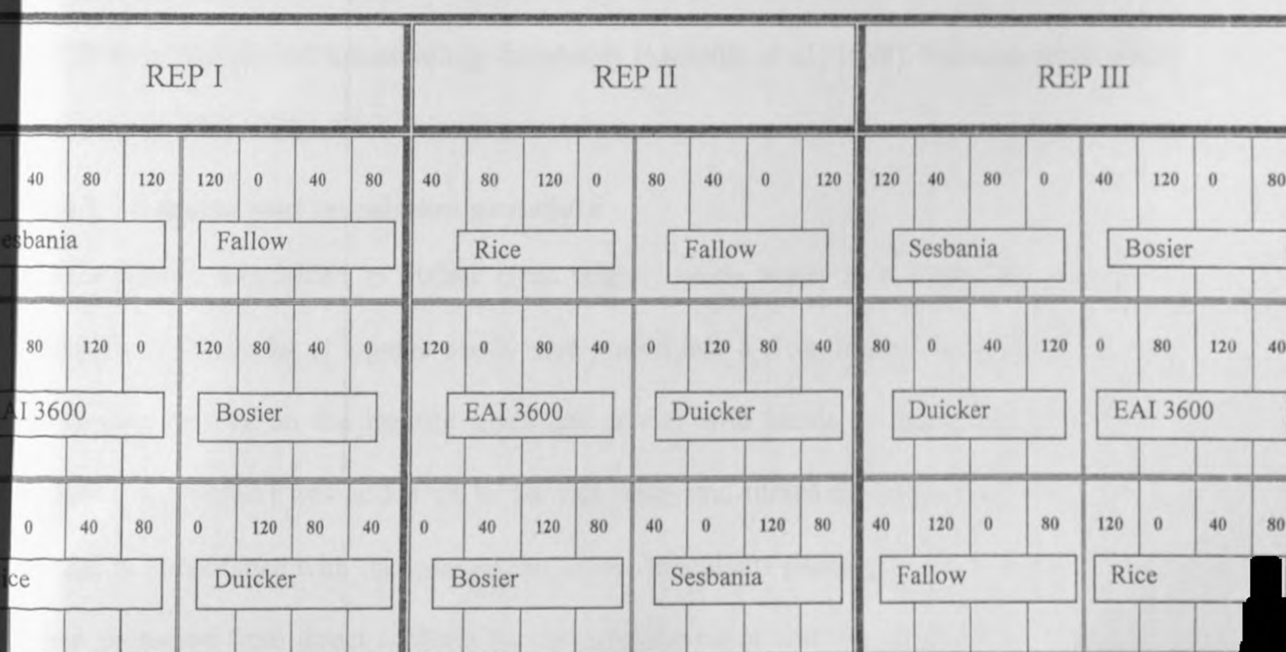
Key: *Plots size 13m x 10m; REP = Replication

After harvesting the preceding crop and incorporating residues, main plots were divided into subplots where four levels of N fertilizer were applied and NIBAM 108 planted in all the plots.

3.3 Treatments Description

The three Soya bean varieties, EAI 3600, Bossier and duiker are of short growth duration adapted to heavy clay soil condition. *Sesbania sesban* is a perennial semi-woody shrub and behaves as an annual. It tolerates waterlogged soils and flooding (Duke, 1981). Sesbania tolerates salinity (McLeod, 1982) and has been used as a green manure for reclaiming saline soils. NIBAM 108 is a non-scented, medium to tall rice variety which is commercially cultivated. It has a medium to high tillering ability, and takes an average of

xperiment II Layout: Succeeding crop testing



ey *Figures indicate Kg Nha-1; Main plot size: 13mx10m; Subplot size: 3mx10m

145 days to mature. It is an Indica type variety with medium thin grains, high milling and cooking qualities. It was chosen because it is high yielding and responds quickly to fertility improvement. Fallow treatment involved leaving land untilled till the next season (Huxley and Van Houten, 1997) to simulate the conventional practice. The ground was maintained at a status similar to that of farmers' paddy field after rice harvesting. Farmers' fields are left undisturbed for about 2-6 months. The fields are mainly grazed during the period before land preparation. However in this experiment, weeds that grew during the fallow period were incorporated into the soil during land preparation 30 days prior to subsequent rice planting. Grazing could not be done due to the limitation of the size of the experimental plot area.

3.4 Crop Management

3.4.1 Rhizobium Inoculant strains

The Seedbed for Soya bean was direct ridged at a spacing of 100 cm apart. Soya bean seeds were initially inoculated with *Bradyrhizobium japonicum* combination of USDA 110 and SEMIA 5019 from Kabete soil microbiology laboratory (Mureithi *et al*., 1998). Sesbania seeds were inoculated with USDA 4066 rhizobium strain.

3.4.2 Legume seed inoculation procedure

Gum Arabic was added to 300ml clean slightly warm water in a bottle and shaken well to dissolve. Fifteen kg of legume seeds were placed into a clean basin. The Gum Arabic solution was then poured on the legume seeds and mixed with hands to wet all seeds. The 30g of inoculants (Biofix) was added on to the wet seeds and mixed thoroughly to uniformly coat all seeds in accordance with the instructions on the inoculants package. The inoculated seeds were then protected from direct sunlight by covering the basin with gunny bag and keeping it under shade. This was followed by drill sowing at a rate of 35 kg/ha into a moist seed bed.

Sesbania sesbsan seed were treated with legume tree seed inoculants from Kabete campus microbiology laboratory following the same procedure.

3.4.3 Planting

Soya bean seeds were drilled on the upper side of the irrigated ridges 20cm apart at a rate of two seeds per hole. Phosphate fertilizer was applied at 60kg $P_2O_5ha^{-1}$. *Sesbania* seeds were broadcast on the seed bed. Insecticide, Fentrothion, was applied at a rate of 1 litre per ha at 35 days after transplanting (DAT) and at 7 days after germination (DAG) for Soya beans. Additionally Benlate fungicide sprays were applied at 40g per 20lt pump fortnightly to protect Soya against powdery mildew disease. Insecticide sprays were also applied at 35 DAG to control aphids, spider mites and leaf feeding insects. Experimental plots were kept weed free by manual weeding at 7, 30 and 45 DAG. Irrigation was maintained to supply the leguminous crops with enough moisture and to keep the rice plants flooded according to growth stage (Wanjogu *et al*., 1995). Grains of Soya bean were harvested at maturity and the Soya bean residue incorporated into the paddy field soil in readiness for the cultivation of the subsequent rice crop.

Rice plots were flooded and tilled using tractor drawn rota-tillers. They were then leveled for transplanting. Nursery bed was prepared in a similar manner and finely leveled to prepare a fine seedbed where pre-germinated seeds were sown. Rice Seedlings were raised in the nursery and transplanted at 28 Days after sowing (DAS) and transplanted at a rate of two seedlings per hill spaced 20 cm x 20 cm apart. During the first season experiment rice was supplied with 120kg Nha^{-1} in two splits; half at transplanting, and the rest at 74 DAT (Matsushima, 1984). Phosphate fertilizer was also applied before transplanting at 60kg P_20_5 ha^{-1} (Wanjogu *et al*., 1995). Insecticide, Fentrothion, was applied at a rate of 1 litre per ha at 35 DAT to control stem borer (*Maliarpha* spp.). Experimental plots were kept weed free by manual weeding at 16 and 35

DAT. Flood irrigation was maintained to keep the rice plants flooded according to growth stage (Wanjogu *et al.*, 1995).

3.4.4 Observations and data collection for the first season experiment: Preceding crop trial

Observations and data collection were done on plant growth and yield parameters, as well as malaria vector larvae populations. Economic analysis was done to determine the gross margin of the test factors.

3.5 Second season (experiment II): cultivation of the Subsequent rice crop

During the second experiment NIBAM 108 was planted in each of the main plots at four N fertilizer rates (0, 40, 80 and 120Kg Nha^{-1}). All other cultural practices were followed as described for the first experiment for rice and in accordance with recommendations of Mwea Rice cultivation manual (Wanjogu *et al.*, 1995).

3.6 Parameters measured during the experiment II

3.6.1 Agronomic data collection

Data on various variables were collected as specified in standard evaluation systems for rice IRRI, (1986) and Gomez and Gomez, (1984). Yield data were obtained from the inner area of the 2m x 5m plots. The parameters observed, measured and recorded for analysis were:

1. **Tiller number (No) at panicle initiation and maturity stages**

   Number of tillers per hill at panicle initiation and maturity stages were determined by counting the tillers from 9 randomly selected hills per plot. Tiller No. per hill were calculated from the average of the 9 selected hills.

2. Plant height at vegetative phase and maturity stage

Plant height (cm) was determined at vegetative phase and at maturity stages. Plant heights were measured using 1 m ruler from the ground level to the tip of the longest leaf or panicle of ten randomly selected hills per plot. The plant height was determined by calculating the average plant height of the 10 hills.

3. Panicle number per m^2 (effective tillers)

Panicle number per m^2 (effective tillers) were determined by counting panicles from 9 hills selected at random per plot and expressed as productive tillers per m^2 by extrapolation using the 20cm x 20cm spacing.

4. Grain number per panicle

Grain number per panicle was obtained from the average number of filled grains per panicle taken from 3 randomly selected hills in each plot.

5. The 1000 kernel weight

The 1000 kernel dry weights were determined by counting 1000 filled grains at 14% moisture content obtained from threshed and winnowed paddy grains of randomly sampled hills from treatment plots.

6. Grain yield

Grain yields were determined from the weight of the grain harvested from each plot after threshing and cleaning and correcting to grain yield per ha at 14% moisture content.

7. Harvest Index (HI)

Harvest Index (HI) was determined from the average dry weight of the entire above ground shoot and grain weight from 3 randomly selected $1m^{-2}$ quandrant per plot and converted to weight per ha by extrapolation. HI (%) was then calculated as follows:

HI = {Grain weight /(Grain weight + Above ground shoot weight)} x 100

8. Plant tissue analysis

Plant tissue analysis for nutrient content of the herbage was determined by drying 100g samples at 70°C to constant weight followed by grinding to <1mm and determination of nutrient composition in the laboratory for N by Kijedahl method, P and K by extraction as described by Okalebo *et al.*, (2002).

9. Soil analysis

Soil analysis was done before and after cropping; 20 days before legume/rice planting and 7 days after harvesting. Two composite soil samples were taken from all treatments plots at 0-15 and 15-30 cmsoil profile depths. The samples were the analysed for pH, organic matter, total N (Kjedahl), available P and exchangeable K (Olsen).

3.6.2 Malaria vector determination: Mosquito Larvae Sampling

Assessment of Malaria vector control was conducted in each of the first season preceding crop trial treatments. Malaria vector larvae were sampled fortnightly in the first season and on weekly basis in the second season by dipping technique. A 350ml dipper was used to scoop water followed by counting the number of *Anopheles gambi* complex larvae. Larvae collected thus were identified as belonging to either *Anopheles arabiensis* or the *Culicine* group of mosquitoes. Mosquitoes of the genus *Anopheles* were easily identified due to their lack of a siphon

(Appendix 4). In addition, abdominal segments III-VII have flattened fan-like hairs. Mosquitoes in the genus *Culex* have a saddle completely encircling segment X. The siphon has at least three pairs of setae on it, not near the base of the siphon (Appendix 4). The larvae were grouped according to species and age (development instars) and graded as early instars (L1, L2) and late instars (L3, L4). The larval sampling was mainly done from transplanting to rice maximum tillering stage. This period of rice growing has been associated with increase in *Anopheles* larval densities and diversity (Mwangangi *et al.*, 2006ab).

3.7 Rice cultivation area mapping

Mapping was done to enhance interpretation and application of results obtained on the potential of the rice-Soya bean system in the context of the entire Mwea Irrigation Scheme. Mapping was done in the entire irrigation scheme to show prevailing rice production patterns both spatially and seasonally. It was meant to establish the main rice crop and ratoon crop patterns, fallow periods and show areas cropped by main scheme farmers and out growers. The maps were also required to show the water supply regime to the different sections and units in the scheme and hence reflect periods of essential and non-essential flooding. The latter occurred when paddies were left idle but flooded awaiting rotavation or during fallow periods when long rains water collected and similarly kept the fields submerged. These patterns were broadly expected to show the general management of this irrigated habitat and point at optimal periods where soya could fit in within the annual cropping cycle of the scheme. This would give indications of the scope for soya to dry up the land, reduce vector breeding sites and hence help control malaria.

3.8 Data Analysis

3.8.1 Agronomic data analysis

Data was analysed with SAS, (1996) and IRRISTAT, 2005. The data obtained were subjected to analysis of variance (ANOVA) and means separated using least significant difference (LSD). The differences were reported at $P \leq 0.05$ and 0.01 levels of significance as described by Gomez and Gomez (1984) and by Statistical analysis programs (SAS, 1996 and IRRISTAT, 2005).

3.8.2 Economic data analysis

3.8. 2.1 Partial budget analysis

Partial budget analysis is the tabulation of expected gains and losses due to a relatively minor change (marginal) in farming method or technology (Amir P. and Knipscheer H.C. 1987 and 1989). The new technology could be technically feasible but this is not a necessary condition for adoption by farmers; the new technology must be profitable. Therefore it is important for scientists developing a new technology or improving an existing one to determine the profitability of the technology. Partial budgets list only those items of income and expenses that change. They (i) measure change in income and returns to limited resources, (ii) provide a limited assessment of risk and (iii) suggest a range of prices or costs at which a technology is profitable. After the changes are determined, the relationship is shown by the following equation:

[Added returns + Reduced costs] - [Added costs + Reduced returns] = [Profit or Loss]

Logic behind partial budget analysis

The farmer's goal is to maximise returns. The following equation describes this relationship:

$$NI = TR - TC$$

where NI is the net income, i.e. the amount of money left when total costs (TC) are subtracted from total returns (TR). Total cost (TC) is composed of the cost of all inputs: variable costs (VC) and fixed costs (FC). Since FC is the same for comparing the new technology and the technology practiced by the farmer, then:

$$TC = VC$$

The farmer wants to know if the new technology will increase his income while the researcher wants to know which technology is potentially more attractive economically. The change in income can be expressed as follows:

$$NI = TR - TC$$

$$NI = TR - VC$$

This relationship can be used as a rule of thumb for partial budgeting, since FC = 0 because by definition fixed costs do not vary (Amir P. and Knipscheer H.C. 1987 and 1989).

If capital is not a constraint, choose the highest NI. Since higher benefits require higher costs, it is necessary to compare the extra (or marginal) costs with the extra (or marginal) benefits.

3.8.2.2 Gross Margin analysis and Source of Additional Benefits

Gross Margin was used to indicate the profitability of each cropping system. The income generating capacity of cropping system was also indicated by the analysis of its gross margin.

This was arrived at by deducting variable costs of production and marketing from the gross value of the crop output, as outlined in equation 3-1 below. The gross value (Total Revenue) is obtained by multiplying the producer price by the total output realized.

Gross margin is the total revenue less the variable costs. It is a useful planning tool in situations where fixed capital is a negligible portion of the farming enterprises in the case of small scale subsistence agriculture The Gross Margin for rice was estimated as a proxy for profitability. The model used for the estimation of the gross margin according to (Olukosi and Erhabor, 1988, 2004 and 2006) is:

$$GM_i = TR_i - TVC_i \qquad \text{(Equation 3.1)}$$

Where: GM_i = Gross Margin for enterprise i

TR_i = Total Revenue for enterprise i

TVC_i = Total Variable Cost for enterprise i

Gross margins per hectare per year were computed to show the profitability of alternating rice production with another crop compared to rice-rice crop (mono crop) per year.

3.8.2.3 Cost Benefit Analysis

Cost-benefit analysis (CBA), sometimes called benefit-cost analysis (BCA), is an economic decision-making approach, used in the assessment of whether a proposed project, is worth doing, or to choose between several alternative ones. It involves comparing the total expected costs of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much (European Commission, 2002).

The benefit-cost ratio (BCR) of Soya bean and second rice crop were computed from the following formula:-

$BCR_i = TR_i/TC_i$

Where;

$TC_i = VC_j + FC_j$

TR_i = Total Revenue from the i^{th} crop

TC_i=total cost from the i^{th} crop

VC_j =Variable Costs for the j^{th} crop

FC_j = Fixed cost for the j^{th} crop

Since fixed cost (FC_j) on irrigation infrastructure is negligible,

then,

$BCR_i = TR_i/VC_j$ (Equation 3.2)

Plate 4.1.2: Cropping systems trial at Mwea showing preceding crop (Soya bean) at Pod filling stage at Mwea showing high foliage for biomass production

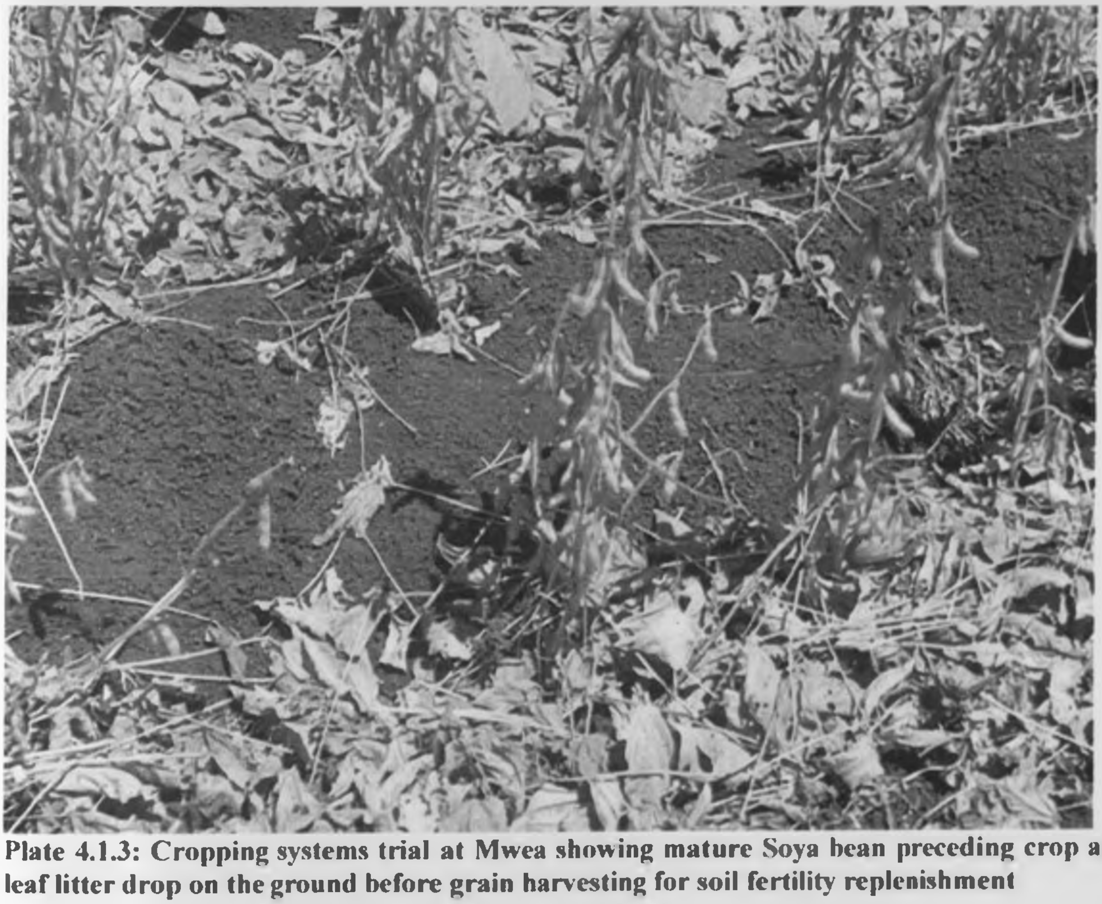


Plate 4.1.3: Cropping systems trial at Mwea showing mature Soya bean preceding crop and how leaf litter drop on the ground before grain harvesting for soil fertility replenishment

Plate 4.1.1: Mature rice crop depict high biomass production and variations in plant vigour among the treatments

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1.0 EFFECT OF CROPPING SYSTEM ON SOIL FERTILITY

4.1.1 Plant Biomass output

During the first season highly significant differences ($P \geq 0.01$) in biomass output was recorded (Table 4.1.1, Plates 4.1.1 to 4.1.3). Rice produced the more biomass followed by Soya bean (EAI 3600 and Duiker varieties). The *Sesbania sesban* treatment gave the lowest biomass followed by fallow.

