THE IMPACT OF RICE BLAST DISEASE, ITS MAPPING AND SUITABILITY ANALYSIS FOR RICE GROWING SITES IN THE GREATER MWEA REGION

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The Impact of Rice Blast Disease, its Mapping and Suitability Analysis for Rice Growing Sites in the Greater Mwea Region

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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This thesis has been submitted for examination with our approval as University supervisors.

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DEDICATION

To my Lovely wife Faith Kihoro, my beloved parents, Mrs. Jacinta Mwangi and Mr. Mwangi Njoroge for their unending support, love and encouragement. God bless you

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
ALDEV	African Lands Development
CAN	Calcium Ammonium Nitrate
DAP	Diammonium Phosphate
DEM	Digital Elevation Model
FAO	Food and Agricultural Organisation of United Nations
GIS	Geographic Information System
GOK	Government of Kenya
GPS	Global Positioning System
IDW	Inverse Distance Weighted
IWUA	Irrigation Water Users Association
JICA	Japan International Cooperation Agency
JSPS	Japan Society for the Promotion of Science
KARI	Kenya Agricultural Research Institute
KSS	Kenya Soil Survey
LE	Land evaluation
LIS	Land Information Systems
LMU	Land Mapping Units
LUT	Land Utilization Type(s)
MCDA	Multi Criteria Decision Analysis

MCDM	Multi-criteria Decision Making
MCE	Multi-Criteria Evaluation
MIAD	Mwea Irrigation Agricultural Development Centre
MOP	Muriate of Potash
MRGM	Mwea Rice Growers Multi-purpose Co-operative Society
NCST	National Council for Science and Technology
NIB	National Irrigation Board
NPK	Nitrates, Potash and Potasium
PWCM	Pairwise Comparison Matrix
RS	Remote Sensing
SA	Sulphur Ammonium
SAS	Statistical Analysis Software
SMCDM	Spatial Multi Criteria Decision Making
SRTM	Shuttle Radar Topographic Mission
SWAG	Scientific Wild Ass Guess
UN	United Nations
USA	United States of America
UTM	Universal Transverse Mercator
WARDA	West Africa Rice Development Association
WUA	Water User's Association

ABSTRACT

Rice is one of the most important cereal crops in Kenya coming third after maize and wheat. It forms a very important diet for a majority of families in Kenya and is the source of livelihood in the Greater Mwea region. The demand for rice in Kenya has increased dramatically over the last few years while production has remained low. This is because rice production has been faced by serious constraints notably plant diseases of which the most devastating is rice blast. Disease mapping and applications of GIS provide a systematic way to spatially link known epidemiologic data on disease systems with relevant features in the environment to develop maps that can then be used, by extrapolation, to predict risk of disease over broad geographic areas where data are not available. Land suitability analysis is a prerequisite to achieving optimum utilization of the available land resources. Lack of knowledge on the best combination of factors that suit production of rice has contributed to low production. The aim of the study was to determine the impact of rice blast disease on the livelihood of the local farmers, map the spatial distribution of rice blast disease and develop a suitability map for rice crop based on physical and climatic factors of production using a Multi-Criteria Evaluation (MCE) & GIS approach. The study methodology employed a questionnaire survey which was subjected to sample population of households in the 7 sections with 70 blocks within Mwea region. The collected data was analysed using SAS Version 9.1. Descriptive statistics were used to summarize the household characteristics, the farm characteristics and the farmers' perceptions of rice blast disease. In the questionnaire, farmers' response on whether they had been affected by the rice blast disease and the total

production per acreage was used to develop an attribute table with GPS points. The GPS points were interpolated to create a geographical distribution map of rice blast disease. Biophysical variables of soil, climate and topography were considered for suitability analysis. All data were stored in ArcGIS 9.3 environment and the factor maps were generated. For MCE, Pairwise Comparison Matrix was applied and the suitable areas for rice crop were generated and graduated. The current land cover map of the area was developed from a scanned survey map of the rice growing areas. From the survey farming was the mainstay economic activity (73.4% of the respondents) of virtually all the respondents selected for this assessment. The remaining respondents were engaged as casual labourers 12.8%, while 7.4% and 3.1% were engaged in business and formal employment, respectively. Among them, formal employment has the highest income earning per annum. The research revealed that almost all the farmers' 98% had awareness and knowledge of rice blast disease. Out of the 98% with knowledge and awareness 76% had been affected by the disease, while 24% had never been affected. The month of October had a higher disease prevalence compared to the other months and 87% of the farmers were first affected by rice blast in the year 2009. Majority of the farmers interviewed (72%) did not engage themselves in any other socio-economic activity even after being affected by the rice blast disease. According to disease mapping results 33.4% of the study area had a moderately high disease density and only 13.7% of the study area was under very low disease density. The present land cover map indicated that rice cultivated area was 13,369 ha. The crop-land evaluation results of the present study showed that, 75% of total area currently being used was

under highly suitable areas and 25% was under moderately suitable areas. The results showed that the potential area for rice growing was 86,364 ha and out of this only 12% was under rice cultivation. This research provided information at local level that could be used by farmers to select cropping patterns and suitability.

Key words: rice farming, socio-economic status, climatic data, land use land cover, disease mapping, multi-criteria evaluation.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Mwea Irrigation Scheme is one of the oldest public irrigation schemes in Kenya. It was started in 1956 by the African Lands Development (ALDEV) department of the then colonial government. After independence, the Government of Kenya formed the National Irrigation Board (NIB) in 1966, and Mwea came under the mandate of NIB, with farmers operating under the rules and regulations of an official settlement scheme. These regulations did not give farmers much scope for participation in decision making on either the production or marketing of their produce. Mwea rice farmers, unhappy with this trend, in 1998 pushed through reforms that entitled them to manage the scheme through their own cooperative. However, this did not work well as the management of the cooperative was soon beset with problems of lack of capacity and expertise. In 2003, a negotiated system was put in place which involved the NIB and Mwea farmers in joint management of the scheme. The farmers have since formed an Irrigation Water Users Association (IWUA) and are involved in decision-making on production (Mati *et al.*, 2010).

According to the 2009 national census, Mwea division had an estimated 150,000 persons in 25,000 households. The Mwea Irrigation Scheme is located in the west-central region of Mwea division and covers an area of about 13,640 ha. Over 50% of the scheme area is used for irrigated rice cultivation while the remaining area is used for subsistence farming, grazing, and community activities (Mati *et al.,* 2010).

Rice is rapidly becoming a major staple food in much of sub-Saharan Africa and is set to overtake maize, cassava, sorghum, and other cereals in the near future. The demand is driven as much by population growth as by urbanization. In addition, the high cost of fuel makes rice attractive as it can be prepared quickly and with less energy requirement (Mati *et al.,* 2010).