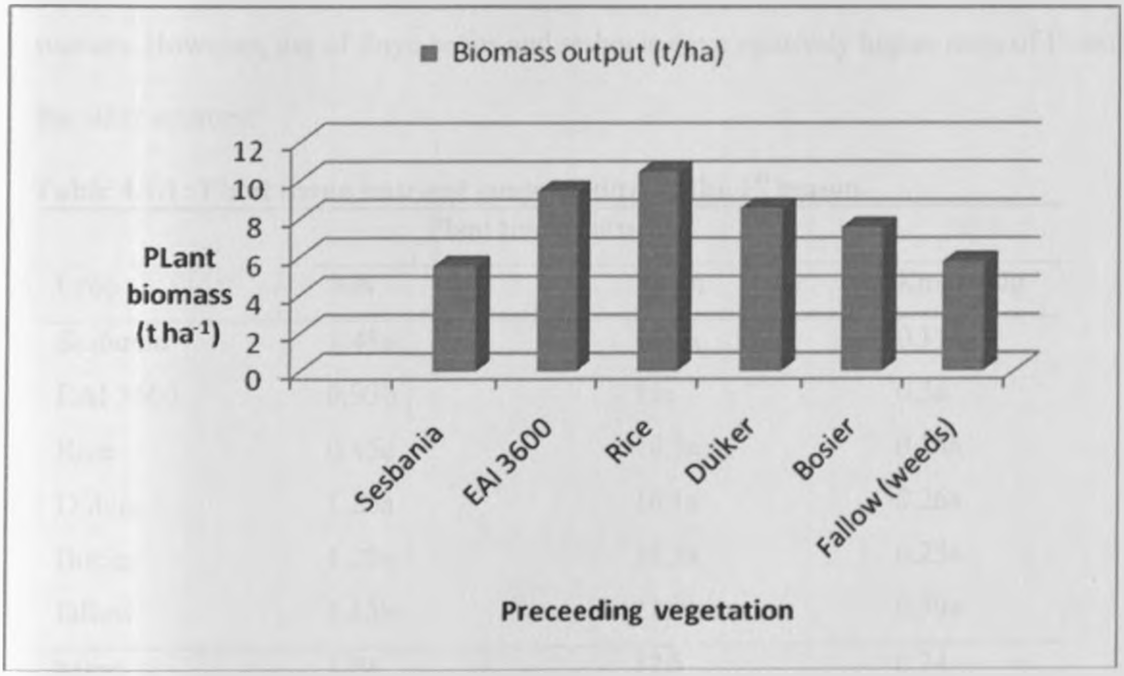


Fig 4.1.1: Cropping system preceding crop biomass output

4.1.1.1 Plant residue nutrient (NPK) content during the first season

The plant tissue analysis N, P and K results are presented in Table 4.1.1 while corresponding total nutrients added to the soil from the return of residue is presented in Fig 4.1.2.

Nitrogen (N)

During the first season there were significant (P<0.05) %N differences among the test plant tissue (Table 4.1.1). *Sesbania* had the highest N followed by Duiker and Bosier. The lowest N was recorded in the rice–rice system.

Phosphorus (P)

There were no significant (P<0.05%) differences among the test soil fertility replenishment sources. However, use of Soya beans and sesbania gave relatively higher rates of P compared to the other sources.

Table 4.1.1: Plant tissue nutrient contents during the 1st season

	Plant tissue nutrients		
Crop	%N	Pppm	Kme/100g
Sesbania	1.48a	12.3a	0.11a
EAI 3600	0.93b	11a	0.3a
Rice	0.45c	10.3a	0.14a
Duiker	1.25a	16.1a	0.26a
Bosier	1.25a	13.3a	0.25a
fallow	1.13b	11.9a	0.39a
Mean	1.08	12.5	0.24
CV	0.43	4.61	0.22
LSD	22	20	50
P>0.05	0.05	0.181	0.132

Key: Means followed by the same letter are not significantly different

Potassium (K)

There were no significant (P<0.05%) K means differences among the soil fertility replenishment plants residue. Nevertheless, the fallow soil fertility replenishment sources followed by the soya bean treatment gave relatively high rates of K

4.1.1.1.1 Total nutrients added to the soil through residue incorporation during the first season

The results are presented in Fig 4.1.2

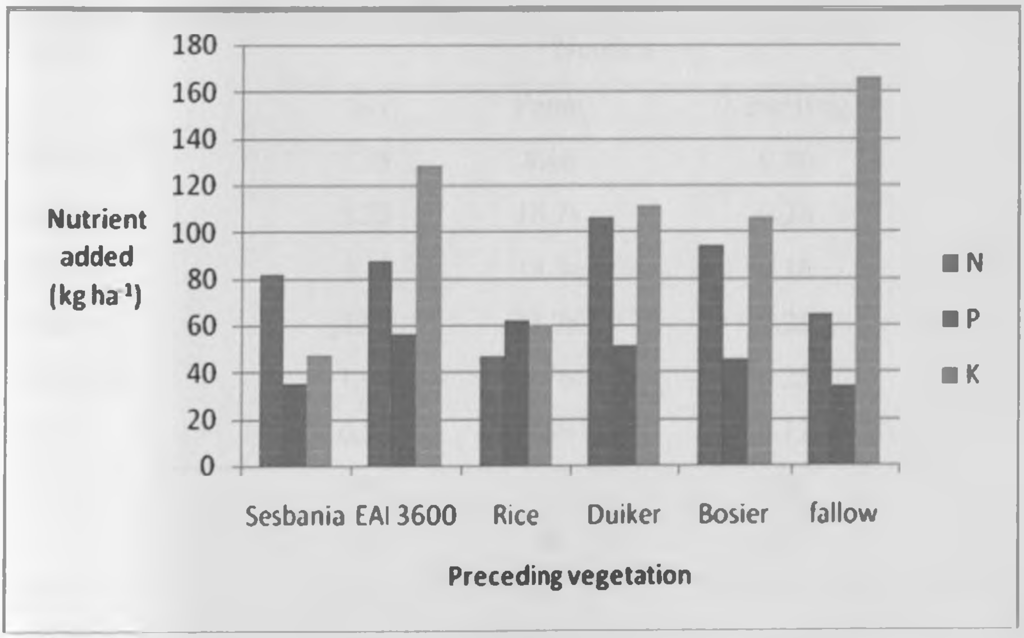


Fig: 4.1.2 Total nutrients added to the soil through preceding plants residue incorporation during the first season at Mwea

The soya bean plants residues replenished averagely higher soil macro nutrients to the soil than the other treatments in exception of Potassium which was highest in fallow (weeds) treatment.

4.1.1.2 Plant tissue analysis for the 2nd season

The results are presented in Table 4.1.2.

During the second season, significant N and P plant tissue content differences were observed among the treatments (Table 4.1.2). *Sesbania* gave higher %N followed by Duiker. Rice straw gave the lowest N content. The highest P content was recorded in duiker followed by Bosier. The lowest P was recorded in *Sesbania* herbage. There was no significant difference among the treatments for K.

Table 4.1.2. Nutrient composition of soil fertility replenishment plant stover during the second season at Mwea

Crop	Nutrient		
	%N	Pppm	Kme/100g
Sesbania	1.35	8.4b	0.40
Duiker	1.23	16.7a	0.26
Bossier	1.16	13.3a	0.16
Fallow	1.09	11.7a	0.25
EAI 3600	1.05	8.7b	0.25
Rice	0.55	9.3b	0.12
Mean	1.05	11.5	0.91
CV	27	26	33.5
LSD	0.521	5.5	5.5
P>0.05	0.041	0.05	0.49

Key: Means followed by the same letter are not significantly different

4.1.1.2.1 Total nutrients added to the soil through residue incorporation during the first season

The results are presented in Fig 4.1.3

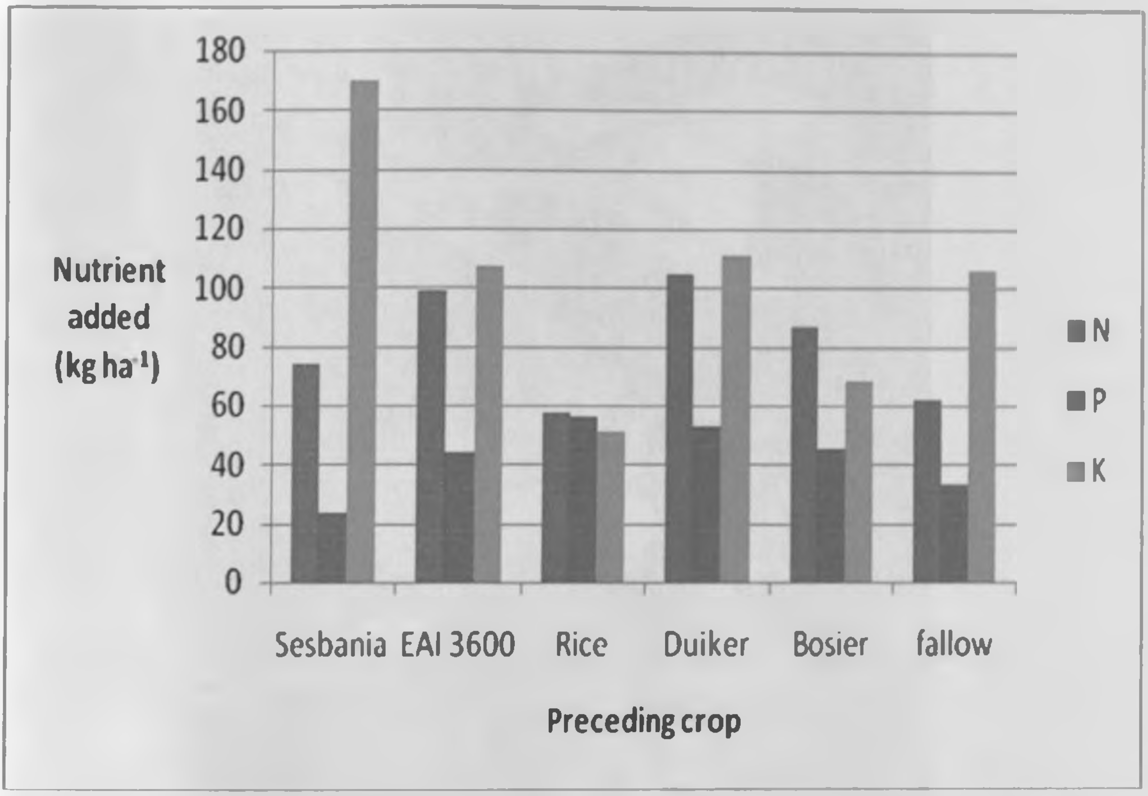


Fig: 4.1.3: Total nutrients added to the soil through residue incorporation during the 2nd season

During the second season soya bean plants residues replenished averagely higher amount of soil nutrients to the soil than the other treatments in exception of K which was highest in *Sesbania sesban* and equivalent in fallow treatment. Rice straw incorporation gave the lowest replenished macro nutrients. The soil N was replenished from the incorporation of plant residue and N fixation depicted by high number of nodules on soya bean plants which were active as observed from their internal reddish colour [Plate 4.1.4].

Plate 4.1.4: Soya bean plant showing root nodules which are abundant in the paddy soil environment

4.1.1.3 Grain harvest from the preceding crop and harvest Index (HI)

Among the grain producing soil fertility replenishment plants, rice gave highly significant grain yield (Table 4.1.3 and Figure 4.1.1). The Soya bean varieties had generally similar yields. No grain harvest was expected from the fallow and *Sesbania* plots. *Sesbania* was incorporated as green manure while fallow plots supported weeds.

Table 4.1.3: Fertility replenishment crop yield and harvest Index (HI)

Treatment	Grain Yield ($kgha^{-1}$)	HI (%)
Sesbania	0	0
EAI 3600	2043	18
Rice (IR 2793)	4946	38
Duicker	2371	22
Bosier	2230	23
Fallow	0	0
CV	34	4
LSD 5%	2282	16
Significance level	***	***

Key: *** = highly significant at $P \leq 0.05$ n=18

Grain production relative to plant biomass is presented in Figure 4.1.4. Rice gave highly significant harvest index (HI) than the legumes. This was determined from the weight of the entire above ground shoot and grain weight of the same plot. HI (%) was then calculated as follows:

HI = {Grain weight /(Grain weight + Above ground shoot weight)} x 100

Figure 4.1.4 shows the grain yield produced relative to the plant biomass output. The harvest index for rice was higher than that of the legumes.

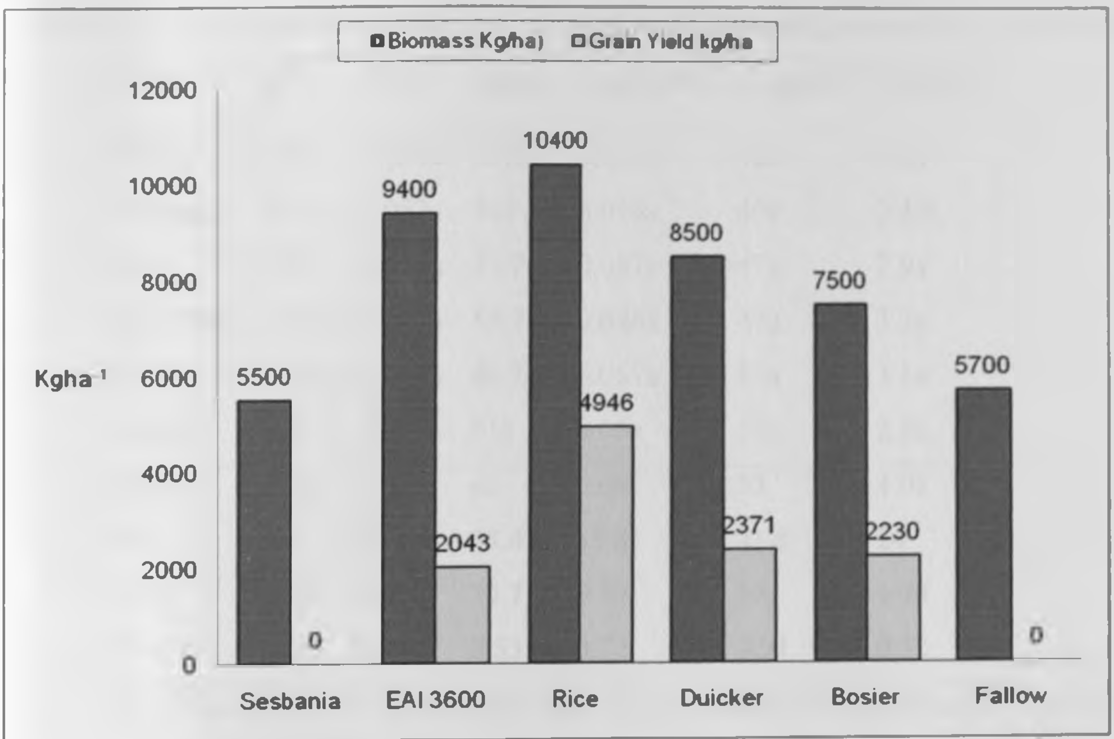


Fig 4.1.4: Soil fertility replenishment system: crop grain and biomass output (Kgha^{-1})

4.1.2 Soil chemical analysis – differences between test and control treatment nutrient gains from soil amendments

The results are presented in tables 4.1.4 to 4.1.6. There was no significant ($P \geq 0.05$) N, P and K levels difference among all the preceding crop treatments except for N in the 15-30cm layer of the soil profile. At the 15-30cm soil profile layer sesbania treatment had higher N than the Bosier Soya bean variety treatment.

Table 4.1.4: Soil nutrients levels after cultivation of preceding crop during the first season

Crop	p^H	% N	Pppm	Kme/100g	K $kgha^{-1}$	SOM%
Bosier	6.75a	0.056a	39.3a	0.047a	42a	3.6a
Sesbania	6.73a	0.052a	52a	0.046a	40a	2.39a
Rice	6.7a	0.059a	74.7a	0.057a	47a	2.9a
EAI 3600	6.73a	0.054a	53.7a	0.046a	47a	3.3a
Fallow	6.71a	0.057a	60.7a	0.067a	53a	3.1a
Duiker	6.75a	0.047a	61a	0.06a	53a	2.8a
Mean	6.75	0.047	61	0.06	53	3.01
CV	4.5	26.7	38.4	39.8	41.8	24
LSD	0.54	0.026	39.7	0.39	36	1.76
P>0.05	0.85	0.93	0.53	0.77	0.94	0.32

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=18

Table 4.1.5: Soil nutrients (0-15cm) after preceding crop during the second season

Crop	% N	Pppm	Kme/100g soil	SOM %
Bosier	0.27	15	0.12	2.62
Sesbania	0.102	15.3	0.18	2.39
Rice	0.102	22	0.17	3.8
EAI 3600	0.088	16.7	0.15	3.3
Fallow	0.097	15.3	0.13	2.9
Duiker	0.1	18.7	0.19	2.1
Mean	0.13	17.2	0.156	2.84
CV	11.5	32.6	32.7	29
LSD	0.266	10.2	0.091	1.51
P>0.05	0.613	0.63	0.48	0.23

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=18

Table 4.1.6: Soil nutrients at 15-30cm soil layer after Fertility replenishment crop during the second season

Crop	% N	Pppm	Kme/100g soil	SOM %
Bosier	0.066b	11.7	0.169	2.58
Sesbania	0.112a	11.3	0.159	3.34
Rice	0.078a	14.0	0.13	3.6
EAI 3600	0.071a	14.3	0.119	2.51
Fallow	0.088a	12.3	0.106	2.78
Duiker	0.084a	12.0	0.134	3.3
Mean	0.083	12.6	0.136	3.02
CV	28.3	38.6	31.6	27.1
LSD	0.043	8.87	0.078	1.49
P>0.05	0.028	0.96	0.51	0.51

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=18

4.1.2.1 Effects of preceding crop on paddy soil NPK and organic matter

Nitrogen

Significant (P<0) soil %N content differences were recorded in Soya bean plants (Table 4.1.2 in page 55). The aerial parts of the *Sesbania* (plate 4.1.5) and most of the Soya bean plants had significantly higher N than rice and fallow treatments.

Phosphorus

The rice tissue contained significantly higher P than the other treatments (Table 4.1.4 in page 60).

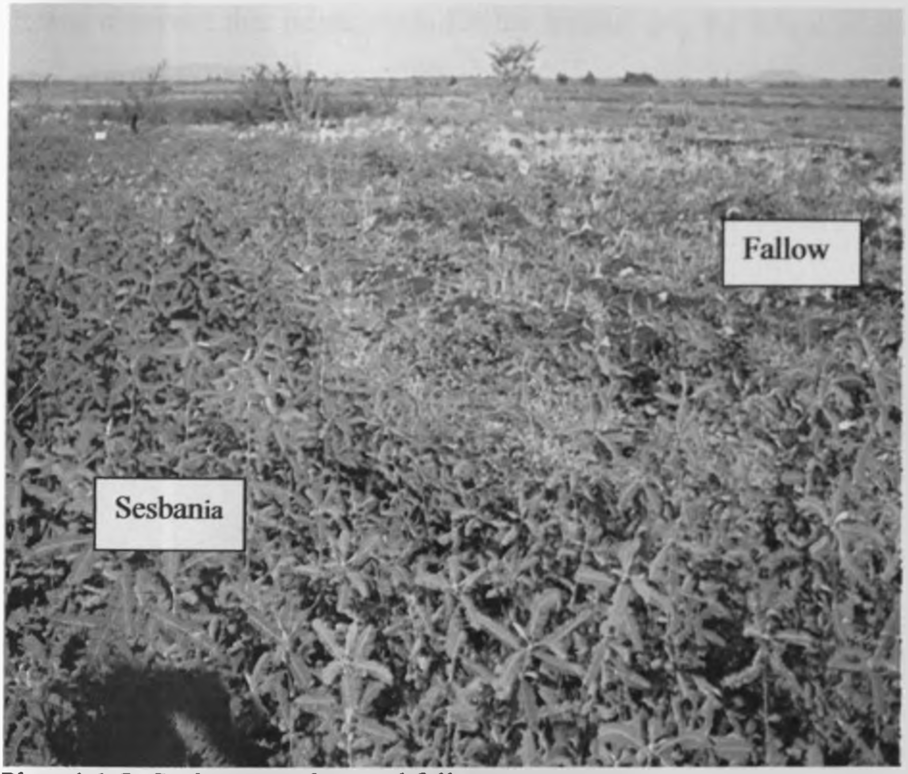


Plate 4.1.5: *Sesbania sesban* and fallow treatments

4.1.2.2 Other Observations

The soya cultivated plots had virtually no weeds during and after the harvesting of the succeeding rice crop (plate 4.1.6). Most weed seeds from previous main rice crop season that remain in the soil germinated and were removed in the process of Soya bean crop land cultivation and weeding, hence the observed low weed pressure in the subsequent main rice season. At the end of Soya bean cultivation, paddy soil tilth was also observed to be more loosened making land prepare for the subsequent rice crop easier. The high weed population in the fallow system resulted to high weed proliferation in the subsequent rice crop than in the Soya bean cropping system. The rice-rice system treatment had more water weeds than the other cropping systems treatments.