Within Kenya, the demand for rice continues to grow as more Kenyans make changes in their eating habits, and as urban population increases. Rice is currently the third most important cereal crop after maize and wheat. Rice is gaining popularity among the rural folk as well and consumption has risen dramatically over the last three years to stand at 300,000 metric tons per annum. But the annual production ranges between 40,000 and 80,000t. The deficit is met through imports (Mati *et al*., 2011).

Rice is currently the most expensive cereal grain in Kenya, with a retail price between US$1.25 and 2.50 per kg in comparison to wheat and maize with a retail price of US$ 0.7 and US$ 0.6, respectively. Most of the rice in Kenya is grown on smallholder farms in government-managed irrigation schemes such as Mwea in Kirinyaga County, Bura and Hola in Tana River County, Perkera in Baringo County, West Kano and Ahero in Kisumu County and Bunyala in Busia County. Smaller quantities of rice are produced along river valleys by individual smallholder irrigators (Mati *et al*., 2010). However, Kenya's rice productivity has remained generally low, with marked fluctuations over the years (Table

1.1) and with limited expansion of irrigated command area. This notwithstanding, isolated technological innovations have been recorded in Kenya (Mati and Penning de Vries, 2005) where communities have overcome huge obstacles to make smallholder irrigated agriculture profitable.

Table 1. 1: Rice production trends in Kenya, 2001-2007

Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Area (ha)	13,200	13,000	10,781	13,322	15,940	23,106	16,457
Production (t)	44,996	44,996	40,498	49,290	57,941	64,840	47,256
Unit price (KSh t^{-1})	26,250	16,060	58,000	65,000	68,000	70,000	53,000
Average yield (t/ha)	1.9	2.0	2.1	2.1	2.0	1.6	1.5
Consumption (tons)	238,600	247,560	258,600	270,200	279,800	286,000	293,722
Import (tons)	201,402	208,944	213,342	223,190	228,206	-	-
Total value (billion KSh)	1.2	0.7	0.7	1.3	0.9	3.3	2.7

Source: National Cereals and Produce Board and Department of Land, Crops Development and Management & United States Department of Agriculture (Government of Kenya, 2009).

1.1.1 Sustainable agriculture and rice production

The concept of sustainable agriculture or farming involves producing quality products in an environmentally benign, socially acceptable and economically efficient way (Addeo *et al.*, 2001), i.e. optimum utilization of the available natural resource for efficient agricultural production. In order to comply with these principles of sustainable agriculture, one has to grow the crops where they are best suited and for which the first and foremost requirement is to carry out land suitability analysis (Nisar *et al*., 2000). This suitability is a function of crop requirements and soil/land characteristics. Matching the land characteristics with the crop requirements gives the suitability. Suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 2005). Besides the land/soil characteristics, socio-economic, market and infrastructure characteristics are the other driving forces that can influence the crop selection. Land suitability analysis has to be carried out in such a way that local needs and conditions are reflected well in the final decisions (Prakash, 2003).

1.1.2 Use of GIS in rice blast disease mapping

Rice farming in Kenya has been affected by rice blast disease which is very devastating and can easily cause complete crop failure so that no yields are realized (Francis, 2007). It is a fungal disease caused by *Pyricularia oryzae*. It can attack the plant at all stages causing seedling and leaf blight in the active growing phase and a neck rot slightly below the head. The first systems are small bluish flecks on the lower leaves which later develop into brown spots with grey centres which finally merge until the whole leaf is brown and shriveled. Early attack leads to failure of the grains to fill with panicles falling over and causing rotten neck. A combination of high nitrogenous fertilizers are optimal conditions for the fungus (Francis, 2007).

Rice blast disease is often a major constraint to rice yields and its impact can be especially severe if a large share of the daily diet consists of a threatened crop (Francis, 2007). Geographical information systems (GIS) provide important tools that can be applied in predicting, monitoring and controlling diseases (Bouwmeester *et al*., 2009). GIS provides a powerful analytical tool that can be used to create and link spatial and descriptive data for problem solving, spatial modeling and presentation of results in tables or maps. For disease mapping and risk assessment, GIS is a powerful tool for displaying and analyzing data during the planning, scoping, and problem formulation phases, during the exposure assessment, and displaying and evaluating the results of the disease risk characterization. It is also a very helpful means for communicating information to disease control managers and other stakeholders (U.S. Environmental Protection Agency, 2004).

1.2 Statement of the research problem

Agricultural resources are considered to be one of the most important renewable and dynamic natural resources (World Food Programme and Ministry of Disaster Management & Relief, 2005). Comprehensive, reliable and timely information on agricultural resources is necessary for a country like Kenya, where agriculture is the mainstay of the national economy. But it is being pressurized by high population growth, emergence of new diseases due to climate change and natural hazards like flood, drought and soil erosion. As a result, the productivity of the land is declining and the country cannot produce as much food as needed for the increasing population. In particular the rice production in Kenya does not meet the food demands for a rapidly growing population (Government of Kenya, 2009).   .

Rice farmers in Kenya's Kirinyaga County continue to count losses due to the rice blast disease. The farmers have been complaining about the disease, which has wiped out almost half of their crop (Africa Agriculture, 2008). The disease is still threatening to drastically reduce harvests. An acre of land under rice usually produces on average 25 bags of rice, but this may reduce to 10 bags (African Agriculture, 2008). In 2007 rice blast destroyed 5600 hectares (13840 acres) of rice in former Central Province, which produces the bulk of Kenya's rice. This is equivalent to 10 to 20 percent of annual output and Kenya had to increase imports. This risks worsening Kenya's food insecurity and makes import of additional quantities even more expensive (UN Office for the Coordination of Humanitarian Affairs, 2008).

This research aims to investigate the impact of rice blast disease in the Greater Mwea region its mapping and analysis of land suitability for sustainable rice farming.

1.3 Research objectives

The general objective of this study was to investigate the social economic status and farming practices of rice farmers in Mwea irrigation scheme, map the extent and spatial distribution of the rice blast disease and land resource optimization strategy for rice, through GIS for higher and efficient rice production.

The specific objectives were;

- To investigate the impact of rice blast disease on the socio-economic status of the local farmers in Greater Mwea region.

- To map and develop a spatial rice blast disease distribution approach using GIS .
- To identify and map suitable and potential sites for future expansion of the rice growing areas using multi-criteria evaluation (MCE).

1.4 Hypotheses

- Rice blast disease has a significant effect to the socio-economic status of the farmers
- The spread of rice blast disease is dependant on measurable bio-physical and environmental variables.
- There is no difference between the amount of land currently under rice cultivation and the potential suitable land for rice growing.

1.5 Justification

Per capita rice consumption in Kenya is estimated to be between 10-18 kg per capita per year (WARDA, 2005). Per capita rice consumption is lower in rural compared to urban areas even though rice consumption by the rural population has been rising steadily. Annual rice consumption is increasing at the rate of 12 % compared to wheat (4%) and maize (1%) (Government of Kenya, 2009). These changes are attributed to change in eating habits of the population. It is therefore expected that demand for rice in the country will continue to increase in the future. Furthermore, promotion of rice production and consumption in Kenya will help remove over-reliance on maize as a staple food hence improve rural and urban households' incomes and food security. There is also an urgent need to ensure that there is optimum utilization of the available resources through sustainable farming. Assessing whether the land is suitable for rice growing should be the first step in addressing the optimal productivity of rice within the region. Identifying new areas for expansion of the rice paddy is the second step to achieving optimal utilization of the area. Carrying out suitability analysis within the Mwea region will thus lead to ensuring and enhancing rice productivity.

Rice blast is the most important disease affecting the rice crop in the world. Since rice is an important food source for much of the world, the effects of blast have a broad range. It has been found in over 85 countries including Kenya. Every year the amount of rice lost to rice blast could feed 60 million people. Although there are some resistant cultivars of rice, the disease still persists wherever rice is grown. A social economic survey within the Mwea region, which produces 80% of the rice in Kenya, was done to help in understanding the impacts of rice blast disease to rice growers. Understanding the extent and spatial distribution of the disease and identifying hot spot areas will help in disease management.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Rice (*Oryza sativa* L.) is one of the most important cereals of the world and is consumed by 50% of the world population (Luo *et al.,* 1998). There are two species cultivated *Oryzae sativa* L (Asian rice) and *Oryzae glaberrima* steud (African rice) (Silue and Notteghem, 1991). *Oryzae glaberrima* is traditionally found in diverse West African agro ecosystems but it is largely abandoned in favor of high yielding *Oryzae sativa* cultivar that has higher agronomic performance (Seebold *et al.*, 2004). However, *Oryzae sativa* cultivars are often not sufficiently adapted to various abiotic and biotic conditions in Africa. *Oryzae glaberrima* has been found to have several useful traits like being moderate to high in their level of resistance to blast (Silue and Notteghem, 1991), rice yellow mottle virus (Attere and Fatokun, 1983); (John *et al*., 1985), rice gall midges, insects (Alam, 1988) and nematodes (Reversat and Destombes, 1995). The variety has also been found to be tolerant to abiotic stresses such as acidity, iron toxicity, drought, and weed competition (Sano *et al*. 1984; Jones *et al*. 1994).

2.2 Rice blast disease

2.2.1 Nature and disease symptoms

Rice blast is one of the most important diseases of rice, caused by the fungus *Magnaporthe oryzae* B.C.Couch (Couch and Kohn 2002). The pathogen may infect all the above ground parts of a rice plant at different growth stages: leaf, collar, node, internode, base, or neck, and other parts of the panicle, and sometimes the leaf sheath (Pinnschmidt *et al.*, 1994). The symptoms are more severe in case of neck blast that is characterized by the infection at the panicle base and its rotting (Bonman *et al.*, 1989). *Magnaporthe oryzae* infects and produces lesions on the following parts of the rice plant: leaf (leaf blast), leaf collar (collar blast), culm (culm nodes), panicle neck node (neck rot) and panicle (panicle blast). In leaf blast initial lesions/spots are white to gray-green with darker borders. Older lesions are white-grey, surrounded with a red-brown margin and are diamond shaped (wide centre and pointed toward either end). Lesion size is commonly 1-1.5 cm long and 0.3-0.5 cm wide. Under favourable conditions, lesions can coalesce and kill the entire leaf. In collar rot, lesions are located at the junction of the leaf blade and leaf sheath and can kill the entire leaf (Padmanabhan, 1974; Bhatt and Singh, 1992; Manibhushanrao, 1994).

Infection to the neck node produces triangular purplish lesions, followed by lesion elongation to both sides of the neck node, symptoms which are very serious for grain development. When young neck nodes are invaded, the panicles become white in colour the so called 'white head' that is sometimes misinterpreted as insect damage. Infected panicles appear white and are partly or completely unfilled. The whitehead symptoms can easily be confused with a stem borer attack which also results in a white and dead panicle. Panicle branches and glumes may also be infected. Spikelets attacked by the fungus change to white in colour from the top and produce many conidia, which become the inoculum source after heading. Panicle blast symptoms includes the panicle appearing brown or black. Node infection includes infected nodes appearing black-brown and dry and often occur in a banded pattern. This kind of infection often causes the culm to break, resulting in the death of the rice plant. The pathogen is most common on leaves, causing leaf blast during the vegetative stage of growth, or on neck nodes and panicle branches during the reproductive stage, causing neck blast (Bonman, 1992). Leaf blast lesions reduce the net photosynthetic rate of individual leaves to an extent far beyond the visible diseased leaf fraction (Bastiaans, 1991). Neck blast is considered the most destructive phase of the disease and can occur without being preceded by severe leaf blast (Zhu *et al.* 2005).

2.2.2 Occurrence and distribution

Rice blast disease is distributed in about 85 countries in all continents where the rice plant is cultivated, in both paddy and upland conditions. Rice blast is present wherever rice is cultivated, but the disease occurs with highly variable intensities depending on climate and cropping system. Environments with frequent and prolonged dew periods and with cool temperature in daytime are more favorable to blast (Chiba *et al.,* 1996; Liu *et al*., 2004).

In Pakistan during the last two decades, rice blast is mostly found in districts of Faisalabad, Toba Tek Singh, Vehari and places like Gaggoo Mandi (Arshad *et al*., 2008). Rice blast has been recorded in the Northern Territory (Stahl 1955; Heaton 1964), Brazil (Prabhu and Morais,1986), Queensland, Australia (Perrot and Chakraborty 1999; You *et al*., 2012), Sri Lanka (Senadhira *et al*., 1980), Colombia (Ahn and Mukelar, 1986), Philippines, Japan, South Korea (Ou, 1985; Pena *et al*., 2007), Egypt (Reddy and Bonman, 1987; Sotodate *et al*., 1991), China (Li *et al.*, 2011).

2.2.3 Favourable factors for disease development

The blast outbreak is unpredictable, however, low temperature (about 22-25^{0}C) and long dew appearance are considered as two important factors recognized to induce blast epidemic and environmental conditions have an effect on the incidence of rice blast (Singh, 1988; Chaudhary and Vishwadhar, 1988; Manibhushanrao *et al*., 1989; Kim and Kim, 1991; Vijaya, 2003; Fukuda *et al.*, 2004; Monma et al., 2004; Iwadate *et al*., 2004). Genetic diversity of the rice blast fungus has also been reported by several workers (Levy *et al.,* 1993; Shen *et al.*, 1993; Zeng *et al*., 2002; Mian *et al*., 2003; Sonia and Gopalakrishna, 2005; Yang *et al.*, 2011).