It was observed that ridges made for the legume crop for irrigation also helped drain the fields during rainfall keeping the paddy field without standing water (plate 4.1.6 and 4.1.7) maintaining an upland environment.

Plate 4.1.6: Appearance of subsequent rice crop treatment plots at harvesting: weeds were high in fallow - rice cropping system

Plate 4.1.7: Appearance of paddy field after soya bean harvesting. Absence of weeds made land preparation for the succeeding rice crop easy.

4.1.3 Soil NPK & Organic matter content after subsequent rice crop

The results are presented in Tables 4.1.7 to 4.1.12 and Figures 4.1.5 to 4.1.7.

4.1.3. 1 Soil Nutrient levels after rice cultivation during the first season

None significant treatment differences were obtained among the treatments for all nutrients (Table 4.1.7 and appendices 3). A similar trend was observed among the N rate treatment (Table 4.1.8). However, P nutrient levels were adequate in all treatments while N and K levels were deficient.

Table 4.1.7: Soil Nutrient levels after the subsequent rice cultivation during first season

Soil P	0 – 15 cm			15 – 30cm		
Previous Crop	%N	P (ppm)	Kme/100g	%N	P(ppm)	Kme/100g
Sesbania	0.074	24.02	0.70	0.082	25.41	0.62
EAI 600	0.072	25.71	0.61	0.093	27.10	0.58
Rice	0.062	24.99	0.63	0.076	26.79	0.56
Duiker	0.059	26.42	0.82	0.069	28.08	0.65
Bosier	0.065	24.76	0.70	0.076	27.81	0.65
Fallow	0.063	25.97	0.77	0.10	27.92	0.68
SE	0.031	0.28	0.29	0.044	4.3	0.28
LSD	0.014	1.25	1.31	0.20	19.27	1.26
CV	162	51	144	183	55	156
Significance	ns	ns	ns	ns	Ns	Ns

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n= 72

Table 4.1.8: Effect of N application rate on soil nutrient levels after succeeding rice crop cultivation during the first season

	0 -15 cm			15 -30 cm		
N rate	%N	Pppm	EX.Kppm	%N	Pppm	EX.Kppm
0	0.067	24.4	0.69	0.079	26.5	0.63
40	0.071	26.3	0.72	0.086	28.14	0.61
80	0.062	25.4	0.71	0.076	26.96	0.66
120	0.064	25.1	0.71	0.094	27.15	0.58
Mean	0.066	25.3	0.7	0.084	27.19	0.62
SE	0.025	3.06	0.24	0.036	3.51	0.23
CV	162	51	144	182	55	156
5% LSD	0.011	13.7	1.07	0.016	15.74	1.03
Sig.	ns	ns	ns	ns	ns	ns

Key: Ns = non-significant; Sig. = significance levels at $P \leq 0.05$ n=72

EX.K = Exchangeable potassium

4.1.3.2 Soil Nutrient levels after rice cultivation during second season

There was no significant interaction between the effects cropping system and the applied mineral N. Soil pH was acid to neutral in all plots. There were significant total nitrogen mean differences among the preceding crop treatments (Table 4.1.9). The N, P, and K levels were low in all plots. Organic carbon was moderately present in all plots. There was no significant mean difference observed among the fertilizer N rates (Table 4.1.10). During the third season, there were significant K mean differences among the previous crop and applied in-organic N rate treatments Tables 4.1.11 and 4.1.12). EAI 3600 plots had the highest K residues while Bosier treatment had the lowest.

Table 4.1.9: Soil nutrient levels after subsequent rice during the second season

Previous crop	PH	TN%	OC%	Pppm	Kme/100g
Sesbania	6.68	0.12	1.98	15.1	0.53
EAI 3600	4.92	0.11	1.92	18.38	0.66
Rice	4.89	0.11	2.05	20.67	0.55
Duiker	4.74	0.12	1.2	16.17	0.66
Bosier	4.9	0.1	1.87	18.29	0.69
Fallow	4.86	0.13	2.06	21.71	0.48
Mean	5.17	0.11	1.98	18.79	0.59
SE	0.7	0.63	0.77	1.41	0.8
CV	47.3	19.2	13.5	26	46.5
5%LSD	2	0.036	0.22	4.01	0.23

Key: TN=Total Nitrogen; OC= Organic Carbon

Table 4.1.10: Effect of N application rate on soil nutrient levels after succeeding rice crop during the second season

N Rates	PH	TN%	OC%	Pppm	Kme/100g
0	6.05	0.11	1.96	18.75	0.65
40	4.88	0.12	2.02	18.61	0.56
80	4.85	0.11	2	19.81	0.65
120	4.89	0.11	1.95	19.98	0.52
Mean	5.17	0.11	1.98	18.79	0.59
SE	0.52	0.51	0.63	1.15	0.65
CV	47.3	19.2	13.5	26	46.5
5%LSD	1.64	0.15	0.18	3.27	0.19
Significance level	ns	ns	ns	ns	ns

Key: Ns = non-significant; Sig. = significance levels at $P \leq 0.05$ n=72; TN=Total Nitrogen; OC= Organic Carbon

Table 4.1.11: Effect of N application rate on soil nutrient levels after succeeding rice crop during the third season

Crop	%N	Pppm	Kme/100g
Rice	0.09	15.3	0.416ab
EAI 3600	0.088	14.6	0.448a
Fallow	0.087	14.7	0.406ab
Bosier	0.078	15.3	0.383b
Mean	0.086	14.4	0.413
CV	19.9	21	17.2
LSD	0.014	2.59	0.06
$P \leq 0.05$	0.33	0.39	0.002

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n= 48

Table 4.1.12: Effect of N application rate on soil Fertility during the third season

N rate	%N	Pppm	Kme/100g
120	0.095	14.3	0.497a
80	0.086	14.5	0.426b
40	0.081	14.3	0.417b
0	0.081	14.7	0.313c
mean	0.086	14.4	0.413
CV	19.9	21	17.2
LSD	0.014	2.59	0.6
P	0.19	0.99	0.001

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n= 48

4.1.3.3 Effects of preceding crop on soil nutrients for the combined Seasons

The results are presented in Figures 4.1.5 -4.1.7

The combined season averages on NPK nutrients depict a trend similar to what is observed in each season.

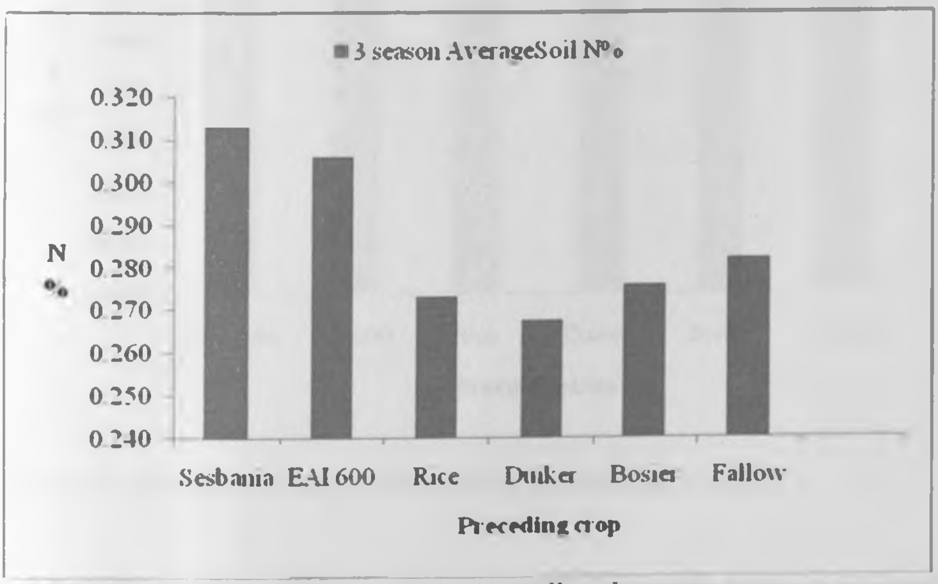


Fig 4.1.5: Average soil N (%) after succeeding rice crop

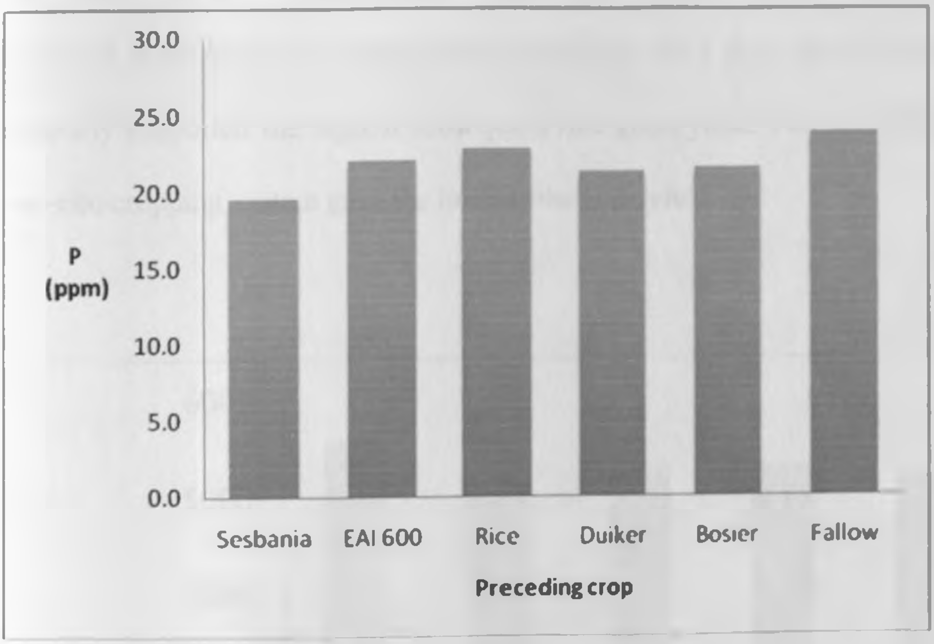


Fig 4.1.6: Average soil P (ppm) after succeeding rice crop

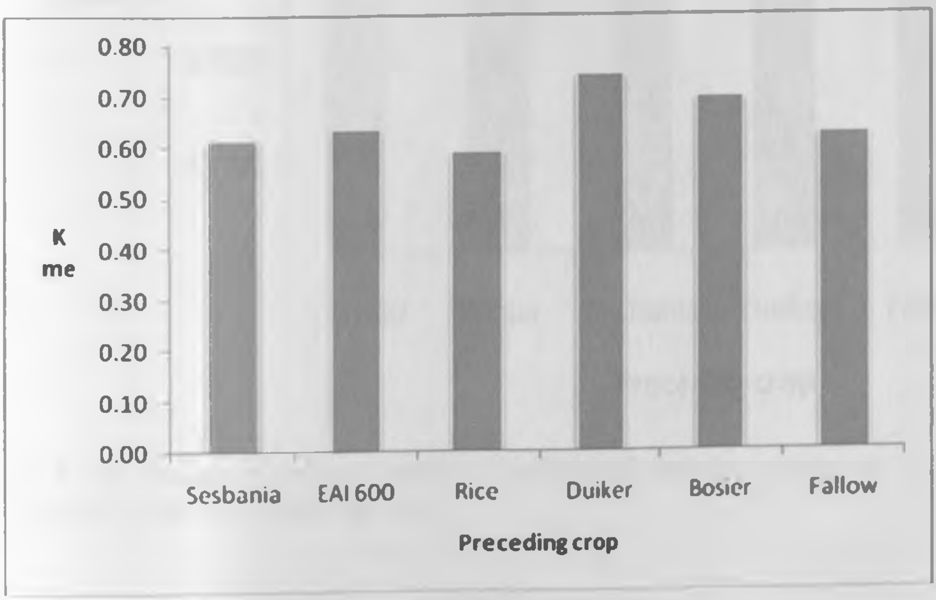


Fig 4.1.7: Average soil K (me/100g) after succeeding rice crop

4.1.3.4 Effects of preceding crop on combined season's average succeeding rice crop yield

The average means of the four season succeeding rice grain yields are presented in Fig 4.1.8. Rice-rice system gave the lowest average seasons succeeding rice yield. EAI 600-Rice gave the highest average yield. The Soya bean-rice, fallow-rice and *Sesbania*-rice cropping systems improved subsequent rice crop grain yields (Fig. 4.2.1 page 84). Soya bean cultivated plots generally supported the highest subsequent rice grain yield. The succeeding rice crop from the rice-rice cropping system gave the lowest rice grain yield.

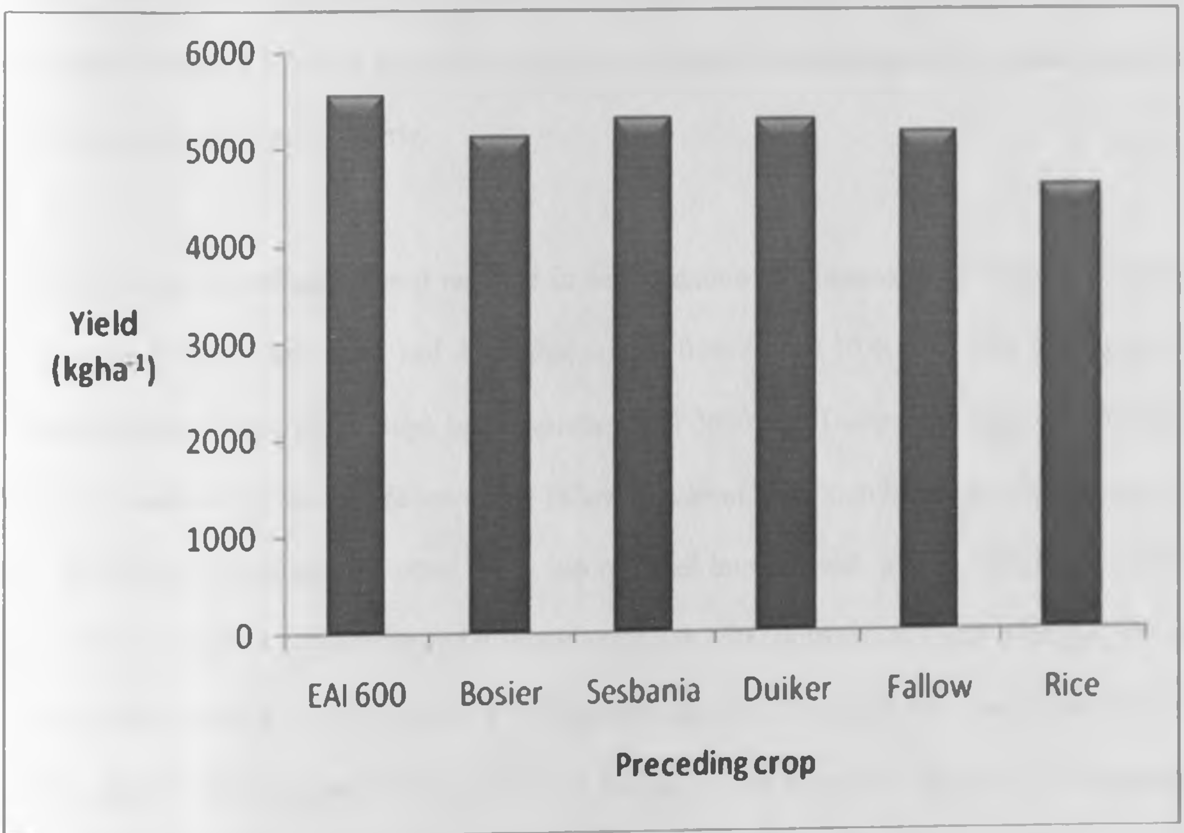


Fig 4.1.8: Combined seasons' average of effects of cropping system on succeeding rice crop yield (kg ha^{-1})

4.1.4 Discussion - Effects of cropping system on soil fertility

4.1.4.1 Preceding crop biomass output

The study has demonstrated the possibility of alternating rice with another crop on the paddy soils of Mwea. It has also shown the effects of rotating rice with the tested crops on soil fertility. The tested cropping systems had varied impact on biomass production, soil nutrient contents, harvested grain and hence income.

Each of the tested preceding crop resulted in accumulation of biomass as indicated in Figures 4.1.1 and 4.1.2 and table 4.1.1 and 4.1.2 that ranged from 5.5 to 10.4t ha^{-1}. Rice produced the highest biomass followed by Soya bean varieties EAI 3600 and Duiker. *Sesbania sesban* gave the lowest amount of biomass followed by fallow treatment. The high biomass output from rice is of significant importance whether when incorporated into the soil, grazed, burned or carried away. If the rice straw is incorporated it would replenish NPK nutrients at levels averaging 60 kg ha^{-1} as sown in table 4.1.1, 4.1.2 and 4.1.3. Together with this, rice straw is known to contain Zn, Si, Mg, and B estimated at 0.05, 65, 3.5 and 0.015kg t^{-1} of rice grain harvested respectively (Dobermann and Fairhurst, 2000). The nutrients are removed from the soil during rice crop grow through nutrient absorption. Consequently, incorporation of rice straw would be more beneficial in improvement of rice production. The incorporated plant residue undergoes the process of decomposition and mineralization to release nutrients that positively contribute in building up the paddy soil plant nutrients pool. The replenished nutrients eventually support the enhancement of subsequent rice crop growth with resultant increase in grain yield. On the other hand, grazing and carrying away of the rice straw as well as the harvested grain deplete the paddy soil essential plant nutrients. Such depleted soil nutrients have to be replaced from external sources for effective subsequent rice crop growth and yield performance.

The rice-rice cropping system has the risk of depleting the soil nutrient reserves because the cropping system does not allow time for rice straw incorporation, decomposition and mineralization before the subsequent rice crop is planted. The tendency of the Mwea farmers to remove/sell rice straw deny the Mwea paddy soil the large amounts of NPK, Silica and micro nutrients required by the rice plant. The situation is further aggravated by removal of P and K through the harvested grain. The deteriorated soil fertility require high quantity of inorganic fertilizers application to correct the situation thus explaining the reason why fertilizer input cost is the highest among the Mwea rice production costs. This is in line with the report of Witts *et al.*, 2007, which indicate that crop residue removal deny the succeeding crop supply of the correct amount of all the nutrients that are not supplied in sufficient amounts from indigenous sources. The report affirms that the crop residue incorporated into the soil adds up to the indigenous soil fertility reserves which is used for supply of balanced macro nutrients (NPK) and micronutrients such as Zinc and Boron to the succeeding rice crop. The resultant high cost of production due to in-organic fertilizers, is eventually, reflected in the high locally produced milled rice prices. The rice prices do not compete favourably with those of imported rice particularly for the non-aromatic varieties. Consequently, rice farmers are discouraged from cultivating the high yielding non-aromatic varieties leading to low rice production of 80t against 300t of rice consumed in Kenya per annum.

The Soya bean biomass output equivalent to that of rice in the Mwea paddy fields indicate significant potential of soya bean-rice cropping system in enhancement of rice field utilization for crop diversification and increased incomes in Mwea. The Soya bean plants dropped all the leaves at maturity as shown in plate 4.1.3. The resultant litter was then incorporated into the soil during land preparation for decomposition and mineralization to replenish soil fertility for the succeeding rice crop. Soya bean residue had a higher nutrient content compared to rice straw and fallow treatment (weeds) and is therefore likely to have had better soil replenishment.

In line with above observation, Soya bean is known to have numerous advantages which include improved soil productivity through increased soil organic matter (SOM) content, improved soil physical and microbial properties (Brush *et al.*, 1989; George *et al.*, 1990). Since soya bean is a deeper rooted crop than rice, it immobilizes much of the leached mineral nitrate N bringing it back to the upper soil horizon reducing N losses from the soil (Brush *et al.*, 1989; George *et al.*, 1990). On the other hand, rice yield increases have often been achieved through the use of N fertilizers, in combination with modern varieties and encouraged by the yield response, farmers increase fertilizer N rates to often excessive levels, while applying insufficient amounts of fertilizer P and K (Witt *et al.*, 2007). This results in an unbalanced supply of nutrients to the crop. Furthermore, nutrients that are formerly not limiting often become limiting with increasing yield targets. The optimal ratio of fertilizer NPK to be applied is site-specific as it depends on the yield target and the supply of each nutrient from the soil nutrient pool. It is likely that the incorporated Soya bean residue supplied the limiting soil nutrients particularly micronutrients that resulted in improved rice growth and grain yield. The results demonstrated the ability of soya bean to replenish soil indigenous nutrient reserves contributing to increased grain yield.

These observations are in line with the findings of Banik and Bagchi (1995) in India who also found that inter-cropping of rice and Soya bean gave the best returns. Walters *et al*., (1992), also reported that upon mineralization, crop residue supplies essential plant nutrients while Nyborg *et al*., 1995 observed that residue incorporation can improve physical and biological conditions of the soil and prevent soil degradation. In reference to the significantly higher subsequent rice grain yields obtained under Soya bean-rice cropping system, it is likely that this is what occurred.

4.1.4.2 Soil fertility replenishment

The highly significant ($P \leq 0.01$) biomass output and subsequent rice grain yield improvement suggest that the preceding crop replenished not only soil macro elements but also micronutrients among other soil fertility factors besides what was measured. The incorporated residue is also likely to have improved soil physical and microbial properties resulting to a general soil fertility improvement that positively contributed to better performance of the subsequent rice growth and grain yield.

The Soya bean residue was easy to incorporate while its grains generated higher income making it the most promising option of maintaining paddy field soil fertility in Mwea. This is reflected by the high yields obtained when the subsequent rice crop was preceded by Soya bean crop. Soya bean hosts *Brandyrhizobium* bacteria that have the ability to fix atmospheric N in the root nodules. The fixed Nitrogen is released through residue mineralization and used by the succeeding crop for plant growth development. It is also used for the manufacture of carbohydrates through the process of photosynthesis (Gardener *et al*., 1985). The contribution of N to the soil nutrient pool by Soya bean can reduce the succeeding rice crop need for inorganic N fertilizer by 50% (Fig 4.1.2) thereby lowering production cost. Thus alternating rice with Soya has shown to have more advantage than the rice-rice cropping system. The result agree with the findings of Buresh *et al*, (1993) and (Palm *et al*., 1997) who reported that weeds (fallow) and legume crops before rice can reduce soil-N loss by assimilating Nitrate-Plant N and then recycle this N through incorporated plant residues where it is rapidly mineralized and used by rice.

The soil Nitrogen, Phosphorus, Potassium (NPK) and soil organic matter (SOM) content levels did not vary significantly. However the nutrient levels maintained were adequate to support effective crop growth as also observed by Dobermann and Fairhurst, (2000). The findings are also supported by Witt *et al*., (2007) who observed that incorporation of stubble and straw into the soil returns most of the nutrients taken up by the crop and helps to conserve soil nutrient reserves in the long term. However, short-term effects on grain yield are often small (compared with straw removal or burning), but long-term benefits are significant. Where mineral fertilizers are used and straw is incorporated, reserves of soil N, P, K, and Si are maintained or even increased (Witt *et al*., 2007). Incorporation of straw and stubble when wet soil is ploughed results in a temporary immobilization of N and transplanting should be carried out 2–3 wk after straw incorporation; alternatively, urea N should be applied along with straw.

Backer *et al*., (1994) also observed that synchronizing soil N supply with N demand by incorporating residues with suitable chemical composition may not immediately increase rice grain yields, but improves long term soil fertility. It is therefore likely that by the time sampling was carried out in this study, decomposition and mineralization had not been completed giving the observed results. However the observed yield trend (Fig 4.1.8) may be a reflection of the effects of the resultant soil fertility replenishment on rice plant growth and yield performance. This is in line with Ladha *et al* (1996) who found that proportions of N fixed by Legume cover crops (LCC) range from 50 to 100%. LCC can provide sufficient N to the food crop through biological nitrogen fixation (BNF) to meet the needs of subsequent crop, if nutrients are made available through decomposition and mineralization. Additionally, other rice growing regions of the world have evaluated and exploited legumes potential to enhance paddy soils fertility (Walters *et al.*, 1992; Nyborg *et al.*, 1995). Similar observation were made by Vendan *et al* (1999) who reported that dual cropping of *Azolla microphylla* with rice enhanced soil available N status and rice grain yield necessitating a skip of second N topdressing at 30 days after transplanting. In India, *Sesbania rostrata* contributed to higher yields of rice (Singh *et al.*, 1999). Its incorporation increased soil organic carbon (SOM) content, available N and available P significantly compared with mineral fertilizer treatment.

4.1.4.3 Quality of Plant residue

Rice and weed residue had significantly low plant tissue N. There were no significant tissue P and K differences among the treatment means. Plant tissue crude protein varied among the test preceding crops. *Sesbania* residue gave the highest protein followed by Duiker and Bosier. Rice residue had the lowest protein content. This may partly explain the low grain yields obtained from the succeeding rice crop in rice-rice cropping system despite the high biomass produced. Sesbania therefore accumulated higher overall N in its dry matter than the other treatments during the growth period.

The amount of nitrogen added to the soil from crop shoot residue was equivalent to a mean of 33kg N ha^{-1} amounting to Kshs6914ha^{-1} in one season. These results demonstrate the potential of green manure crop and the importance of incorporating crop residue in a rice-legume cropping system in improvement of soil fertility for sustainable increase in rice grain yield. This is reflected in the high yield differences recorded when a legume crop preceded a rice crop. The trend assumed relates to the quality of residue incorporated. The findings agree with that of Dakora and Keya, (1997) which showed that in a single year, the pruning of *Sesbania sesban* can provide to a hectare of upland cereal crop, up to 448 kg N, 314 Kg P, 125 Kg K, 114 Kg Ca and 27.3 Kg Mg thus making the foliage of this legume the "ideal" fertilizer.

However there were unanticipated results in terms of soil fertility levels (NPK and SOM). Lack of significant differences observed in soil nutrients among the treatments in exception of N in the 15-30cm soil profile layer could be attributed to the timing of sampling which might have coincided with the time when the residues were not fully decomposed or mineralized. Soil sampling was done after the legume crop cultivation and after harvesting the subsequent rice crop. In the latter case rice crop might have absorbed the accumulated nutrients resulting to the observed NPK levels.

Similarly various researchers have attempted to describe nutrient release by plant residues (Cornforth and Davis, 1968; Wilson *et al.*, 1986; Palm *et al.*, 1988). Decomposition of shoots of forage legumes or prunings of legume trees can be rapid. The reports suggest that 40% or more of the N in legume shoot material can be released in less than two weeks after addition to the soil. This means that the N may be released before the crop has attained the growth stage that can take full advantage of the nutrient. Backer *et al* (1994) observed that synchronizing soil N supply with N demand by incorporating residues with suitable chemical composition may not immediately increase rice grain yields, but improves long term soil fertility. The synchronisation of nutrient release from organic matter with optimum timing for uptake by crops is a major challenge for research (Woomer and Ingram, 1990). Consequently, the effects of the soil fertility improvement are better expressed by the plant growth parameters and the grain yield of the subsequent rice crop. Similar observations are recorded by Moroyu, (1983) and Kaneta *et al*

(1989). These researchers observed that in paddy soils under crop rotation, upland crops often suffer from moisture stress due to the physical condition of the soil. Flooding soil for rice cultivation suppresses organic matter decomposition. When paddy soil is then used for upland crops, the accumulated mineralizable nitrogen is rapidly decomposed and becomes available for these upland crops. On the other hand, the rotation from wetland to upland oxidizes not only the plow layer but also the subsoil. When rice is subsequently grown in the same field again, rice can elongate its roots to a considerable depth and absorb a large quantity of nutrients.

Since decomposition of organic matter is much faster under upland conditions than under flooded ones, nitrogen availability to the soil decreases rapidly after soil is rotated from wetland to upland use (Maeda, 1987). Inevitably, repeated rotation may exhaust the level of organic matter in the soil (Moroyu, 1983). Therefore, the introduction of upland crops such as legumes. which contribute to an increase in nitrogen fertility, should be considered in such a cropping system.

4.1.4.4 Amount of nutrients added to the soil

In this study rice straw was incorporated into the soil unlike the Mwea farmers' practice where rice straw is removed from the field. The fact that rice straw was incorporated into the soil gave unanticipated results. Thus the analyzed soil nutrients NPK in rice treatments remained almost similar to other treatments except for N in the 15–30cm (lower) profile.

The results of this research clearly demonstrated the potential of cultivating soya bean for the replenishment of the Mwea heavy clay soils fertility. Though rice produced the highest biomass. the quantity was not proportional to the observed succeeding rice yield. The quality and quantity of soya residue was superior and positively influenced the subsequent rice grain yield. Farmers the quantity was not proportional to the observed succeeding rice yield. The quality and quantity of soya residue was superior and positively influenced the subsequent rice grain yield. Farmers can therefore be encouraged to adopt the Soya bean-rice cropping system to improve rice yields and incomes.

4.1.4.5 Grain yield

Among the preceding crops, rice recorded the highest grain yield harvest. The high grain yield is accompanied by higher removal of the soil macro and micro nutrients through crop harvest. The resultant depletion of essential rice nutrients from the paddy soil lead to higher nutrient deficiency for the succeeding rice crop. This explains why continuous rice-rice cropping system eventually results in low grain yields compared to rice mono cropping as reported by Kuria, (2004 and 2006). The resultant low income has discouraged farmers from attempting to cultivate a second rice crop.

However, the suitability of Soya bean-rice cropping system can help minimize the mining of the soil rice specific nutrients and hence improve subsequent rice crop yield performance. Maximum yield performance difference between the legume-rice and rice-rice systems at zero N fertilizer level was over 31% (Fig.4.1.2). Equivalent yields were obtained from the Soya- rice-system and rice-rice system at 0KgN ha^{-1} and 40 $KgNha^{-1}$ respectively. This equated to a saving of 40 Kg N ha^{-1} amounting to $Kshs8381ha^{-1}$. The saving would reduce cost of production and positively improve rice farmer`s income.

4.2.0 EFFECTS OF CROPPING SYSTEM ON SUCCEEDING RICE CROP YIELD AND AGRONOMIC TRAITS

4.2.1 Effect of cropping system on rice yield

The results are presented in tables 4.2.1 and 4.2.2. There was no significant interaction between the main effects preceding crop and applied N rates for yield (P=0.62) [Appendix 3].

Significant yield differences ($P \leq 0.05$) among the different organic soil fertility replenishment systems were observed (Table 4.2.1 and 4.2.2). Rice-rice cropping system gave the lowest yield followed by the fallow-rice cropping system. Yield from plots previously planted with Soya bean were generally highest. This trend was maintained in the first and second seasons (Table 4.2.1).

Table 4.2.1: Effect of fertility replenishment system on subsequent rice yield (kg ha^{-1})

Preceding Crop	Yield kg ha^{-1}	
	First year	**Second year**
EAI 600	5531a*	5567a
Bosier	5345ab	4906bc
Sesbania	5283ab	5322ab
Duiker (Soya bean)	5200ab	5391ab
Fallow	5117bc	5202ab
Rice	4767c	4438c
CV	2.03	11.4
LSD	362	486
P	0.05	0005

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=72

There were significant yield differences among the soil fertility replenishment sources and the rates of the in-organic nitrogen fertilizer applied. The highest yield was obtained in Duicker Soya bean 120 kg N ha^{-1} plots (Fig. 4.2.1 in page 84).

Sesbania and Duiker were dropped from further testing during the third and fourth season to concentrate on the best performing soya bean varieties EAI 3600 and Bosier. A similar trend to that of the first and second seasons (Table 4.2.2) was observed. Significant ($P \leq 0.05$) yield differences were obtained among the different cropping systems. Soya bean-rice treatments gave the highest yield followed by Farrow-rice treatment during both seasons. Rice-rice cropping system had the lowest average yield during both seasons.

Table 4.2.2 Effect of preceding crop on subsequent rice yield during the third and fourth seasons

	Yield (kg ha^{-1})	
	Third Season	**Fourth Season**
Bosier	6307 a	5561b
EAI 3600	6247 a	6104a
Fallow	5581 b	4516d
Rice	5270 c	5057c
Mean	5851	5310
CV	9.9	9.5
LSD	511	425
P	0.02	0.0001

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=48

4.2.2 Effect of N rate on subsequent rice yield

Significant yield differences ($P<0.05$) were obtained between the different rates of N applied in previously plots where preceding crops were grown (Table 4.2.3). Highly significant mean yield differences were recorded. The 120KgN ha^{-1} gave significantly higher yield in all plots. Yield generally declined with decrease in rate of N fertilizer. The 0kgN ha^{-1} gave the lowest yield.

Table 4.2.3 Effect of N rate on subsequent rice yield during the first and second seasons

N Rate (Kg Nha^{-1})	Yield ($Kgha^{-1}$)	
	First season	Second season
120	6596a	6364 a
80	5282b	5543 b
40	5111c	4920 c
0	3839d	3825 d
Mean	5207	5138
CV	8.7	11.4
LSD 5%	303	397
P5%	0	0.0001

Key: Means followed by the same letter are not significantly different at $P\leq 0.05$ n=72

From Figure 4.2.1 rice-rice plots recorded the lowest yield at both the cropping systems and the different levels of N. Soya bean-rice plots generally gave the highest yield at all N levels.

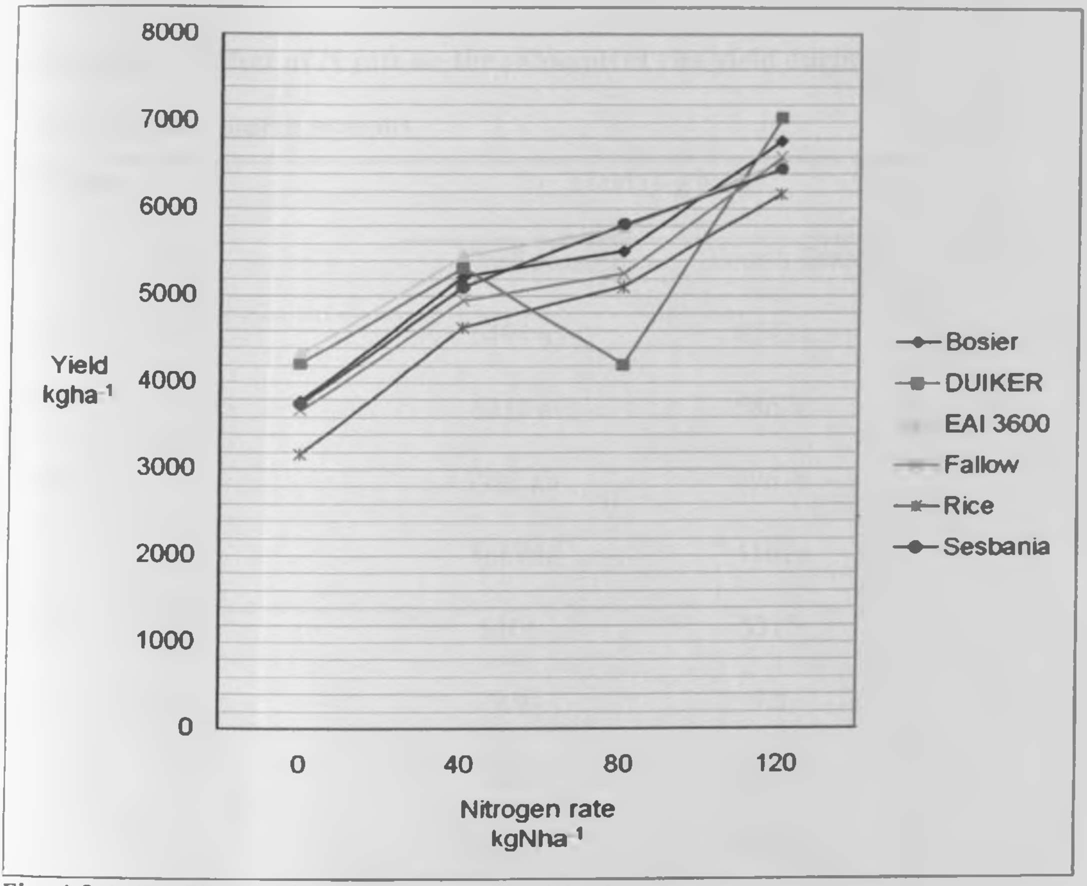


Fig. 4.2.1: Profile plot for N rate versus fertility improvement sources

Significantly ($P<0.05$) different yields among the treatment means were obtained (Table 4.2.4) during the third and fourth seasons. The 120kg N ha^{-1} gave the highest yields while the lowest were realized in the zero N treatment. However during the third season the 0 and 40kgN ha^{-1} treatment rice grain yields were not significantly different.

Table 4.2.4 Effect of N rate on the subsequent rice yield during the third and fourth seasons

N- rate	Yield (Kg ha^{-1})	
	Third season	Fourth Season
120	6494 a	6243a
80	6257 a	5867a
40	5985 ab	4967b
0	5669 b	4161c
Mean	6101	5310
CV	9.9	9.5
LSD	511	425
P	0.017	0.0001

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=48

Plate 4.2.1 Comparison of mature rice from Soya bean-rice and fallow-rice cropping systems; note the more weeds in Fallow rice cropping system

4.2.3 Effect of preceding crop on the subsequent rice yield components and agronomic traits

4.2.3.1. Effect of fertility replenishment method on subsequent rice tillering

There were no significant rice tiller number differences among the treatment means at maturity during the first season (Table 4.2.5). There were also no significant productive and non-productive tiller number differences among the treatments during the first season (appendix 2). During the second season highly significant tiller number mean differences were recorded. The lowest tiller numbers per hill were recorded in the plots previously cropped with rice. Highest tiller numbers were observed in plots preceded by duiker Soya bean followed by that of Sesbania-rice cropping system.

Table 4.2.5: Effect of fertility replenishment method on subsequent rice tillering at maturity during the first and second seasons

	Tiller number per hill at maturity	
Fertility Source	First season	Second season
EAI 3600	32	31ab
Bosier	34	31ab
Sesbania	34	32ab
Duiker	32	33a
Fallow	34	31ab
Rice (IR 2793)	31	28b
Mean	32.6	31
CV	12.3	11.3
LSD 5%	3.3	2.8
P 5%	0.28	<0.0001

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=72

4.2.3.1.1 Effect of Fertility replenishment method on rice productive tillers during the second season

There were no significant productive and non-productive tiller number per hill mean differences among the fertility replenishment methods (Appendix 2).

4.2.3.1.2 Effect of mineral N application rate on rice plant tillering

The results are presented in Tables 4.2.6 to 4.2.8. Crop and Nitrogen rate interaction was not significant (P=0.27) for tiller number per hill (Appendix 3). The main effects previous crop was also not significant (P=0.28) for tiller number per hill. The main effect N rate significantly influenced tillering (P<0.0001). Tiller number increased significantly with each increase in N level during the first and second seasons. A similar trend was recorded for the productive and non-productive tillers during the second season. However during the third season (Table 4.2.8). tillering differences were only significant at 120 Kg N ha^{-1}.