The optimum temperature for the mycelial growth of *P. grisea* is said to be 25 to 30^{0}C (Awoderu *et al.,* 1991; Okeke *et al.* 1992; Arunkumar and Singh, 1995) while minimum temperature for the growth of the species is 80 – 90^{0}C and thermal death point is 51 – 52^{0}C (Nishikado, 1927; Yang *et al.,* 2011). Physical and micro-climatic factors that may influence the life cycle of the pathogen (Hashimoto, 1981), including spore liberation, transport, deposition, infection, latency, and sporulation. For each phase of the life cycle, an optimum of environmental factors often exists for blast. Thus, subtropical or temperate environments, where canopy wetness is frequent along with moderate temperature, are particularly inducive to blast (Teng, 1994). Excessive nitrogen fertilizer promotes the disease. On the other hand, moderate water stress also favors the disease, especially the sporulation of the pathogen. Blast can be a major disease of both lowland and upland rice, under favorable conditions—for example, extended duration of leaf wetness, a high amount of nitrogen, and cool temperature. In general, the severity of leaf blast epidemics is dependent on two key phases of the disease cycle: infection (a deposited pathogen spore infects a healthy leaf site) and sporulation (the amount of spores produced by a blast lesion over an infectious period). Another critical factor that determines the likelihood of a blast epidemic is related to the genotype of the rice variety that is cultivated, to the diversity of the pathogen that is present, and their interaction. Choi *et al*., (1987) recorded that the optimum temperature for conidial germination of *Pyricularia oryzae* on a glass slide was 26-30 degrees C, at which temperature at least 4 h of leaf wetness was required.

The temperature and incidence of paddy blast was negatively correlated i.e. -0.88, -0.80, -0.95, -0.84 respectively. This indicated that the disease incidence increases with the decrease of temperature. Humidity was positively correlated with Paddy blast i.e. 0.95, 0.90, 0.99, 0.89, 0.93 respectively indicating an increase in disease incidence as humidity increased. Rainfall was also positively correlated with incidence of disease i.e. 0.80, 0.90, 0.88, 0.93 and 0.84 respectively (Shafaullah *et al*., 2011).

2.2.4 Disease cycle

The pathogen may go through several disease cycles in a single season. Myceliam and conidia in the infected straw and seeds are important sources of primary inocula (Guochang and Shuyuan, 2001). The seed borne inoculum fails to initiate the disease in the plains due to high soil temperature in June. In both tropical and temperate regions, the fungus overwinters in straw piles or grain. In tropics, one method of survival is through infection of collateral hosts such as *Rottboellia cochinchinensis, Eleusine indica, Panicum repens, Digitaria marginata, D. sanguinalis, Brachiaria mutica, Leersia hexandra, Dinebra retroflexa, Echinochloa crusgalli, Setaria intermedia, S. viridis, S. faberi* and *Stenotaphrum secondatum* (Du *et al*., 1997).

The most probable source of perennation and initiation of the disease appears to be the grass hosts and early sown paddy crop. The disease cycle is short and most damage is caused by secondary infections. Air can carry the conidia for long distances. The conidia from these sources are carried by air currents to cause secondary spread. Most conidia are released at night in the presence of dew or rain. In the canopy of rice plants, newly developed leaves act as receptors for the spores. The maximum number of spores produced was 20,000 on one lesion on leaves and 60,000 on one spikelet in one night (Webster and Gunnell, 1992; Zeigler *et al*., 1994; Inoue, 2001). Under favourable moisture and temperature conditions (long periods of plant surface wetness, high humidity, little or no wind at night and night temperatures between 12– 32 °C) the infection cycle can continue (Lau and Hamer, 1998; Kato, 2001; Lu *et al.,* 2007; Kim *et al.,* 2009).

2.3 Management practices

2.3.1 Cultural practices

Split applications of nitrogen based on actual requirements of the crop are recommended to reduce disease intensity (Santos *et al.,* 2003; Koutroubas *et al*., 2008; Lu *et al*., 2011). The excessive use of nitrogen fertilizer promotes luxuriant crop growth, which increases the relative humidity and leaf wetness of the crop canopy, and so favors blast (Saifulla and Maharudrappa, 1992). Flooding the soil as often as possible can be effective, particularly in tropical areas where conditions are not very favorable to blast. The application of silicon fertilizers (e.g., calcium silicate) to soils that are deficient in this element has reduced blast. Because of its high cost, silicon should be applied efficiently. Cheap sources of silicon, for example, straw of rice genotypes with high silicon content, can be considered to make this approach economically viable. In tropical upland rice, crops sown early after the onset of the rainy season are more likely to escape blast infection than late-sown crops. Early sowing allows escape from the build-up of inoculum originating from neighboring farms. The paddy variety grown upland with film mulch showed a higher grain yield than that in non-mulch plots and reached a close level to that in lowland conditions (Xu *et al.,* 2012). Vijaya (2002) reported that the highest blast disease incidence was recorded at 10x10 cm and lowest at 20x15 cm spacing. The highest yield was recorded at 20x10 cm and the lowest was at 10x10 cm.

Diseased straw and stubble must be burned or composted, otherwise they can become inoculum sources for the next crop season. Sowing into water eliminates disease transmission from seeds to seedlings because of the anaerobic condition that is unfavorable to the pathogen. Rice grain yield is the final product of a combination of different yield components, the relative importance of which varies with the location, season, crop duration, and cultural system (Yoshida 1983; Koutroubas and Ntanos, 2003).

2.3.2 Rice host plant resistance

The control of this disease is difficult because of the high variation in the races of the fungus over locations and years (Zeigler *et al.,* 1997). It is common that resistant varieties became susceptible after a short time in production (Wang et al., 1989). Gowda *et al.*, (1993) reported that Netravathi is derived from the cross IET2886 x Red Annapurna and also displays improved resistance to blast and complete resistance to gall midge matures in 135-140 days, with height 104 cm and submergence tolerance of 5-7 days.

The most usual approaches for the management of rice blast disease include planting of resistant cultivars, application of fungicides, and manipulation of planting times, fertilizers and irrigations (Mbodi et al., 1987; Naidu and Reddy, 1989). Varieties OMCS94, OM1706, IR64, IR62032, OM1570, OM723-11, OMCS5, NCM10-20, OM1726, TEP HANH and BONG DUA were considered to possess durable resistance. There are some more reports quoted by different scientists (Liu et al., 2009; Sere et al., 2011; Sun *et al.,* 2011).

The molecular genetics of blast resistance has been extensively studied (Jena and Mackill, 2008), leading to many DNA markers corresponding to major resistance genes identified. Some 40 genes for major resistance to blast are known. Reliance on major resistance genes, however, is risky because new genotypes of the pathogen can evolve rapidly and overcome host resistance (Zeigler *et al.,* 1994). Nonetheless, some resistance genes are found to confer broad-spectrum resistance against pathogen strains tested. Partial resistance, on the other hand, is usually controlled by multiple genes, and it may offer a more stable form of resistance. Combining broad-spectrum resistance genes with multiple quantitative resistance genes may be a promising approach to develop durable resistance (Jena and Mackill, 2008; Manosalva *et al.,* 2009). In some situations, blast can be managed through the use of diverse varieties with different levels of resistance and modified cultural practices. Good control of panicle blast can be achieved through interplanting rice varieties (Zhu *et al.,* 2000). Multilines, comprising several near-isogenic lines each carrying different resistance genes, have been successfully used to control blast in Japan (Koizumi, 2001).