Table 4.2.6 Effect of N rate on the subsequent rice plants tillering during the first season

N Rate (Kg N ha^{-1})	Tiller No. per hill at 74 DAT	Tillers No. per hill at maturity
120	28	47
80	30	33
40	24	31
0	25	20
Mean	27	33
LSD 5%	3	2.7
CV	17.3	12.3
P5%	0.0003	0.001

*Means followed by the same letter are not significantly different at $P \leq 0.05$ n=72

Table 4.2.7 Effect of N levels on the succeeding rice plants productive tillers during the second season

N rate (kg N ha^{-1})	Tiller Number per hill	Productive Tiller Number per hill	Non-Productive tiller number per hill
120	31 a	29 a	2 a
80	26 b	24 b	2 b
40	23 c	22 c	1 b
0	19 d	18 d	1 c
Mean	25	23	1.5
CV	11.3	12	5.1
LSD	1.9	1.9	0.5
P	0.0001	0.0001	0.0001

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=72

Table 4.2.8. Effect of Nitrogen rate on subsequent rice tillering at maturity during the third season

N-rate (kg N ha^{-1})	Tiller No per hill
120	19 a
80	16 b
40	16 b
0	14 b
Mean	16
CV	20
LSD	2.7
P	0.008

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=48

4.2.3.2 Effect of fertility replenishment method on subsequent rice plant height

4.2.3.2.1 Effect of fertility replenishment method on subsequent rice plant height at maturity during the first and second seasons

There were significant plant height mean differences among the treatment means at maximum tillering (75 DAT) stage during the fourth season (Table 4.2.9). The Soya bean-rice cropping system produced significantly taller plants than rice-rice and fallow-rice cropping systems.

Table 4.2.9: Effect of fertility replenishment method on the subsequent rice plants height at 75 DAT

Crop	Plant height (cm)
EAI 3600	55.4a
Bosier	52.8a
Rice	48.5b
Fallow	47.5b
Mean	51
CV	9.2
LSD	4
P>0.05	0.001

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$; n=48

There were significant subsequent rice plant height differences ($P \leq 0.05$) at maturity among the cropping systems during both seasons (Table 4.2.10 and Fig. 4.2.1). The tallest plants were observed in Soya bean EAI 3600 for the two seasons. The shortest ($P \leq 0.05$) plants were observed in fallow-rice and rice-rice treatments during the first and second seasons respectively.

Table4. 2.10: Effect of fertility replenishment method on the succeeding rice plants height at maturity during the first and second seasons

	Plant Height(cm) at maturity	
Fertility Source	First year	Second year
EAI 3600	88a	83a
Bosier	81bc	82a
Sesbania	84abc	82a
Duiker	87ab	78b
Fallow	80c	82a
Rice	82bc	78b
Mean	83.7	81
CV	7.2	2.7
LSD 5%	2.4	4
P5%	0.001	<0.0001

Key: Means followed by the same letter are not significantly different at P≤ 0.05 n=72

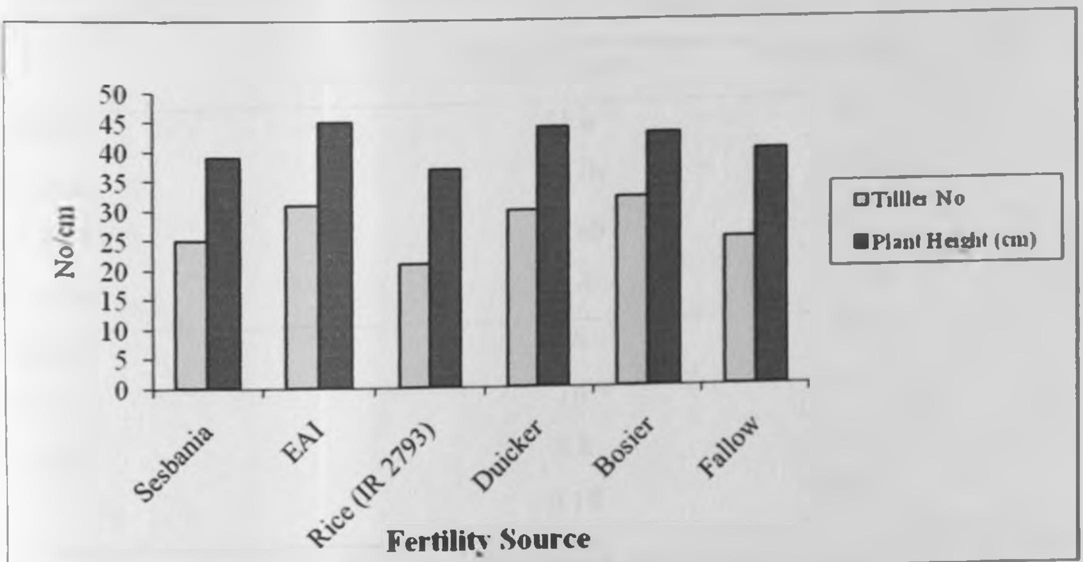


Fig 4.2.2: Effect of fertility replenishment method on tiller number and plant height

Generally the tallest plants were recorded in previously Soya bean planted plots (Fig 4.2.2). Tillering also followed a similar trend. Crop and Nitrogen rate interaction was not significant for tiller number (P=0.27) [Appendix 3]. The main effect of previous crop was also not significant for tiller number (P=0.41).

During the third season the rice-rice plots had significantly taller plants at maturity than Bosier-rice plots (Table 4.2.11). However, plant height differences were not significantly different from those of EAI 3600-rice and fallow-rice cropping systems. During the fourth season EAI 3600 and Bosier had significantly higher plant height differences at maturity. Rice-rice cropping system had the shortest plants followed by the fallow-rice cropping system.

Table 4.2.11: Effect of previous crop on rice plant height at maturity during the third and fourth seasons

Previous Crop	Plant height (cm)	
	Third Season	Fourth Season
Rice	81 a	76c
Fallow	77 ab	78bc
EAI 3600	77 ab	81a
Bosier	71 b	79ab
Mean	76	78.5
CV	14	3.8
LSD	8.8	2.5
P	0.18	0.002

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=48

4.2.3.2.2 Effect of N rate on subsequent rice plant height during the first season

Crop and Nitrogen rate interaction was not significant (P=0.29) for plant height (Appendix 3). The main effects previous crop was also not significant (P=0.19) for plant height. Highly significant plant height mean differences were recorded at 74 DAT (panicle initiation stage) [Table 4.2.12] and at maturity for the first season (Table 4.2.14). At 74 DAT the 120 kg N ha^{-1} rate had significantly (P<0.01) taller plants followed by 80 kg N ha^{-1} treatment. The 40 and 0 kg N ha^{-1} had the shortest plants.

Table 4.2.12: Effect of N rate on the subsequent rice plants height at 74 DAT during the first season

N Rate (kg N ha^{-1})	Plant Height 74 DAT	
	First season	Fourth scason
120	43.0a	51.1
80	42.3a	49.5
40	40.0b	52.8
0	40.0b	50.9
Mean	41	51
SE	0.7	0.9
LSD 5%	2.0	9.3
CV	7.2	4
P5%	0.0015	0.43

Key: Means followed by the same letter are not significantly different at P≤ 0.05 n=72

Table 4.2.13: Effect of N application rate on subsequent rice plant height at maturity during the first, third and fourth seasons

N- rate (kg N ha^{-1})	Plant height (cm)		
	First season	Third season	Fourth Season
120	82bc	74	78.6
80	89a	79	79.4
40	85ab	77	78.4
0	78c	74	77.5
Mean	84	76	78.5
CV	4.8	14	3.8
LSD	8.5	8.8	2.5
P	0.008	0.57	0.5

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=48

At maturity stage plant height mean differences were non-significant during the third and fourth seasons.

4.2.3.3 Effect of fertility improvement methods on 1000 grain weight

4.2.3.3.1. Effect of fertility improvement methods on 1000 grain weight during the Second season

The 1000 grain weight differences were non-significant for the effect previous crop (Tables 4.2.14 and 4.2.15). The mean 1000 grain weight was 27.5g. The effects of preceding crops tested had no significant difference in influencing in 1000 grain weight.

Table 4.2.14: Effect of fertility improvement methods on 1000 grain weight during the Second season

Previous crop	1000 grain weight (g)
EAI 3600	27.5
Ducker	27.6
Sesbania	27.4
Fallow	27.8
Bosier	27.3
Rice	27.6
Mean	27.5
LSD	0.73
CV	3.2
P Value	0.56

Key: Means followed by the same letter are not significantly different at P≤ 0.05 n=72

Table 4.2.15: Effect of preceding crop on subsequent rice 1000 grain weight

Previous Crop	1000 grain weight (g)	
	Third Season	Fourth Season
Fallow	27.9 a	26.5
Rice	27.6 ab	23.3
EAI 3600	27.3 bc	26.7
Bosier	27.0 c	26.3
Mean	27.4	26.5
CV	2.3	2.7
LSD	0.53	0.6
P	0.01	0.57

Key: Means followed by the same letter are not significantly different at P≤ 0.05 n=48

4.2.3 3.2 Effect of N rate on 1000 grain weight

Highly significant 1000grain weight differences were observed among the N rates during the second season. The 120 kg N ha^{-1} level had the heaviest grains while 0 kg N ha^{-1} recorded the lightest grains. This trend was maintained during the fourth season (Table 4.2.16). However, there were no significant grain weight differences during the third season (Appendix 3).

Table 4.2.16: Effect of N rate on 1000 grain weight during the second and fourth seasons

N- Rate kgNha^{-1}	1000 grain weight (g)	
	Second season	Fourth season
120	28.0 a	27.1a
80	27.7 a	26.6ab
40	27.4 ab	26.4bc
0	27.0 b	25.8c
Mean	27.5	26.5
CV	3.2	2.8
LSD	0.6	0.61
P	0.0075	0.003

Key: Means followed by the same letter are not significantly different

4.2.3.4 Grain Number

Significant ($P<0.05$) grain number differences among the treatment means were observed during the third and fourth seasons. During the third season Bosier had the highest grain number while EAI 3600 had the least (Table 4.2.17). The grain sterility was not significantly different ($P<0.05$) among the treatments. During the fourth year both grain number and grain sterility mean differences were significantly different (Table 4.2.18). Rice-rice cropping system had the highest grain number.

Table 4.2.17 Effect of soil fertility replenishment on grain number per panicle during the third season

Previous crop	Grain number Per panicle	Fertile grains	Sterile Grains	% sterility
Bosier	87	79 a	8	9
Rice	87	78 a	9	10
Fallow	85	75 ab	10	12
EAI 3600	78	69 b	9	12
Mean	84.4	75.4	9	10
CV	10.6	10.8	29	27.7
LSD	7.5	6.9	2.2	2.5
Previous crop	0.071	0.02	0.43	0.29

Key: Means followed by the same letter are not significantly different at P≤ 0.05 n=48

Table 4.2.18 Effect of fertility replenishment method on grain number per panicle during the fourth Season

Crop	Total grain No per panicle	Fertile grain No per panicle	Sterile grain No per panicle
Rice	97a	86	10a
Fallow	91b	82	9ab
Bosier	89b	82	8b
EAI 3600	89b	82	7b
Mean	91	83	8
CV	7.2	8.5	26
LSD	5.6	5.9	1.8
P>0.05	0.02	0.32	0.01

Key: Means followed by the same letter are not significantly different at P≤ 0.05 n=48

4.2.4 Discussion - Effects of cropping system on crop yield and agronomic traits

Cultivation of Soya bean or *Sesbania* before rice significantly increased the subsequent rice crop grain yield. Rice-rice cropping system gave the lowest rice grain yield. Rice grain yield also increased with increase in inorganic N fertilizer during the first season and gave varying results thereafter hence showing the need for soil fertility improvement. Maximum yield difference between the legume-rice and rice-rice cropping systems at zero N fertilizer level were over 31% (Fig. 4.2.1). Similar yield differences were obtained from the rice-soya and rice-rice cropping systems at 0KgN ha^{-1} and 40 $KgNha^{-1}$ respectively giving a saving of 40 Kg N ha^{-1}. These results demonstrate the potential of alternating rice with Soya bean or *Sesbania* to increase income through the increased rice yield and the saving on reduced use of inorganic fertilizer N. The Legume-rice cropping systems positively influenced the succeeding rice yield components resulting in increase in rice grain yield. There were significant tiller number differences among the cropping systems during the second season. Cultivating a legume before rice improved the tillering of the succeeding rice crop. The highest tiller number was recorded in Soya bean plot followed by Sesbania while the rice-rice cropping system produced the least number of tillers. The cropping system had no significant effect on the productive and non-productive tillers. The 1000 grain weight was also not significantly influenced by the cropping system. However the grain numbers per panicle varied significantly during the last two seasons. The rice-rice cropping system recorded the highest grain number per panicle. Consequently, the observed yield variations could be mainly attributed to tillering differences among the cropping systems.

Tiller numbers varied significantly among the different levels of inorganic N. The $120KgNha^{-1}$ recorded the highest tiller numbers. Tiller numbers were generally similar among all the nitrogen

This indicates that effective tillers were attained without mineral N where soil fertility was replenished through legume cultivation. The rice plants were tallest in legume cultivated plots while those from fallow plots were the shortest. This further affirms that paddy soils supported better crop performance where rice was alternated with a legume crop. Highly significant plant height differences were recorded at 74 DAT (panicle initiation stage) and at maturity. At 74 DAT the 120KgN ha^{-1} rate had significantly ($P<0.01$) taller plants followed by 80 Kg N ha^{-1}. The 40 and 0 Kg N ha^{-1} had the shortest plants. Plant height was unaffected by variation in inorganic N levels during the fourth and the third seasons. Similar observation were made by Meyer (1987) indicating that wheat grain yield, following a green manure sweet clover crop were 96% higher than continuous wheat yields and 9% higher than following fallow when unfertilized and, 31 and 10% higher respectively, when fertilized with 56 Kg N ha^{-1}. Morris *et al*., (1986) reports that a fast growing tropical legume can accumulate more than 80 Kg N ha^{-1} in 45 days and that rice yield responses exceeding 2t ha^{-1} are possible from green manure incorporated soils. Buresh *et al*, (1993) also observed that weeds (fallow) and legume crops before rice can reduce soil - N loss by assimilating Nitrate - Plant N and then recycling this N through incorporated plant residues where it is rapidly mineralized and used by rice. Backer *et al*., (1994) observed that synchronizing soil N supply with N demand by incorporating residues with suitable chemical composition increase rice grain yields in the long term. According to Geriek (1999) *Azolla mexican* when applied to experimental fields in Turkey increased total soil N by 38-56% and contributed to total soil organic matter. In India, 45 day old *Sesbania aculeata* (daincha) at 12 ton ha^{-1} was incorporated *in situ* 3 days before rice transplanting against farm yard manure and *Crotalaria juncea* and alongside 50%, 75% and 199% recommended dose of inorganic N fertilizers (Hemalatha *et al*., 1999).

The Soya-rice cropping system has other accrued benefits besides soil fertility improvement for higher crop performance. The system results in production of soya bean grain which is important for improvement of nutrition and income. Like most legumes, Soya beans are an excellent source of dietary fibre, complex carbohydrate and plant protein. Soya beans are relatively high in fat, mainly unsaturated fat and therefore a rich source of energy. For example, 100g dried, raw Soya beans contain 35.9g protein, 15.8g carbohydrate, 8.5g water, and 18.6g fat, of which just 2.3g is saturated fat (Carrao and Gontijo, 1993). More certain is the cholesterol-lowering effect of Soya bean protein. A recent meta-analysis of the effects of Soya bean protein on serum lipids in 29 controlled clinical trials showed that total cholesterol decreased by 9.3%, LDL-cholesterol ('bad' cholesterol) decreased by 12.9%, triglycerides decreased by 10.5%, and HDL-cholesterol ('good' cholesterol) increased by 2.4% in the intervention (Soya bean protein) groups compared with the control groups. These beneficial effects on serum lipids are likely to result in a considerably reduced risk of coronary heart disease (Carrao and Gontijo, 1993). Other potential benefits of legumes include their extremely low glycogenic index, which suggests that they may be a particularly important food for diabetics and individuals at risk of becoming insulin resistant, and the relief of menopausal symptoms (Carrao and Gontijo, 1993). The other benefits of alternate crops are improved soil fertility, reduced nutrient leaching, reduced build-up of pests, and reduced weeds population (Plate 4.1.6); spread workload, reduced risk of weather damage, reduced reliance on agricultural chemicals, and increased net profits as also observed by Tanaka *et al.*, (1998).

Plate 4.2.2: Other Advantages of alternating rice with Soya: Low weed population in the succeeding rice crop

The study suggests the need to lay emphasis on alternating cultivation of rice with a legume crop particularly soya bean. It also appears that it is more beneficial to incorporate rice straw in the soil rather than selling at the average price of Kshs500 per acre (3t of rice straw) at the time of this study, burning or grazing particularly where two rice crops are to be cultivated. The soya-rice cropping system can therefore be recommended as a better way of growing rice in Mwea.

4.3.0 EFFECTS OF CROPPING SYSTEM ON MALARIA VECTOR POPULATION

4.3.1 Effects of cropping system on Malaria vector densities

The results of the effects of the cropping systems on malaria vector larval densities are presented in Figures 4.3.1 and Tables 4.3.1 to 4.3.3. Plates 4.3.1 to 4.3.8 present the cropping systems related agricultural activities that were observed to have significant influence in the modification of the ecosystem and hence contributed in elimination of mosquito breeding habitats resulting in reduced larval densities.

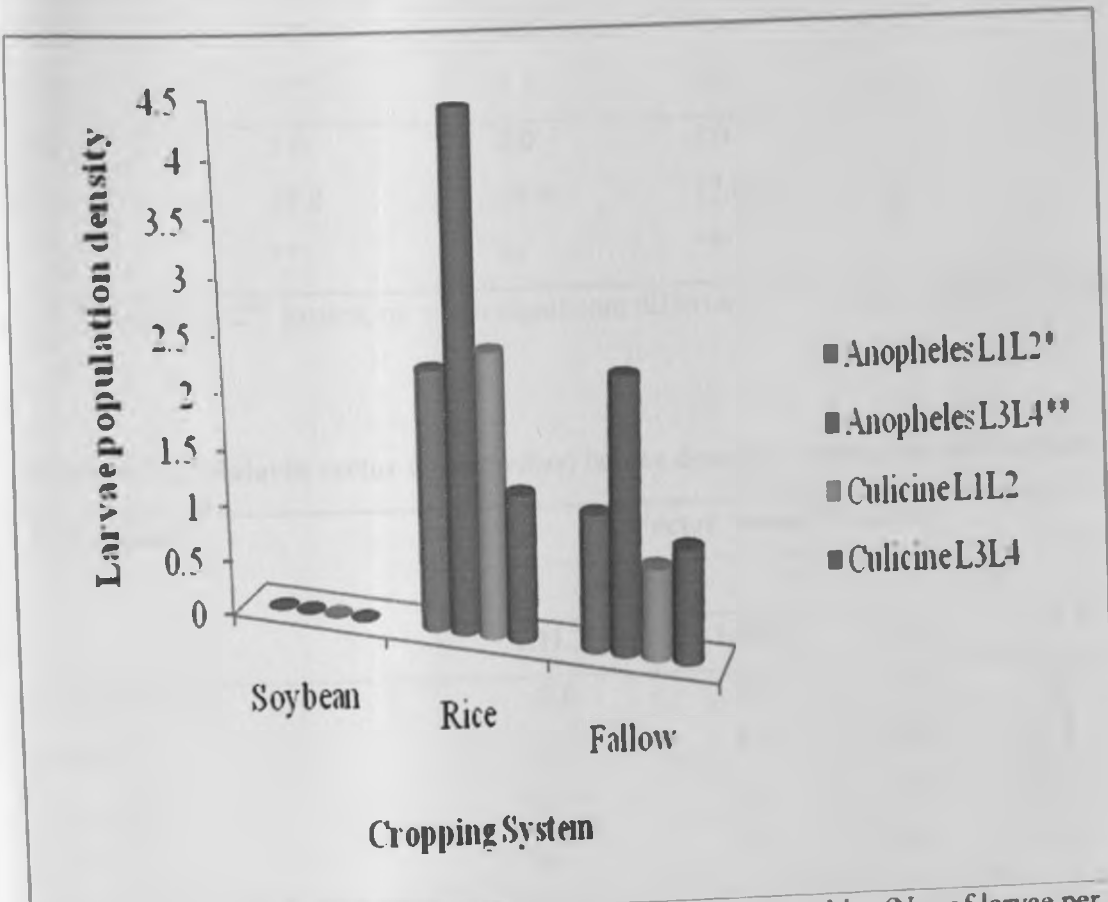


Figure 4.3.1 First season malaria vector (*Anopheline*) larva densities (No. of larvae per 10 dips)
* = 1st Instar; **= 2nd Instar

Significantly higher Anopheles vector larval densities were recorded from the rice-rice and rice-fallow cropping system than in the rice-Soya bean system (Figure 4.3.1 and table 4.3.1and 4.3.3). A similar trend was also obtained for the *Culicine* spp. larval densities.

Table 4.3.1: Malaria vector (*Anopheline*) larvae densities during the second season

Treatment	Malaria Vector Larvae densities			
	Anopheles Larvae		Culex Larvae	
	L1L2[a]	L3L4[b]	L1L2	L3L4
EAI3600	0.0	0.0	0.0	0.0
Bosier	0.0	0.0	0.0	0.0
fallow	2.1	1.2	2.2	1.0
Rice	3.2	1.3	4.1	2.3
LSD	2.0	2.0	2.0	3.0
CV	17.8	18.9	17.8	17.6
P	**	ns	**	**

a=1st Instars; b=2nd Instars; ns = non-significant difference; ** = highly significant difference

Table 4.3.2: Malaria vector (*Anopheline*) larvae densities during the third season

Treatment	Vector larvae densities			
	Anopheles		Culex	
	L1L2[a]	L3L4[b]	L1L2	L3L4
EAI3600	0.0	0.0	0.0	0.0
Bosier	0.0	0.0	0.0	0.0
Fallow	2.0	1.0	3.0	2.0
Rice	4.0	4.0	5.0	6.0
LSD	0.9	1.8	0.4	1.0
CV	5.1	9.7	2.0	4.5
P	**	**	**	**

a = 1st Instar; b = 2nd Instar; ** = highly significant difference

4.3.2 Effects of rice growth stages and cultivation operations on vector densities

The rice-rice and rice-fallow vector population densities results are presented in Figure 3.2.

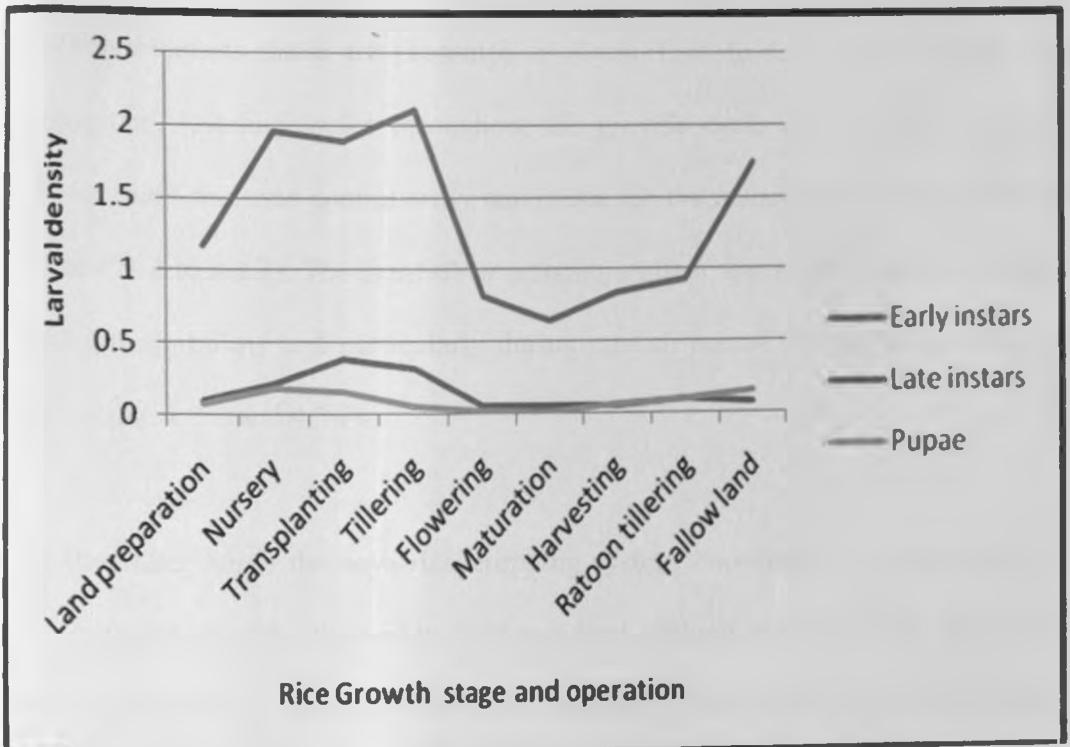


Figure 4.3.2: Anopheline mosquitoes larval densities (#larvae/10 dips) in relation to rice cultivation stages and operations at Mwea

A clear pattern was observed in rice plots in relation to rice growth cycle and the Anopheline pre-adult population densities (Table 4.3.2). *Anopheles* larval densities in the paddy habitat category were highest between land preparation and late tillering stage for both the main and ratoon crop. The larval densities increased from land preparation and were highest between early and late tillering stages. Larval densities then declined significantly at flowering stage and were lowest at the maturation stage but increased post harvest (fallow land). Late instars and pupae were low though there was a strong correlation between the late stage *Anopheles* larvae and the pupae (r = 0.591).

4.3.3 Influence of cropping system on vector breeding habitat

The observations made are presented in Plates 4.3.1 to 4.3.7. The rice-rice cropping system maintained standing water throughout the growth cycle of the rice plant. This created an environment that was continuously conducive for the malaria vector breeding and development (Plate 4.3.1 to 4.3.3). The rice-fallow cropping system also allowed water to collect in the paddy field during fallow and particularly during rainfall period creating favourable vector breeding sites (plate 4.3.1 and 4.3.8).

On the other hand, the soya-rice cropping system encouraged the maintenance of an upland environment whereby the paddy field was kept without standing water making it unfavourable for vector breeding. However the upland condition of the paddy field made it easy to walk in the field and crop management (Plates 4.3.4 to 4.3.7). It is the presence of the ridges in the Soya bean cultivated plots that helped drain excessive water unlike in the rice-rice cropping system. Hence, Soya bean cultivation enabled modification of the ecosystem which not only eliminated the malaria vector breeding sites but was also environmental friendly. Thus the cropping system recorded zero larval density scores against the higher scores observed in rice-rice and rice-fallow cropping systems.

Plate 4.3.1: Rice-rice cropping system activities that create conducive Mosquito breeding conditions

The draining of standing water to avoid water logging the Soya bean crop helped create the upland environment (Plates 4.3.3, 4.3.4 and 4.3.7) thereby successfully eliminating malaria vector larvae breeding habitat. Ridging for the soya bean cropping prevented the formation of the water pools that would otherwise occur in fallow rice fields and serve as the major malaria vector larva breeding sites. The drive to grow a health Soya bean crop to generate extra income would encourage farmers to maintain the upland ecosystem and therefore enhance malaria vector control.

Plate 4.3.2: Standing water in rice-rice cropping system provide conducive mosquito vector breeding sites

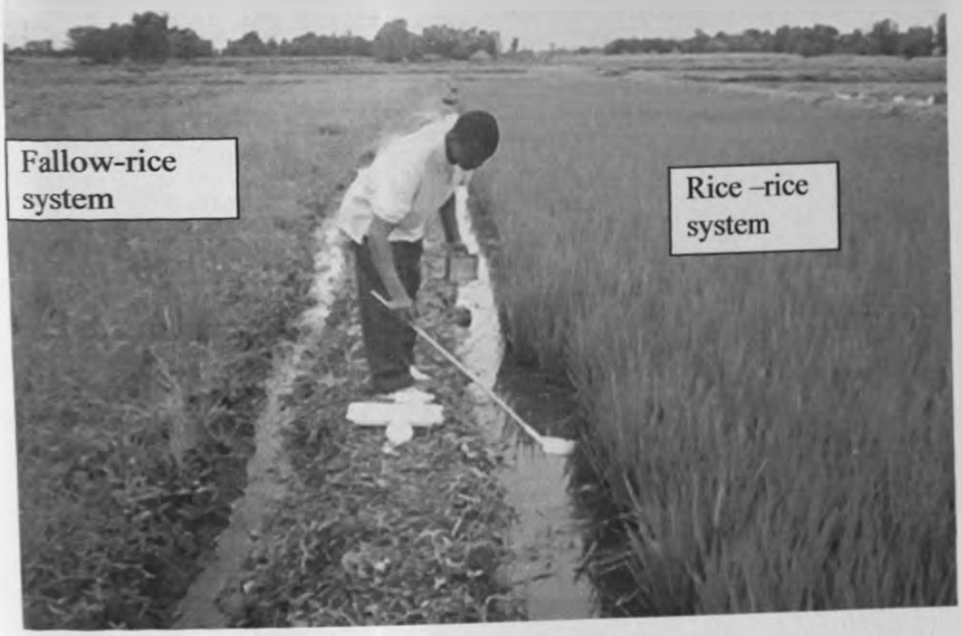


Plate 4.3.3: Mosquito larvae sampling by dipping technique

Plate 4.3.4: Appearance of a rice field following dry tillage for Soya cultivation

Plate 4.3.5: Drained soya bean field allow walking for easy management of the crop

Plate 4.3.6: Irrigating Soya crop in paddy fields: Ridging allow irrigation and drainage of excess water

Plate 4.3.7: Ridging Paddy fields maintain field free of standing water from soya bean sowing to maturity creating unfavorable environment for mosquito breeding

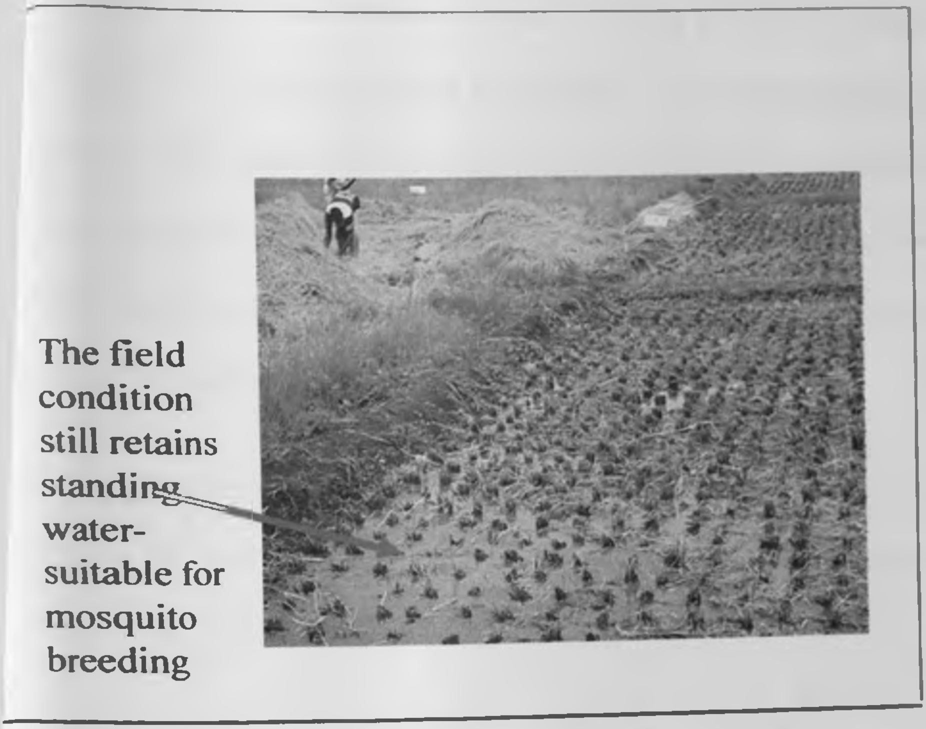


Plate 4.3.8: Appearance of a harvested plot of a 2nd rice crop from rice-rice treatment

4.3.4 Rice cultivation area mapping to determine the pattern for malaria vector control through crop rotation

Figures 4.3.3 shows the prevailing rice production patterns; main rice crop and ratoon crop patterns; fallow periods and areas cropped by main scheme farmers and out-growers.; water supply regime to the different sections and units in the scheme and hence reflect periods of essential and non-essential flooding. Non-essential flooding occurred when paddies were left idle but flooded awaiting rotavation or during fallow periods when long rains water collected and similarly kept the fields submerged.

About 83 % of Scheme farmers (12,561 acres) were shown to harvest their rice crop in December (the rest in January), allowing regeneration of a ratoon crop which they harvested in

February-March. Water was drained around harvest time and returned for growth of the ratoon crop. This period was followed by early flooding of the land staggered according to planting groups (1^{st} – 4^{th} group) that start in April-May. The cropping program is staggered within the 4 groups to help share the inadequate irrigation water during the favourable rice growing period. Land preparation is by rotavation and follows the flooding schedule that run between April-May and August-September period. Rice sowing starts in mid July and seedlings are transplanted from mid August

Out growers in the irrigated area adjacent to the main Scheme boundaries occupied an equivalent 25% of the total Scheme area. They plant their rice in December and harvest in March (Fig. 4.3.3).

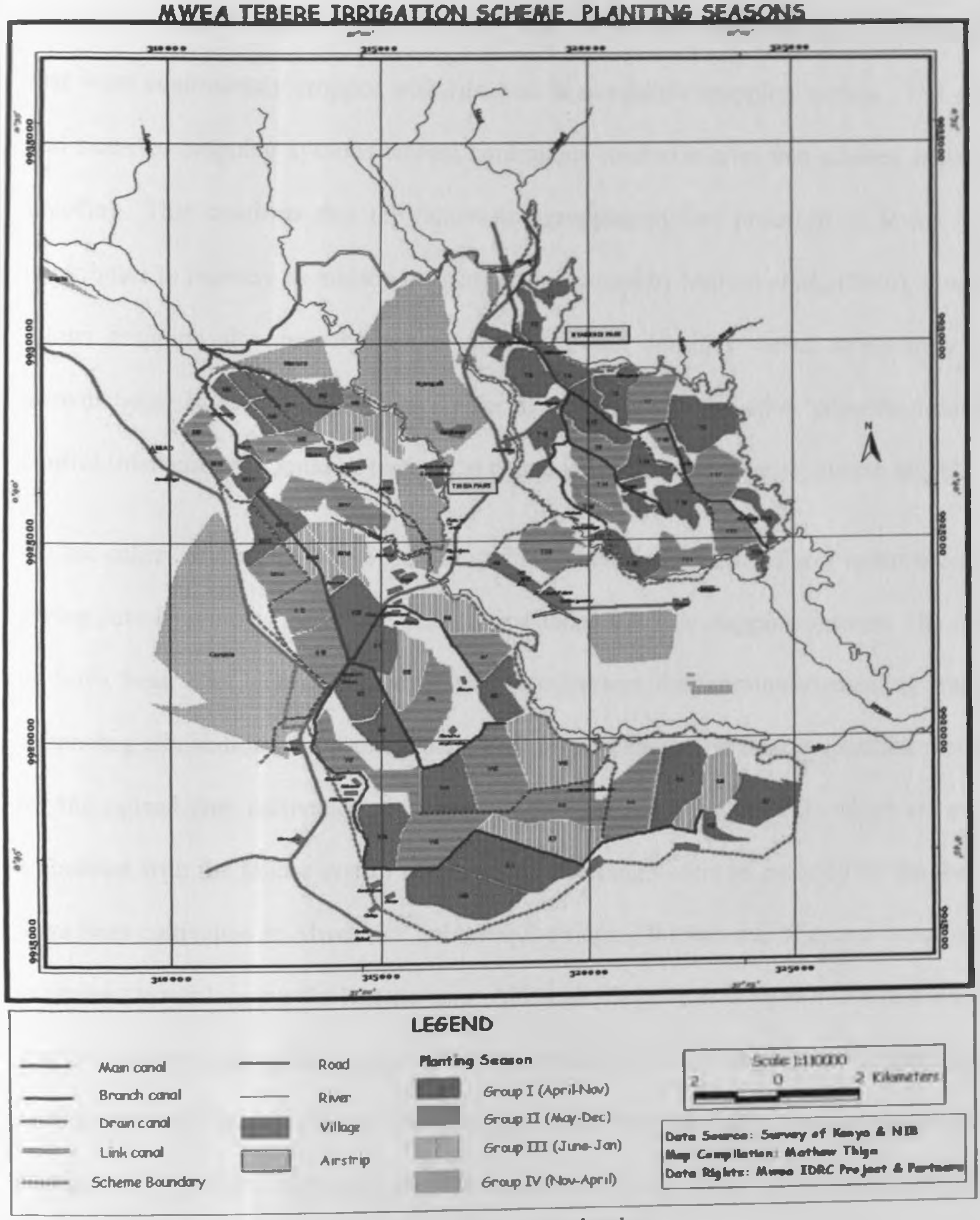


Figure 4.3.3: Mapping for Crop rotation and vector reduction

4.3.5 Discussion - Effects of cropping system on malaria vector population

The results indicate highly significant *An. arabiensis* and *culicine* larva in the experimental plots that were continuously cropped with rice and in rice-fallow cropping system. The rice-fallow and rice-rice cropping systems created continuous conducive sites that allowed malaria vector breeding. This confirms that the fallow-rice cropping system practiced in Mwea rice fields contributes to increase in malaria incidences as reported by Mutero *et al.*, (2000). Similarly rice ratoon cropping also increased vector density. Vector densities varied significantly with rice growth being highest during the rice tillering stage. Thus any other possible malaria vector control interventions should be targeted to coincide with the rice tillering growth stage.

On the other hand alternating Soya bean with rice eliminated the malaria vector breeding sites giving zero larval densities unlike the rice-rice and rice-fallow cropping systems. The cultivation of Soya bean after rice created an upland environment that eliminated standing water hence enhancing elimination of malaria vectors breeding habitats. The land preparation method used for the upland crop cultivation discouraged accumulation of water pools which are commonly associated with the fallow system where vector breeding occurs as reported by Ijumba, (1997). Soya bean cultivation in Mwea rice fields require ridging for removal of excess water (drainage) to prevent water logging the legume crop. Although Soya bean is known to withstand a higher degree of water logging than most cultivated crop legumes, prolonged water logging inhibit its growth and cause high yield loss. Cultivation of Soya bean after rice would therefore encourage drainage of the paddy fields particularly during the long rains. This would extensively reduce the vector breeding habitat scheme wide to break the vector cycle and hence positively contribute to other efforts of the malaria disease control in the region.

The study also demonstrated the potential of the rice fields to support cultivation of Soya bean after rice. The current long fallow and flooding period in Mwea could be avoided by cultivating Soya bean after the main rice crop or ratoon rice crops which would take advantage of the long rains precipitation. Cultivation of soya bean after rice has the advantages of soil fertility replenishment, elimination of the vector breeding sites and production of the highly valued Soya bean grain for nutrition improvement. Additionally the soya-rice cropping system has potential to improve farmers' health by reducing malaria vector, drudgery and hours of working in flooded paddy fields. Working for long hours in flooded paddy fields is not only tedious but also predispose people to infection by water borne diseases such as Bilharzia.

The presence of the vector on the fallow paddy field is of much significance considering that rice-fallow cropping system is the conventional practice in Mwea. In the rice-fallow cropping system, paddies are left unattended where grazing livestock leave behind hoof marks that trap water during rainfall. These hoof marks become the major vector breeding sites in paddy fields. This may explains why long rains are followed by a spell of high malaria disease incidences in the study region. These observations are in agreement with the findings of Ijumba, (1997) who concluded that the small pools created by drying out the rice fields remained highly productive for the malaria vector. He observed that in improperly leveled fields, numerous small puddles are left behind and this could even increase the egg laying potential in absence of flood water. The cultivation of the soya bean crop in upland environment promotes draining of the water pools often formed in fallow land. Consequently, the system of alternating rice with Soya bean is a potential farm based-managed intervention strategy that could provide an opportunity for malaria vector control in Mwea. The elimination of malaria vector will reduce disease impact and result in healthy farmers enabling them to allocate more of their time to increased agricultural productivity.

The patterns observed during area mapping broadly showed the general management of the rice irrigated habitat and pointed that Soya bean could fit within the annual cropping cycle of the scheme. It could be cultivated during the long rains and short rains for the main scheme and out-growers area respectively. The mapping indicates the scope for soya cultivation after rice/ratoon to dry up the land, reduce vector breeding sites and hence help control malaria.

Soya bean has higher nutritional value than cereals and tuber crops commonly consumed by the Mwea community. Cultivation and utilization of Soya bean would complement the community's dietary composition for health improvement. A healthy body is less prone to disease infection and would in turn have higher and better quality work output (Mutero, 2003). The Soya bean-rice cropping system would therefore enable the farmers to allocate more time in agricultural activities resulting in increased rice output. The finances committed to paying hospital bills would then be saved and contribute to improvement of crop husbandry and enhancement of food security and household incomes.

It can be therefore concluded that there is need to encourage farmers to adopt the Soya bean–rice cropping system to compliment other national efforts that are focused in eradicating malaria disease.