2.3.3 Chemical control practices for rice blast

Haq *et al.,* (2002) conducted an experiment to evaluate various fungicides like Captan, Acrobat, Bayeltan, Sunlet, Dithane M-45 Trimiltox and Derosal in controlling the mycelial growth of *Pyricularia oryzae* under the laboratory conditions and found that Captan and Acrobat were the most effective fungicides. Varier *et al.,* (1993) used seed treatment with Tricyclazole at 4kg/kg seed which proved effective after 40 days of sowing. Dubey (1995) conducted field trails of eight fungicides for control of *Pyricularia oryzae*, Topsin M + Indofil M-45 proved to be most effective against leaf blast disease of rice. Minami and Ando (1994) reported that probenazole induces a resistant reaction in rice plants against infection by rice blast fungus. Gouramanis (1995) found that fungicides Carbendazim, Pyroquilon, Thiophanate methyl and Chlobenthiazone reduced the leaf blast disease of rice. On the other hand Tricyclazole was effective in reducing the neck blast. Enyinnia (1996) evaluated two systemic fungicides Benomyl and Tricylazole on Faro / 29, a rice cultivar, at full booting stage and reported good control of natural infection of rice leaf blast. Filippi and Prabhu (1997) reported that propagation fungicide (40 g a.i. per Kg of seed) was effective in controlling leaf and panicle blast. Sood and Kapoor, (1997) evaluated 7 fungicides against leaf and neck blast of rice caused by *Magnaporthe grisea.* The fungicides were sprayed at the recommended rates at booting and heading stage. Tricylazole was the most effective, reducing leaf and neck blast by 89.2% and 97.5% and increasing the yield 43.3% as compared with the untreated control. Moletti *et al*., (1998) conducted field trials against *Pyricularia oryzae,* and found that Pyroqulion granules or wettalble powder 2 kg / ha once or twice gave good results against leaf blast. Tirmali and Patil, (2000) conducted field experiment on susceptible rice cultivar E. K. 70 and 5 new fungicide formulations viz. Antaco 170, Carpromid 30 SC, Fliqiconazate 25 WP, Ocatve 50 WP and Opus 15.5 SC. These fungicides were sprayed at tillering, booting and heading stages of crop. The new formulations reduced neck blast incidence by 16.27% to 29.23%, Opus 15.5 SC was highly effective in controlling neck blast by 29.23% and increasing grain yield. Tirmali *et al*., (2001) reported the efficicacy of new fungicides in controlling rice neck blast caused by *Pyricularia oryzae* on rice cultivar Ek- 70 (blast susceptible) treated with WIN 30 SC (Capropamid), Folicur 250, WE Swing 250 Ec and Beam 75 WP at maximum tillering panicle initiation and at heading stage of crop and found that all these new fungicides resulted in significantly reduced neck blast. Chaudhary (1986) reported that Edifenphos addition of either Sandovit (0.1%) or Tispre (0.1%) was effective in reducing foliage infection by *Pyricularia oryzae*. Reddy and Satyanarayana (1988) recorded that Edifenphos and carbendazim gave good control of *Pyricularia oryzae*. Chemical management is more effective for managing the damage caused by the *Pyricularia oryzae* (Peterson, 1990; Saifulla and Seshadri, 1992; Sood and Kapoor, 1997; Vijaya, 2002; Tripathi and Jain, 2005; Swamy *et al.*, 2009; Perini *et al.*, 2011; Dey *et al*., 2013).

Prabhu and Filippi (1993) noticed that seed treatment with Pyroquilon (4 g/kg seed) or Pyroquilon (4 g/kg seed) + Carbofuran (4.8 g/kg seed) significantly reduced leaf blast at 38 d after sowing in cultivars IAC 25, IRAT 112 and IAC 47. Leaf blast and biomass production at 58 d after sowing were negatively correlated (r =-0.91, P=0.01). Rabicide 30WP, Nativo SC and Score 250 EC treatments were made with dose rates of 3 g/liter H_2O, 0.8 gm/liter H_2O and 1.25 ml/liter of H_2O and proved effective in all the three weeks in reducing the disease (Prabhu et al., 2003; Kim et al., 2008; Ghazanfar *et al.*, 2009).

Tirmali *et al.*, (2011) showed that Swing 250 EC was the best fungicide in controlling the disease and resulted in increased crop yields. Prasad and Gupta (2012) recorded that the combination of Flubendiamide 20 WDG @ 0.25 g/l+Isoprothiolane Fungi 1 @ 1.5 ml/l was most effective against blast and fetched average grain yield of 23.53 q/ha.

Di-potassium hydrogen phosphate (DHP) had been reported to induce blast resistance by Manandar *et al.,* (1998); Pham *et al.,* (2000). Treating the seeds with Tricyclazole 75 wp @ 1.5 g/kg seeds or with Carbendazim 50 wp @ 2 g/kg seeds or Need based application of Tricyclazole 75 wp @ 0.6g/l or Isoprothiolane 40 EC @ 1.5 ml/l or Iprobenphos 48 EC @ 2ml/l or Carbendazim 50 wp @ 1g/l etc. Jamal-u-Ddin et al., (2012) recorded that Mancozeb appeared as the most effective fungicide that completely inhibited the mycelial growth of the *Magnaporthe oryzae*.

Seeds treated with Natri-tetraborate ($Na_2B_4O_7$) reduced disease incidence from 27% to 19 % in greenhouse and about 7% of neck blast incidence under field condition (Du *et al.,* 2001). Tricyclazole (0.06 %), Kitazine (0.1 %) and Ediphenphos (0.1 %) were found significantly superior in controlling the disease and also resulted in significant increase in yield in Tricyclazole sprayed plots (7783.33 kg/ha.) followed by Ediphenphos (6941.66kg/ha.), Kitazine(6850.00 kg/ha.) with B:C ratio 1:2.64, 1:2.39, 1:2.31, respectively (Ganesh *et al.*, 2012).

Varma and Santhakumari (2012) recorded that foliar spraying Isoprothiolane at 1.5 ml/l significantly decreased the disease incidence (78.3%) and intensity (89.7%), followed by carpropamid (67.5 and 80.5% disease incidence and intensity, respectively) and carbendazim (56.9 and 73.1% disease incidence and intensity, respectively) over the control. The highest increase in grain and straw yield over the control was also recorded with isoprothiolane (22.5 and 28.3%), followed by carpropamid (20.5 and 25.7%).

2.4 Land resources

2.4.1 Definition

FAO (1993) defines land as an area of the earth's surface, including all elements of the physical and biological environment that influences land use. Land comprises the physical environment including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use (FAO, 1976). Indeed, land is an essential natural resource, both for the survival and prosperity of humanity, and for the maintenance of all terrestrial ecosystems. Over millennia, people have become progressively more knowledgeable in exploiting land resources for their own ends. The limits on these resources show up when human demands on land are very large (FAO, 1995).