4.4.0 EFFECTS OF THE CROPPING SYSTEMS ON COSTS AND BENEFITS

4.4.1 Partial Budget analysis

The results of the effects of cropping systems on subsequent rice grain yield are presented in tables 4.2.1 and 4.2.2 in pages 81 and 82 respectively. The effects on yields due to applied N are indicated in table 4.2.3 and 4.2.4 on pages 82 and 84 as well as in Fig. 4.2.1 on page 83.

Rice grown after the Soya bean crop (EAI 3600 variety) treatment gave significantly ($P<0.05$) higher grain yield (5567 $Kgha^{-1}$) compared to the rice grown after rice (4438 $kgha^{-1}$) giving a yield difference of 1129 $kgha^{-1}$ (Table 4.2.1 page 81).

There was 21% rice grain yield increase achieved with half of the normally applied Nitrogen (N) fertilizer (Fig 4.2.1 page 83). In the Soya bean-rice cropping system, 40Kg N ha^{-1} gave higher yields than 80kg N ha^{-1} in the rice-rice cropping system. This implies that rice following a Soya bean crop would require half of the N applied in rice-rice system. In the conventional rice cropping system farmers use 572kg kg of Sulphate of Ammonia (SA) fertilizer (21%N) per ha costing Kshs25,143. Since the Soya bean-rice cropping system results in a saving of 191kg SA per ha it would therefore reduce cost of production by Kshs8381ha^{-1} equivalent to 33% N fertilizer saving.

Table 4.4.1 presents the resultant Soya bean-rice cropping system Partial budget analysis.

Cultivation of Soya beans as a preceding crop to rice showed multiple benefits (Table 4.4.1). The benefits include Kshs47,011 ha^{-1} from the harvested Soya bean grain yield of 2317 kg ha^{-1}, Kshs33,870 ha^{-1} as the quantified 1129 kg ha^{-1} marginal increase in subsequent rice yields in Soya bean-rice cropping system above control and Kshs8381ha^{-1}obtained as the saving on reduced use of inorganic fertilizer. The Soya bean-rice cropping system leads to an increase in net income amounting to Kshs**61,317**.

Table 4.4.1: Partial budget Analysis for the proposed Rice-Soya bean rotation at Mwea Irrigation Scheme

GAIN ha^{-1}	**Value ha^{-1} (Kshs)**	**LOSS ha^{-1}**	**Value ha^{-1} (Kshs)**
Extra Revenue		**Revenue Foregone**	
2371 kg Soya bean ha^{-1} X Kshs27	71130	4946kg ha^{-1} rice @ Kshs30	148380
1129 kg ha^{-1} rice @ Kshs30 marginal increase in rice yield	33870		
Reduced Costs		**Extra Costs**	
Second rice crop expenses @ Kshs120435 ha^{-1}	120435	Total cost of producing one ha @ Kshs24119	24119
247kg ha^{-1} @ Kshs31 Saving on Nitrogen fertilizer	8381		
Total	**233,816**		**172499**
Change in net Income			**+61,317**
Total Scheme (8000ha) net income			**490,536,000**

4.4.2 Cropping systems gross margin computation and comparison

4.4.2.1 Preceding crop gross margins (GM)

The Gross Margins per hectare for the preceding test crops are presented in Table 4.4.2 and 4.4.3.

Among the soil fertility improvement system (preceding crop), rice gave the highest grain yield (Table 4.4.2) as well as the highest total revenue. The Soya bean varieties generally gave similar pulse grain yield. Duicker variety had the highest revenue among the soya bean varieties. There were no direct revenue realized from both Sesbania and fallow systems.

The preceding crop gross margins (GM) for soya bean varieties were higher than for rice (Table 4.4.2). Soya bean variety, Duicker, had the highest GM while EAI3600 had the lowest. Sesbania had negative GM while fallow system had zero GM.'

Table 4.4.2: Preceding crops treatment means per ha gross margins at Mwea

Crop	Grain Yield (kgha^{-1})	Total Revenue ha^{-1} *(Kshs)	Total variable Costs ha^{-1} (Kshs)	Gross Margin ha^{-1} (Kshs)
Sesbania	0	-	17000	-17,000
EAI 3600	2043	61290	24,119	37,171
Rice	4946	148380	120,435	27945
Duicker	2371	71130	24,119	47,011
Bosier	2230	66900	24,119	42,781
Fallow	0	-	0	0

Key: *Total Revenue = output x price.

Higher GM (P=0.0001) was obtained from duiker and Bossier soya bean varieties, followed by rice crop (Table 4.4.3). No grain harvest was expected from the fallow-rice and *Sesbania*-rice cropping systems. *Sesbania* was incorporated as green manure. Weed flora from the fallow system does not directly add to the income of the rice field holder when grazed to livestock other than those owned by the farmer. The weeds were also incorporated into the soil during this study. Their contribution to the income is realized through the returns from the subsequent rice crop harvest difference above the rice-rice treatment.

Table 4.4.3 Preceding crop Gross Margins Analysis at Mwea

Crop	Gross Margin ha^{-1} (Kshs)
Duiker	41,070a
Bossier	36,191a
Rice	33,969b
EAI 3600	28,821b
Fallow	0.0c
Sesbania	-6508c
Mean	22,257
CV	18
LSD	7322
P%	0.0001

Key: Means followed by the same letter are not significantly different at $P \leq 0.05$ n=48

4.4.2.2 Subsequent rice crop gross margin (GM)

The Gross Margins for the subsequent rice crop are presented in Table 4.4.4

The highest gross margin was observed from EAI3600-rice treatment which recorded 191% difference above the Rice-rice cropping system (Table 4.4.4). Rice-rice cropping system had the lowest GM.

From table 4.4.4 the contribution of fallow cropping system weeds in terms of soil fertility replenishment and hence to income is given by fallow-rice (FR) minus rice-rice (RR) treatment GM. That is:

FRGM-RRGM = Kshs34365-17655

=Kshs16,710

Table 4.4.4 Subsequent rice crop treatment means gross margins at Mwea

Cropping System	Rice Grain Yield	Total Revenue [a]	Total variable Costs	Gross Margin	Gross margin Difference above control[b]
	($kgha^{-1}$)	(Kshs) ha^{-1}	(Kshs) ha^{-1}	ha^{-1} (Kshs)	(%)
EAI 600-Rice	5549	166470	120,435	46,035	161
Bosier-Rice	5126	153780	120,435	33,345	89
Sesbania-Rice	5303	159090	120,435	38,655	119
Duiker-Rice	5296	158880	120,435	38,445	118
Fallow-Rice	5160	154800	120,435	34,365	95
Rice-Rice	4603	138090	120,435	17,655	0

Key: [a]=Total Revenue = output x price; [b] = Rice-rice cropping system

4.4.2.3 Annual gross margins (GM) for both the preceding crop and succeeding rice crop

The annual GM for both the preceding crop and the subsequent rice crop are presented in Table 4.4.5.

The annual gross margins differences above the control treatment (rice-rice) were highest (positive) in all Soya bean-rice cropping systems and lowest (negative) for the Sesbania-rice treatment followed by fallow-rice cropping system (Table 4.4.5). There were variations in annual GM among the different Soya bean varieties above control. Duicker-rice treatment had the highest GM differences followed by EAI3600-rice treatment. Bosier-rice treatment recorded the lowest GM differences.

Table 4.4.5: Annual gross margin comparison on 3 years yield means of preceding crop and main season rice crop at Mwea

Cropping system	Preceding crop gross margin ha^{-1} (Kshs)	Subsequent rice crop gross margin ha^{-1} (Kshs)	Total Annual Gross margin ha^{-1} (Kshs) Margins	Gross margin Difference above control (%)
EAI 600-Rice	37,171.00	46,035	83,206.00	82
Bosier-Rice	42,781.00	33,345	76,126.00	67
Sesbania-Rice	-17,000.00	38,655	21,655.00	-53
Duiker-Rice	47,011.00	38,445	85,456.00	87
Fallow-Rice	-	34,365	34,365.00	-25
Rice-Rice	27,945.00	17,655	45,600.00	-

4.4.2.4 Succeeding crop yield differences above the control

The Succeeding crop yield differences above the control are presented in Fig 4.4.1

The legume-rice cropping system gave higher subsequent rice grain yield than the rice-rice cropping system, with an average margin of 15% (Fig. 4.4.1). EAI 3600 rice cropping system maintained the highest yield increase differences that averaged 21% for two seasons.

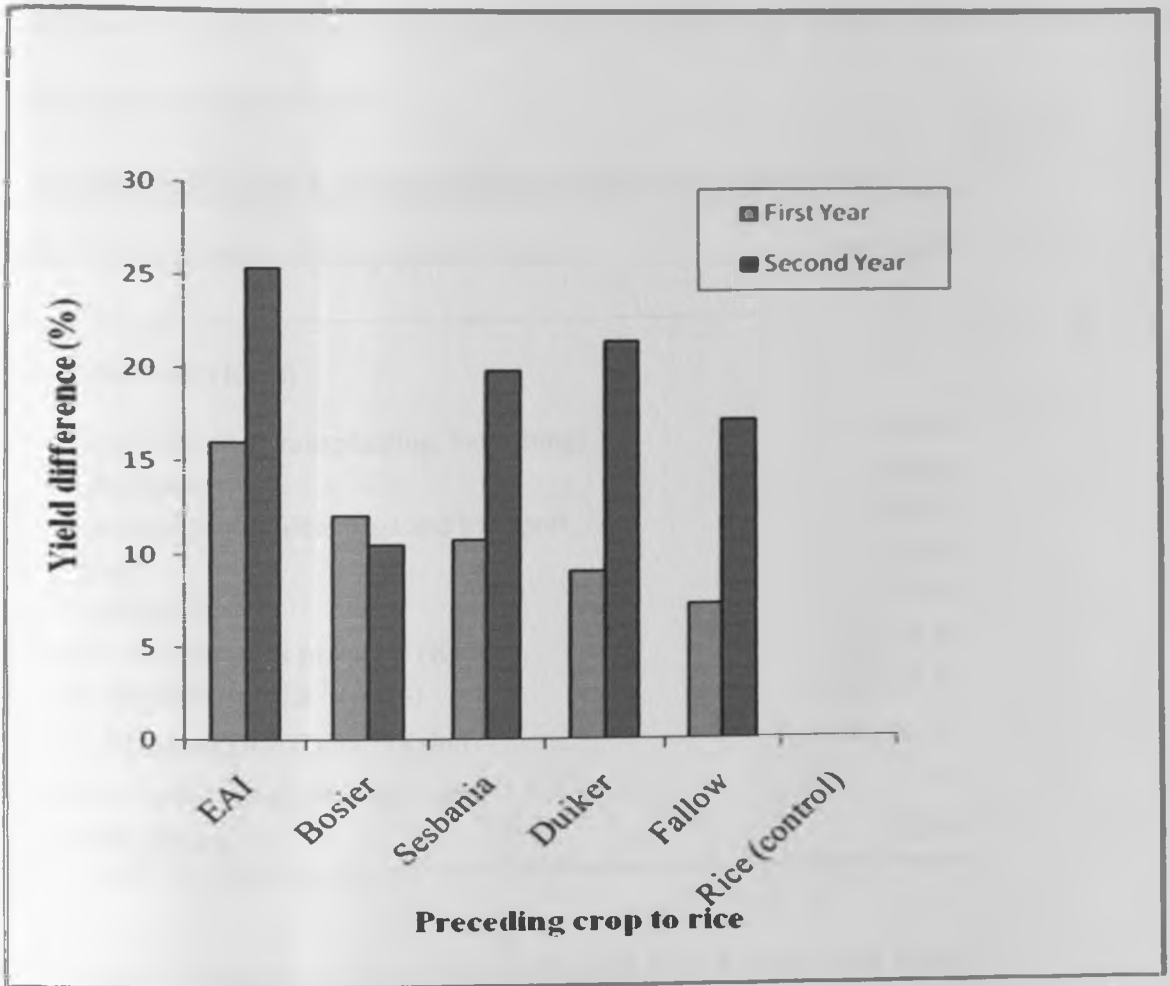


Fig 4.4.1: Cropping systems subsequent rice yield compared to rice-rice at Mwea (control)

4.4.3 Rice-Soya bean Profitability and Benefit cost ratio

The results of the gross margins for the second rice crop and Soya bean are presented in tables 4.4.6, 4.4.7, Figures 4.4.1, 4.4.2, and Plate 4.4.1).

The total revenue per hectare for the second rice crop and the highest yielding Soya bean variety are Kshs148,380 ha^{-1} and Kshs71,130 ha^{-1} respectively (tables 4.4.8 and 4.4.9).

The gross margins for the preceding rice crop and Soya bean are Kshs27,945 ha^{-1} and Kshs47,011 ha^{-1} respectively. The benefit-cost ratio (BCR) at a price of Kshs30 per kg for rice and Soya bean is 1.23 and 2.95 respectively. Yields were 4946Kgha^{-1} and 2371Kgha^{-1} for rice and Soya beans respectively.

Table 4.4.6: Rice Gross Margin, Benefit-Cost Analysis and Yield

Rice Total revenue (4946kg @Kshs 30) ha^{-1}	**148,380.00**
Variable cost (Kshs)	
Labour (Sowing, transplanting, harvesting)	23,850.00
Land preparation	4000.00
Fertilizers, pesticides, bags and transport	15,490.00
Seed	1,400.00
Irrigation	4,000.00
Total variable costs per acre (Kshs)	**48,740.00**
Total variable costs ha^{-1} (Kshs)	120,434.89
Gross Margin (TR-TC) ha^{-1} [Kshs]	27,945.11
Benefit - cost ratio (Revenue /costs)	1.23
Yield in Kg ha^{-1}	**4946**

Table 4.4.7: Soya bean Gross Margin, Benefit-Cost Analysis and Yield

Soya beans Total Revenue (2371 Kg ha^{-1}@Kshs 30 Kg^{-1})[Kshs]	**71,130.00**
Variable cost (Kshs) ha^{-1}	
Labour (Sowing, planting, weeding, harvesting)	10,313.00
Land preparation	4,926.00
Fertilizers and pesticides	4,137.00
Seed	2,362.00
Irrigation	1,750.00
Total variable costs (Kshs)	24,119.00
Gross Margin (TR-TC) ha^{-1} [Kshs]	47,011.00
Benefit - cost ratio (Revenue /costs)	2.95
Yield in Kgha^{-1}	**2,371**

4.4.4 Benefits of Soya bean-rice cropping system elimination of malaria vector

The results obtained are indicated in Figure 4.4.2. Cultivation of Soya bean after rice significantly eliminated malaria vectors as indicated by the zero vector larva scores in Soya bean-rice cropping system. This translates to a reduction in malaria disease and mosquito bite nuisance with resultant human health improvement. The economic significance of this is the reduction the loss of agricultural work which occur during malaria sickness. The saved time labour time will be committed to crop productivity for increased rice and Soya bean production to generate more income.

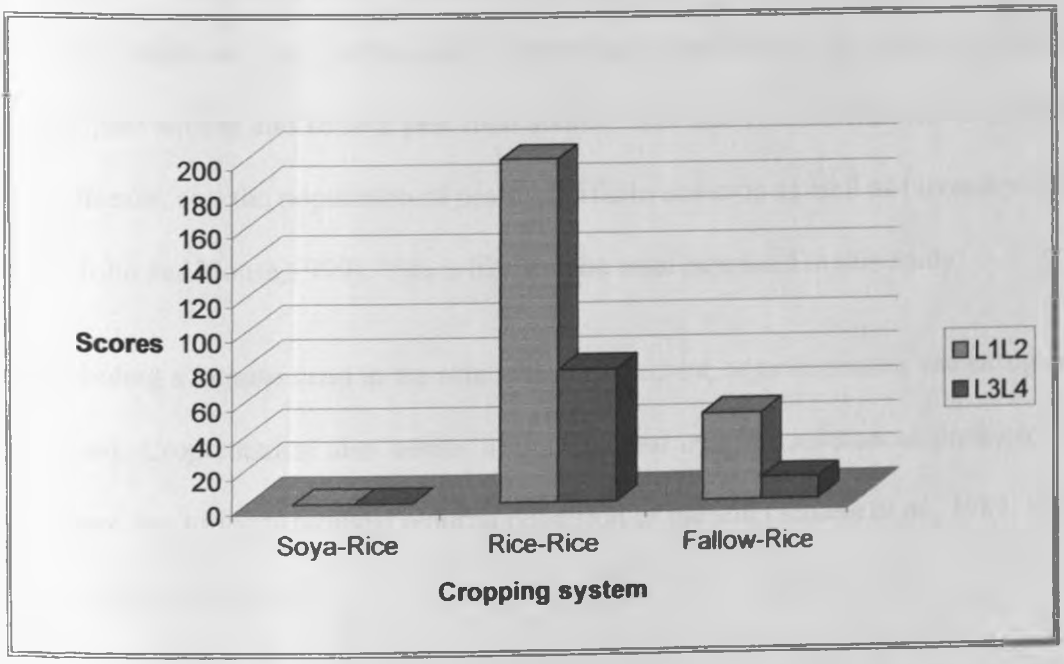


Fig 4.4.2 Malaria Vector Larvae (*Anopheline*) scores among the cropping systems
Key: * L1L2: 1st and 2nd lower instars of mosquito larva; L3L4:3rd and 4th instars

4.4.5 Discussion – Effect of cropping system on costs and benefits

Alternating the cropping of rice with Soya bean contributed to an increase in the follow-up rice crop grain yield by 21% as indicated in Table 4.4.1. The system improved soil fertility via increase in soil nitrogen and organic matter that led to reduction in use of inorganic fertilizers by half. This is attributed to the overall general improvement in soil chemical and physical properties that appear to have promoted better plant growth. The legume-rice cropping system maintained the soil under upland condition, allowing paddy soil to recover from the negative effects of long flooding (water logging) hence improving its nutrient availability leading to the observed improved crop performance. Cultivating legume before the main rice crop is known to reduce pest habitat and reduce pest food source. It is also reduces the risk of soil nutrient loss, plant disease, and the population of pests specific to one crop as well as increase yields (Russels, 1963; John and House,1990). This is likely to be what happened in this study.

By including a legume crop in the rotation, soil structure, organic matter, and nitrogen supply are improved. Crop rotation also assists in the removal of toxic substances produced in the plant root-zone due to the prolonged reduced condition of the soil (Kaneta *et al.*, 1989, Moroyu, 1983 and Walters *et al.*, 1992).

The increase in rice yield, the returns from Soya bean and resultant reduction in fertilizer use can positively impact on increasing household income and reducing poverty among the rice farming community.

Preceding crop and subsequent rice gross margins (GM)

The fallow-rice and *Sesbania*-rice cropping systems had no direct financial advantage compared to the Soya bean-rice system. *Sesbania* is incorporated as green manure while fallow plots support weeds which are conventionally grazed by livestock that do not necessarily belong to the owner of the paddy field Thus, the benefits accrued from livestock grazing and the use of weed residue for green manure or fodder valued at Kshs16,710 does not trickle down intrinsic monetary return to the rice farmer. However, the direct benefits accrued from the Sesbania and fallow systems through soil fertility improvement are partially realized from the returns of the subsequent rice crop as presented in table 4.4 4 Sesbania-rice and Fallow–rice cropping system gave 119% and 95% annual gross margin respectively above the rice-rice system Thus the direct financial benefit from Sesbania and fallow are given by the difference between GM from the subsequent rice grain yield of the two systems and that of Rice-rice system which amounts to Kshs21,000 and Kshs16710 respectively, However, when the total annual GM is considered Sesbania-rice and fallow-rice cropping systems give less direct benefit to the farmer than the Rice-rice system as recorded in table 4.4.5 Never the less, the Fallow-rice cropping system maintains higher income than the Sesbania system The fallow period has intangible benefits in that the community members who keep livestock also graze in the paddy fields. Since the upland crop field rents for Kshs5000 it can be concluded that the farmer contributes almost the same amount of money to society gains.

The gross margins of second rice crop are less than those from the Soya bean The benefit cost ratio (BCR) for rice is also lower than that of Soya bean, implying that the second rice crop associated costs of resources are too high. This observation agrees with the finding of Kuria (2004) that all the resources used in production of second rice crop were inefficiently allocated, giving technical efficiency (Upton, 1964) of rice double cropping enterprise as only 68% Soya bean-rice cropping system would therefore, be preferred to rice-rice cropping system

Accrued Health benefits

The observed financial benefits from Soya bean-rice cropping system would be expected to enhance cultivation of Soya bean in paddy fields with resultant increase in production and availability of the high protein legume products. This would promote consumption of the nutritious Soya bean products among the rice farming community with resultant improvement in farmers' diet for better health. In the case where farmers are motivated to sell the soya beans, the generated finances may be used to purchase finished soya bean nutrient rich products to improve their diet. The improved incomes would also enable the farmers to purchase drugs and mosquito nets as well as construct mosquito prove houses. A healthy community will in turn commit more time towards agricultural production for improved food security and increased farm incomes as also observed by Mutero, (2005). Soya beans are an excellent source of dietary fiber, complex carbohydrate and plant protein. They are relatively high in fat, mainly unsaturated fat, and are therefore a rich source of energy. Soya bean protein consumption is known to improve human health in cholesterol-lowering. Soya beans are also particularly important food for diabetics and individuals at risk of becoming insulin resistant, and they also give some relief of menopausal symptoms (Appleby, 2001; Seralathan *et al.*, 1987). Soya bean could be sold for industrial processing of Soya bean beef, oil, milk, and other products (Carrao and Gontijo, 1993). Soya bean is also valuable for production of a high protein seed cake from the residue left after oil extraction which has a high nutritional value for livestock feeding (MOALDM, 1995b). Increased Soya bean cultivation will hence improve livestock farming in the rice farming community. Livestock assist in puddling paddy fields and therefore reducing human workload In addition to these livestock provide milk and meat that supplement health improvement A study on malaria in Mwea (Mutero *et al.*, 2003) indicated that cattle provide alternate source of blood to the anopheles female mosquitoes thereby drawing them away from biting people

Malaria is the most serious health problem in the study area. Cultivation of Soya bean after rice significantly eliminated malaria vectors by mopping up standing water Ridges made for Soya bean cultivation helped to drain water from the paddy field, hence eliminating highly potential malaria vector breeding sites. Soya bean-rice cropping system effectively eliminated the vector (larvae), unlike the rice-rice and rice-fallow cropping systems In the fallow-rice cropping system, paddies are left unattended after harvesting the main rice crop and this is where livestock are grazed. Livestock leave behind hoof marks which become major malaria vector breeding sites (Ijumba, 1997). Soya bean cultivation on ridges encouraged the drainage of excess water, as confirmed by the zero scores of the vector recorded in the Soya bean-rice cropping system. Soya bean crop (planted in ridges) therefore effectively mopped up surface water, hence reducing malaria vector breeding sites. The rice plots had high larval scores and were followed by the fallow-rice plots. The latter two treatments represented the typical production systems practiced by farmers in Mwea (Muturi *et al.*, 2006 and Mwangangi *et al.*, 2006ab).

Soya bean cultivation in rotation with rice crop altered the ecology of the paddy field resulting in the reduction of malaria vector population and hence playing a significant role in malaria control and health improvement in irrigated rice farming. This would allow farmers to invest most of their energy and time in agricultural production for enhancement of their livelihoods Considering that a substantial part of the farmers' income is used to cater for medical bills

(Lindsay *et al.*, 1995), improved health would also unlock finances to support timely crop management operations to boost rice yield and income

The improvement in soil fertility management will help reduce the yield losses often caused by low or no application of in-organic fertilizers due to lack of finances at the peak stage of plant nutrient requirement. These benefits coupled with the observed lower weeds population in Soya bean-rice cropping system than in the rice-rice and fallow-rice cropping systems, present a workable opportunity for sustainable increase in rice and Soya bean crops output while conserving the environment in line with WHO, (1982).

The Soya bean cropping system would also enhance the utilization of the labour, land and water resources with resultant expansion of the area under rice production. Once the Soya bean-rice cropping system is wholly adopted, there will be a substantial increase in rice grain and Soya pulse output that would contribute positively to the GDP and improve food security to mitigate food crisis. These findings, coupled with observation that Soya bean-rice cropping system has increasing returns to scale (Kuria, 2006), makes Soya bean-rice cultivation the most sustainable agricultural system of choice for increasing gross margins of rice farming in Mwea.

A soya been production study by Kuria, (2006) showed that the returns to scale for Soya bean was increasing, indicating that there was need to expand on the use of labour, capital, fertilizer, pesticides and seeds. Returns to scale were constant for the case of second rice crop, implying that there is no need to expand the use of resources. Constant returns to scale imply that output of second rice crop has attained the optimum level and cannot be enhanced by investing more resources. Thus employing further resources in double rice cropping would lead to a waste of resources. The increasing returns to scale suggest that, if all relevant factors were increased by a given percentage, Soya bean yields would increase by a percentage greater than the percentage increase in the input factors. The study indicated that increasing resources on Soya bean production would have the advantage of increasing Soya bean productivity In this case, farmers should invest more of their resources on the Soya bean cropping system in order to optimize production and income.

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This study has tested and demonstrated the effects of rice-rice (*Oryza sativa* L.), Sesbania (*Sesbania sesban* L.)-rice, Soya bean (*Glycine mark*)-rice and fallow-rice cropping systems on the subsequent rice crop growth and yield The study shows that alternating rice with other plants and incorporating residues in the rice fields enhance soil NPK, soil organic matter (SOM), crop growth and grain yield The cropping systems influenced field condition, soil fertility, plant growth, and yield variably with legume-rice cropping system indicating potential to impact favourably on farmer's income, health and the environment

5.1.1 Effect of cropping system on Soil NPK, soil organic C and use of inorganic fertilizers

Rice and Soya bean produced the highest significant biomass quantities while the fallow treatment gave the lowest amount of biomass followed by *Sesbania sesban*. However, rice residue was of lower quality in nutrient content than that of *Sesbania* and Soya bean The effect of the quantity and quality of biomass was reflected in the succeeding rice crop grain yield performance trend. The rice growth and yield performance positively correlated with the quality of the biomass incorporated into the soil. The cultivation of Soya bean as well as *Sesbania sesban* before rice and the incorporation of green manure and Soya residue improved soil fertility. The biomass decomposed gradually releasing nutrients and organic matter to the soil with resultant increase in soil nutrient pool as well as possibly improving soil physical properties. The legume-rice cropping system is a major divergence from the conventional rice-

rice and rice-fallow cropping systems that had promote residue removal from the paddy field with resultant decline in soil fertility.

The generally non-significant NPK levels observed among the test fertility improvement systems suggest slow and incomplete residue decomposition and mineralization rate It is likely that by the time soil sampling was done the residue may not have been completely decomposed/mineralised for nutrient absorption by the subsequent rice plants, hence the nutrient mean differences were not very prominent. However the significantly higher subsequent rice grain yields in the legume cropping systems is an indication that soil fertility was improved Further research is therefore necessary to ascertain the synchronisation of the residue decomposition with crop growth

Crop residue is a vital natural resource for conserving and sustaining soil productivity It is the primary substrate for replenishment of soil organic matter (SOM). Upon mineralization, crop residue supplies essential nutrients to soil nutrient pool which support the growth of the subsequent plants. It is therefore likely that the tested legume based cropping systems improved soil fertility via improvement in soil chemical and physical properties besides other factors Incorporation of crop residue is associated with increase in micro-nutrients and improvement of soil physical properties with resultant enhancement of subsequent crop growth and yield performance However, the effects of the soil micronutrients on the improvement of the paddy field soil fertility after residue incorporation were not in the scope of this study The observed yield increase in legume-rice cropping systems may hence be attributed to improvement in soil physical properties and micronutrients rather than on macro-nutrients alone. The differential improvement on the rice crop growth and grain yield among the cropping systems is a reflection of soil fertility replenishment.

The low soil N, P, K after cultivation of the subsequent rice implies that the crop had utilized most of the nutrients replenished by the preceding crop in exception of Ca and Organic carbon which were moderately available and adequate respectively. This partly confirms reason behind the decline in rice grain yields reported to occur when a rice crop is followed up by another without replenishment of the limiting soil nutrients This therefore, emphasize on the need to alternate rice with a legume crop to replenish soil fertility for increased subsequent rice grain yield.

The *Sesbania sesban* biomass quantity was second from the lowest and had similar nutrient content to that of Soya bean. *Sesbania sesban* cultivation and incorporation also increased succeeding rice grain yield by over 16% above the control. However, *Sesbania* is of limited domestic use compared to Soya beans, a factor that would discourage its adoption for cultivation in rotation with rice despite its promising ability to improve soil fertility. However it is most likely that its use will increase as the inorganic fertilizer prices continue to increase Furthermore, since *Sesbania* plant has little domestic use, its residue has low possibility of being removed from the paddy field unlike Soya bean residue and rice straw

The possibility of alternating other crops with rice, particularly legumes, would be an important mile stone towards replenishing paddy soil fertility for increased rice output in Mwea

5.1.2 Effect of cropping systems on rice grain yield and agronomic traits

The Soya bean-rice cropping system generally maintained better plant growth performance and the highest rice grain yield. Cultivation of soya before rice and incorporation of soya bean residue into the soil improved soil fertility as reflected by superior crop growth performance and higher rice grain yield. The rice-rice cropping system followed by the fallow-rice cropping system gave the lowest succeeding rice grain yields and hence confirmed past Mwea farmers' experience in attempted rice-rice cropping system. The rice-rice and rice-fallow cropping systems are associated with removal, burning or grazing of rice straw practices that accelerate decline in soil fertility resulting to low rice grain yield.

Incorporation of plant residue improves physical and biological properties of the soil. Since plant residues were incorporated in all the treatments, soil fertility differences among the treatments were not very prominently expressed. However, the significant yield differences observed among the cropping systems suggest influence of other soil fertility improvement factors on subsequent rice plants growth and yield performance besides those determined in this study. Consequently, the contribution of crop residue micro nutrients to paddy soil fertility replenishment and rice grain yield will need further research. Similarly the effect of eliminated flooding and the presence of upland environment created during Soya bean cultivation as well as the incorporation of crop residue on soil physical properties should be further investigated.

The study suggests the need to lay emphasis on alternating cultivation of rice with Soya bean crop and incorporation of rice residue in the soil instead of disposal through selling, burning or grazing. Hence the soya-rice system should be recommended as the cropping system of choice to Mwea rice farmers for enhancing rice yields and incomes.

5.1.3 Effect of the cropping systems on malaria vector population

The Soya bean-rice cropping system was effective in malaria vector control having eliminated mosquito larvae during Soya bean cultivation unlike in the rice-rice and rice-fallow cropping systems. The cultivation of Soya bean in rice fields improved drainage through the ridges made for soya bean. In the process of maintaining an upland environment for the soya bean crop, the field was kept free of standing water thereby eliminating mosquito breeding sites. In the conventional system cattle graze on paddy fields leaving behind hoof mark depressions which trap water and become the major vector breeding sites. Soya bean cultivation after rice also means that livestock grazing is minimized hence reducing malaria vector breeding. Soya bean-rice cropping system would not only reduce malaria vector populations through ecosystem change but also other water borne disease vectors leading to improved human health, reduced expenditure on medical bills and save on the agricultural work time lost in sickness. The cropping system would also reduce deaths that occur due to malaria complications. Availability and consumption of the nutritious Soya grain products would improve farmer's diet and health enabling them to allocate more time and finances to agricultural productivity for increased rice output to boost food security and income.

5.1.4 Cost effectiveness of using organic soil nutrient sources to improve rice crop growth and yield

The legume-rice cropping systems improved crop growth and grain yields. The soya-rice cropping system gave higher benefits realized from rice yield increase, Soya bean grain yield and reduction in inorganic Nitrogen fertilizer. The Mwea paddy soils have been considered difficult to work because they are mainly vertisols. The soya-rice cropping system appeared to improve paddy soil workability. The cropping system also resulted in decline in weeds during the growth of the subsequent rice crop. Additionally, the cropping system would result in improved human health with subsequent reduction in medical bills and agricultural labour hours lost in sickness. The production of the high value soya grain as well as reducing malaria vectors and hence malaria incidences portray immense potential for health and income improvement. Soya bean has great economic importance and its grain is a cheap source of rich and high quality protein reserves. No other protein rich food can be produced in as large quantities and as economically as the Soya bean. Soya bean yields more protein per unit area of land than any other crop.

The introduction of Soya bean crop will lead to a shift from a mono-cropping system to crop diversification and intensification in paddy fields. Soya bean-rice cropping system has therefore the potential to increase rice yield and profitability for the rice farmers. Additionally if Soya bean-rice cropping system is fully adopted, the Mwea paddy fields can produce 37,050 tons of Soya beans worth Kshs1.4 billion during the rice off-season period.

Soya bean-rice cropping system has demonstrated the potential to support sustainable increase in rice yields. The rice-soya cropping systems replenish the soil fertility enabling cultivation of another rice crop and ratoon rice. Ratoon rice can produce over 50% yield of the main rice crop within a period of 1.5 to 2 months. The ratoon rice has very low cost of production and can generate income equivalent to that of the main crop. Enhancement of ratoon rice production would therefore largely promote utilization of production resources and hence farmers' income. Soya cultivation in paddies has potential to improve soil fertility and hence support soya-rice-ratoon cropping system. This would ultimately increase annual rice output per unit area and therefore contribute positively in improvement of national food security.

The cultivation of soya crop after rice will increase household incomes from sales of increased rice yield, pulse grain as well as from the savings made on reduced inorganic Nitrogen fertilizers use and saving on money used spent to pay medical bills The system would increase farmer's income through year round engagement of the labour, water (particularly from the April-June rainfall) and land resources that remained idle during the rice off-season periods The cropping system has an overall potential of increasing agricultural productivity and reducing Malaria, thereby contributing positively to the global millennium development goals (MDG, 2005) of eradicating extreme poverty and hunger as well as combating malaria disease and ensuring environmental sustainability.

The Soya bean-rice cropping system has demonstrated multiple beneficial effects that can enhance food security and nutrition as summarized here below:

1. Production of high value grain legume
2. Replenishment of soil fertility
3. Increased succeeding rice grain yield
4. Elimination of Malaria and other water borne disease vectors
5. Production and promotion of utilization of the highly nutritious Soya bean grain
6. Promotion of crop rotation, diversification and intensification
7. Increased incomes from increased rice yield, Soya bean grain, reduced use of inorganic N fertilizer and reduced medical bills
8. Utilization of paddy field even during the April-June rainfall period where other legumes fail due to damage by water logging

5.2 RECOMMENDATIONS

The Soya bean-rice cultivation system should be the system of choice for the irrigated rice farmers in Mwea. The system should be introduced as an alternative to rice monoculture in Mwea Irrigation Scheme for increased rice production and incomes, improved human health and nutrition and preserving the environment. However, further research is required to ascertain the synchronisation of the crop residue decomposition with plant growth. Additionally, the effects of the residue micro nutrients on paddy soil fertility and rice grain yield should be further evaluated. Similarly, the effects of the upland environment created by Soya bean cultivation and the incorporation of crop residue on the soil physical properties may require further investigations. It will be also important to carryout economic evaluation to determine the full impact of the Soya bean-rice cropping system in the region.

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APPENDENCES

Appendix 1: Meteorological data for Mwea irrigation research station

Month	Air temp Max °C	Min °C	Rel. hum. %	Sun-shine Hours	Solar rad Lang	Wind Speed Kph	Evap Pan mm	Rain fall mm
Jan	27.7	17.6	80	6.9	566	5.05	4.2	174.9
Feb	29.7	16.4	67	8.3	663	3.99	5.5	82.9
Mar	29.9	16.7	71	8.2	655	4.60	5.6	96 8
Apr	29.8	18.0	77	8.0	618	3.69	4 9	233.2
May	27.3	17.8	65	6.5	561	4.21	5.2	137.0
Jun	26.2	16.2	82	5.1	462	1.72	3.7	41 8
Jul	23.8	15.2	83	2.1	298	1.30	2.3	10.1
Aug	26.1	16.0	60	4.6	471	5.08	5.1	7.0
Sep	28.3	16.7	75	6.0	589	4.37	5.0	8.2
Oct	30.2	16.3	70	7.6	642	4.01	6.2	6.5
Nov	28.0	16.5	81	6 8	559	4.83	4.7	108.3
Dec	29.6	14.0	69	9.7	679	4.30	6.1	1.3
Total	336.6	197.4	880	79.8	6763	47.15	58.5	908 0
Mean	28.1	16.5	73	6.7	564	3.93	4.9	75.7

Source: Mwea irrigation research station situated 200m from the experimental plots

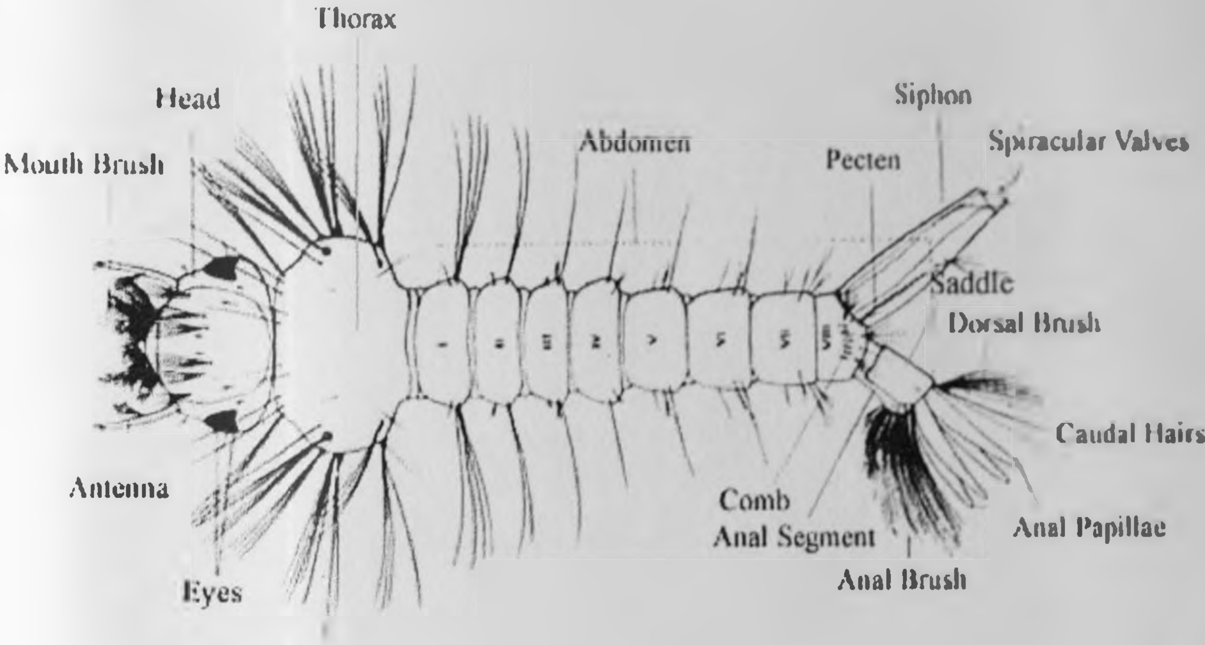
Appendix 2. Mean square for all variables measured for previous crop and N rate during the second season

Source of Variation	DF	Yield	1000Gwt	plant height	Tiller NO	Productive tillers	Non-productive tillers
Replication	2	74628.1ns	0.0072 ns	4.39ns	19 06ns	18 51ns	0 13ns
Preceding crop	5	1990193.42***	0 438 ns	62 52***	7.69ns	5 82ns	0.09ns
Rep*Preceding crop	10	145598.15ns	0.737ns	23.37*	8 91ns	8 15ns	0.59ns
N Rate	3	19222714.54***	3.635**	378.22***	444 3***	356 22***	6 36***
Preceding crop*N Rate	15	152812.39ns	0.37ns	7.77ns	5.5ns	3.51ns	0 86ns

Appendix 3. Analysis of variance for plant height and tillering during the 2nd season

Dependent Variable: Tiller Number

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Rep	2	513.527778	256.763889	15.85	< 0001
Crop	5	107.444444	21 488889	1.33	0.2751
Rep*Crop	10	190.638889	19.063889	1.18	0.3377
Nrate	3	6218.833333	2072.944444	127.97	< 0001
Crop*Nrate	15	307.000000	20.466667	1.26	0.2741



Appendix 4. A mosquito larva. The main parts used for identification are the head and antennae, siphon, pecten, saddle, and anal segment