Land has been defined in variety of ways by different researchers and organizations working in the field of agriculture and land reforms. It includes the results of past and present human activities e.g., reclamation from the sea, vegetation clearance and also adverse results, like soil salinization. Purely economic and social characteristics, however, are not included in the concept of land; these form part of the economic and social context (FAO, 1976; Dent and Young, 1981).

Land is not the same everywhere; it is, self-evidently, the other focus of land-use planning. Capital, labour, management skills and technology can be moved to where they are needed, land cannot be moved and different areas posses different opportunities and also different management problems. Reliable information about land resource is thus essential for the land use planning (FAO, 1993a). As far as definition of land is concerned, soil, climate, relief and hydrology, are incorporated as key words. Socio-economic and demographic parameters are not taken as an integral part of the definition. Thus we can say that land refers not only to soil but also landform, climate, hydrology, vegetation and fauna, together with land improvements such as terraces and drainage works. Another definition of land adopted by land degradation is that as a delineable area of the earth's terrestrial surface, embracing all attributes of the biosphere above or below this surface, including those of the near surface climate, the soil and terrain forms, the surface hydrology including shallow lakes, rivers, marshes and swamps, the near-surface sedimentary layers and associated groundwater and geo-hydrological reserves, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.) (IDWG/LUP, 1994). However, FAO (1995) for the first time, put forward the complete definition of land incorporating socio-economic aspects as well. Land resources consist of two main categories (i) natural land resources without any effort made through human activities and (ii) land resources created including the product of human activities such as dykes and polders (Dent and Young, 1981)

At the same time basic functions performed by land to support human beings and other terrestrial ecosystems are numerically presented as follows (FAO, 1995): Provision of biological habitats for plants, animals and micro-organisms and provision of physical space for settlements, industry and recreation; A store of wealth for individuals, groups, or a community through production of food, fiber, fuel or other biotic materials for human use; Co-determinant in the global energy balance and the global hydrological cycle, which provides both a source and a sink for greenhouse gases; Storehouse of minerals and raw materials for human use with regulation of the storage and flow of surface water and groundwater and buffer, filter or modifier for chemical pollutants; Storage and protection of evidence from the historical or pre-historical record (fossils, evidence of past climates, archaeological remains, etc);

2.5 Geographic Information Systems in land resource planning

Understanding relationships between environmental factors (such as socio-demographic, economic, political, and physical variables) and health is a complex undertaking, and implies consideration of a range of variables at micro, macro, and intermediary levels. A Geographic Information System (GIS) can act as a facilitating mechanism to allow appropriate integration and presentation of the databases that encompass these variables. A GIS is also used to investigate statistical relationships that may vary from place to place. This spatial analysis is valuable for identifying significant relationships among those variables that influence geographical outcomes at a range of aggregations from local to international, data permitting (Candace *et al*., 2008). GIS can then be used to present results from the analysis (patterns in the data) in the form of visually appealing, high-impact maps. These maps can tell powerful stories and communicate relationships in a way that otherwise may not be possible with other techniques (Parchman *et al.*, 2002; Mullner *et al*., 2004). GIS has the ability to integrate variety of geographic technologies like GPS and Remote Sensing. To this end, GIS has been used in the domains of land resource planning, environmental health, disease ecology, and public health as a tool for processing, analyzing, and visualizing data (Kistemann *et al.*, 2002).

There are many definitions for Geographic Information Systems, yet it is generally acknowledged that it is a computer-based system used for the integration and analysis of spatial data, which has the ability to generate extensive relational databases. A GIS can be defined as an organized collection of five key components: i) computer hardware, ii) computer software, iii) geographic (cartographic) and attribute (other variables) data, iv) GIS-trained personnel, and v) statistical techniques and methods for data modeling and analysis (Richards *et al*., 1999; Thrall, 1999; Cromley and McLafferty, 2002; Chung *et al*., 2004).

GIS software provides the functions and tools designed to easily capture, store, update, manipulate, analyze, and display all forms of geographically referenced information efficiently (Thrall, 1999; Bernardi, 2001; Riner *et al*., 2004). A GIS database is similar to other relational databases, with the exception that one of the database fields encodes the location of the item on the surface of the earth using x, y coordinates. In this way, a GIS can be used to integrate spatial data, or data that are characterized by location, and related qualitative or quantitative information (e.g., social, economic, health, environmental conditions), which are listed as 'attributes' of the spatial location. This is done within a single system and allows for the analysis of these attributes by geographic location. It is a powerful tool that is highly effective at combining disparate data sources to visually illustrate complex relationships within that data (Candace *et al*., 2008). Thus, a Geographic Information System can be used to address research questions or practical applications of: *condition* – what is at …?; *location* – where is …?; *trend* - what has changed since…?; *pattern* – what spatial patterns exist?; and *modeling or scenario-building* – what if…?. In other words, it can be used to track the geographic location of people, places, events, actions, or impacts, to conduct spatial or statistical analysis on the variables of interest, and to create maps that display the spatial distributions and relationships of those variables (Phillips *et al.*, 2000; Schlundt *et al*., 2001; Bedard and Henriques, 2002).

2.6 Disease Surveillance

One of the most common and longstanding uses of GIS in plant pathology/public health is for disease surveillance, which is the compilation and tracking of information on the incidence, prevalence, and spread of disease (Rushton, 1998; Wall and Devine, 2000). There are two interrelated components of disease surveillance – disease mapping and disease modeling. Disease mapping is used to understand the geographical distribution and spread of disease in the past or present (Myers *et al.*, 2000; Robinson, 2000). Disease modeling is closely related to risk analysis and is used to forecast future disease spread or epidemic outbreaks and to identify those factors that may foster or inhibit disease transmission (Myers *et al*., 2000; Robinson, 2000).

Landscape epidemiology involves the identification of geographical areas where disease is transmitted. The Russian epidemiologist Pavlovsky (1966) expressed the theory of landscape epidemiology, that by knowing the vegetation and geological conditions necessary for the maintenance of specific pathogens in nature, one can use the landscape to identify the spatial and temporal distribution of disease risk. Remote sensing and GIS can be combined to study the structure and composition of a landscape.

Disease outbreaks are often as a result of the combination of social, environmental, and individual crop variables each with a unique spatial expression (Boone *et al*., 2000). Disease mapping is a natural application of GIS as it facilitates the integration of all of these variables for analysis. This geographic outbreak of infectious diseases can help in identifying point source outbreaks or clusters of disease beyond a containment zone, elucidating dispersion patterns, and giving direction and coordination to control strategies (Boone *et al*., 2000). In these cases, a GIS is a map-based tool that can be used to study the distribution, dynamics, and environmental correlates of diseases as statistical relationships often exist between mapped features and diseases (Boone *et al*., 2000).

2.7 Land Suitability Analysis

The management of natural resource is a cross boundary issue that should be emphasized in all planning processes with multi sectoral approach (administrative and geographical).

Land suitability is part of land use planning methodology and defines possible options for the future land use and helps to describe these interactions (policies, institutions and information management) (Ignas, 2004). Land suitability is the fitness of a given type of land for a defined use (FAO, 1976). The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976; 2007)

The way the people use the land is based on the available skills, knowledge, culture and experiences. The land use attitude changes when the income of land changes through e.g. improved technology (Ignas, 2004). Land suitability assessment is similar to choosing an appropriate location, except that the goal is not to isolate the best alternatives, but to map a suitability index for the entire study area. Senes and Toccolini (1998) combine UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development. Malczewski (2006) also used map overlays to define homogeneous zones, but then they applied classification techniques to assess the agricultural land suitability level of each zone. Combining GIS and MCDA is also a powerful approach to land suitability assessments (Florent *et al.*, 2001).

The development of land suitability maps also presents an opportunity for all governmental departments involved in land management to compare their points of view and coordinate their policies. Furthermore, subject to the agreement of the decision makers, all the interested stakeholders (e.g. the public, construction enterprises, environmental NGOs) could also be involved in the procedure. In such a case, the land suitability maps could be widely accepted and the population at large could more easily endorse decisions based on these maps (Florent *et al.,* 2001).

FAO (1985) analyzed land suitability mainly based on the land quality. Land quality is a complex attribute of land that has a direct effect on land use (FAO, 1993). These attributes are availability of water and nutrients, rooting condition and erosion hazards. Most land qualities are determined by interaction of several land characteristics, which are measurable attributes of the land. The value of land quality is the function of the assessment and grouping of land types in to orders and classes in the framework of their fitness. Generally, land suitability is categorized as suitable (S) and not suitable (N). Whereas, S features lands suitable for use with good benefits, N denotes land qualities which do not allow considered type of use, or are not enough for suitable outcomes (FAO, 1985). Land suitability is primarily the potential biological productivity of land (FAO, 1985). Productivity of land can be determined by environmental components such as climate, local topography (roughness, steepness, and exposure), soil type and existing vegetation. Land suitability classification is developed by considering different factors of land characteristics. Based on suitability of each land use, a weighted value ranging from 5 (unsuitable) to 1 (most Suitable) are given. The weighted value of each factors are reclassified for each land use. Each parameter is given a value based on its suitability for each land use type. The weighted value of all land characteristics factors are added and their average value of them is taken to determine the suitability of land for each land use type. The average value is categorized into five suitability classes to get the final suitability for each land use (FAO, 1993).

Table 2. 1: Structure of land suitability classes and subclasses

Order	**Class**	**Description**
Suitable (S)	S1 (Highly suitable)	Land having no, or insignificant limitations to the given type of use
	S2 (Moderately suitable)	Land having minor limitations to the given type of use
	S3 (Marginally suitable)	Land having moderate limitations to the given type of use
Non-suitable (N)	N1 (Currently not suitable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	N2 (Permanently not suitable)	Land with so severe limitations which are very difficult to be overcome

Land suitability analysis using a scientific procedure is essential to assess the potential and constraints of a given land parcel for agricultural purposes (Rossiter, 1996). In the recent past, the ill effects of land use on the environment and environmental sustainability of agricultural production systems have become an issue of concern. The problems of declining soil fertility, stagnant yield level and unfettered soil erosion are associated with intensive agriculture in industrialized countries; while over exploitation of natural resources and scarcity of inputs like chemical fertilizers denote intensive agriculture in the developing areas (Martin and Saha, 2009). Land evaluation and crop suitability analysis using GIS and remote sensing would resolve these issues while providing better landuse options to the farmers. Hence, analysis of crop suitability under various systems that could be grown in a given area is essential. GIS is an important aid for spatial decision making (Carver, 1991; Pereira and Duckesstien, 1993). Developments in GIS have led to significant improvements in its capability for decision making processes in land allocation and environmental management (Jiang and Eastman, 2000). MCE is one of the most important procedures for GIS based decision making processes (Jankowski, 1995; Malczewski, 2000).

Site /Land suitability assessment is inherently a multicriteria problem (Mendoza, 2004). That is, land suitability analysis is an evaluation/decision problem involving several factors. According to Mendoza (2004), a generic model of site/land suitability can be described as: S = f (x1, x2,…, xn); Where S = suitability measure; x1., x2, …, xn = are the factors affecting the suitability of the site/land.

The principal problem of suitability analysis is to measure both the individual and cumulative effects of the different factors; x1,…, xn. In other words, suitability analysis generally involves determining an appropriate approach to combine these factors (Mendoza, 2004). Suitability analysis is a methodology or a set of analytical procedures that simulate real world conditions within a GIS using their spatial relationships of geographic features to locate optimally suitable geographic areas for a specific land use. In order to locate optimally suitable geographic areas for a specific land use, criteria development is crucial. Criteria can be of two kinds: factors and constraints. Constraints are Boolean criteria that constrain (i.e. limit) the analysis to particular geographical regions. In contrast, factors are criteria that define some degree of suitability for all geographic regions (Eastman, 2006). The composite effect of physical parameters determines the degree of suitability and also helps in further categorising the land into different classes of development. Moreover, the process of suitability assessment is very much dependent upon the prevalent conditions, such as pressure on land.

2.8 Role of GIS for Land Suitability Analysis

The distinguishing feature of Geographic Information System (GIS) is its capability to perform an integrated analysis of spatial and attributes data. GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multi-source datasets such as data on land use, population, topography, hydrology, climate, vegetation, transportation network, public infrastructure, etc. The data are manipulated and analyzed to obtain information useful for a particular application such as landuse suitability analysis (Malczewski, 2003).

According to Foote and Lynch (1996) cited in Prakash (2003), the ultimate aim of GIS is to provide support for spatial decisions making process. In multicriteria evaluation many data layers are to be handled in order to arrive at the suitability, which can be achieved conveniently using GIS. In the context of land suitability analysis, GIS helps the user to determine what locations are most/least suitable for specific purpose. In this way the results of GIS analysis can provide support for decision making. It also enables one to create and modify any land suitability analysis that makes the best use of available data.

2.9 Spatial MultiCriteria Decision Making (SMCDM)

An important advantage in using a GIS to perform a spatial MCDM study is the ease with which one can develop valuation criteria based on neighbourhood analysis operations

(Pereira and Duckesstien, 1993; Malczewski, 2006). The quality of a site for a specific use often lies not only on the values of environmental variables at the site, but also on its vicinity. Land suitability evaluation, conceptualized as an MCDM problem, implies the assignment of values to alternatives that are evaluated along multiple dimensions or criteria. Specifically for land suitability evaluation in a raster GIS environment, each grid cell in the database is taken as an alternative to be evaluated in its quality or appropriateness for a given end, and each thematic layer represents a criterion for the process or evaluation (Pereira and Duckesstien, 1993).

Spatial multicriteria decision problems typically involve a set of geographically defined alternatives (events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Jankowski, 1995; Malczewski, 1996, Prakash, 2003). Spatial multi-criteria analysis is vastly different from conventional MCDM techniques due to inclusion of an explicit geographic component. In contrast to conventional MCDM analysis, spatial multi-criteria analysis requires information on criterion values and the geographical locations of alternatives in addition to the decision makers' preferences with respect to a set of evaluation criteria (James *et al.*, 2002). This means analysis results depend not only on the geographical distribution of attributes, but also on the value judgments involved in the decision making process. Therefore, two considerations are of paramount importance for spatial multi criteria decision analysis: (1) the GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability); and (2) the MCDM analysis component (e.g., aggregation of spatial data and decision makers' preferences into discrete decision alternatives) (Carver, 1991; and Jankowski, 1995).

The general objective of MCDM is to assist the decision maker in selecting the 'best' alternative from the number of feasible choice-alternatives under the presence of multiple choice criteria and diverse criterion priorities (Jankowski, 1995, Prakash, 2003). The problem of multicriterion (multiobjective) choice in decision making is the paramount challenge faced by individuals, public, and private corporations. The challenge of multicriterion choice can be attributed to many spatial decision making problems involving search and location/allocation of resources. These problems, often analysed in GIS, include location/site selection (Jankowski, 1995). Hence, Site suitability assessment is inherently a multi criteria problem. That is, land suitability analysis is an evaluation/decision problem involving several factors. SMCDM which refers to the application of Multi-Criteria Analysis (MCA) deals with these spatial decision problems.

Chakhar and Mousseau (2008) defined spatial decision problem as those problems in which the decision implies the selection among several potential alternatives that are associated with some specific locations in space. Spatial decision problems typically involve a large set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria (Malczewiski, 2006). The alternatives are often evaluated by a number of individuals (decision makers, managers, stakeholders, interest groups). The individuals are typically characterized by unique preferences with respect to the relative importance of criteria on the basis of which the alternatives are evaluated.

MCDM problems involve criteria of varying importance to decision makers and information about the relative importance of the criteria is required (Saaty and Vargas

1988; Malczewski, 2000). This is usually obtained by assigning a weight to each criterion. The derivation of weights is a central step in defining the decision maker's preferences. A weight can be defined as a value assigned to an evaluation criterion indicative of its importance relative to other criteria under consideration. The larger the weight, the more important is the criterion in the overall utility (Malczewski, 1999; cited in Drobne and Lisec, 2009). In the procedure of MCE, weights can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the criteria (Malczewski, 2003; Eastman, 2006). The comparisons deal with the relative importance of the two criteria involved in determining suitability for the stated objective. Accordingly, many spatial decision problems give rise to the GIS based multi criteria decision analysis (GIS-MCDA) (Malczewiski, 2006).

Matching of social-economic, environmental conditions and different requirements to assess the suitability is carried out by different methods. Although a variety of techniques exist comparison of weight is the most accepted type. Development of weight in pairwise comparisons developed by Saaty (1977) is one of the promising decision making tools. In the past the AHP method was used for evaluation of technological processes mainly in agriculture and horticulture (Böhme, 1986). This approach enables us to compare different variants and rank the factors, criteria and parameters according to their importance. The first introduction of this technique to a GIS application was that of Rao *et al.*, (1991), although the procedure was developed outside the GIS software using a variety of analytical resources (Vo, *et al.*, 2003). The AHP is a practical and effective method for solving multi-criteria decision problems (Guo and He, 1998) which uses hierarchical structures to represent a problem and then develop priorities for alternatives based on the judgment of the user (Saaty, 1980). Land suitability analysis consists of multiple criteria and alternatives which must be evaluated by a decision-maker in order to achieve a goal. The AHP provides a systematic method for comparison and weighting of these multiple criteria and alternatives by decision-makers.

Compared with other methods used for determining weights, e.g., Delphi method, the AHP method is superior because it can deal with inconsistent judgments and provides a measure of the inconsistency of the judgment of the respondents. Multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives are used in AHP. The fundamental input to the AHP is the decision maker's answers to a series of questions of the general form, "how important is criterion relative to criterion B, C, D, E etc" which is called pairwise comparisons. The comparisons are measured on a ratio scale. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measurements of the alternatives in terms of each individual decision criterion. Evaluation of the elements by comparison will yield preferences these preferences carries numerical values in nine point scale as described by Saaty and Vargas (1988).

The steps involved in AHP as designed by Saaty (2000) were further elaborated by (Mau-Crimmins *et al.*, 2003). He described the processes as objective criteria and alternatives can be many which are organized in hierarchical form. Relative importance of the criteria and preferences among the alternatives is to be made by pairwise comparisons. Then priority weight for criteria is calculated through preference. Finally the AHP process is completed by multiplying the criteria vector by the alternative matrix.

GIS and MCDA can benefit from each other (Laaribi *et al.*, 1996; Malczewiski, 1996; Thill, 1999; and Chakhar and Martel, 2003; Malczewiski, 2006). On the other hand, GIS techniques and procedures have an important role in analyzing decision problems. Indeed, GIS is often recognized as a decision support system involving the integration of spatially referenced data in problem solving environment. On the other hand, MCDA provides a rich collection of techniques and procedures for structuring decision problems, and designing, evaluating, and prioritizing alternative decision (Malczewiski, 2006)

It is important to note, however, that GIS and MCE techniques are merely tools which provide a means to an end. Without knowledge and expertise of the operator and decision maker, and without appropriate data, such tools will be useless (Carver, 1991).
Nevertheless, GIS MCE applications appear to represent potentially fruitful areas for further research and development.

2.10 Crop Requirement

Crop requirements are conditions of a given land necessary or desirable for a successful and sustained practice of a defined land use type (FAO, 1983). Evaluation of crop requirements is a useful tool in assessing crop adaptability and suitability in a given area.

Biophysical crop requirements refer to the need for favourable climatic and soil attributes. The climatic requirement is concerned with attributes such as temperature, rainfall, length of growing period, frost hazard, drought hazard, etc. The soil requirements refers to conditions of rooting, wetness, fertility, excess salt, ease of cultivation, mechanization potential, etc. Management conditions may, however, change the relative impact of these attributes. In practice, it is very difficult if not impossible to include in any evaluation all the environmental requirements that affect crop performance (FAO, 1983, 2007).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Description of the study area

The study was conducted in Mwea division of Kirinyaga county, and its surrounding areas, located about 100 km northeast of Nairobi. Mwea command area is divided into five sections: Tebere, Mwea, Thiba, Wamumu, and Karaba, which are served by two rivers, the Nyamindi and the Thiba. The Nyamindi river system serves Tebere, while the other four sections are served by the Thiba river. Water is extracted from both rivers by gravity and is distributed through unlined open channels (Mati *et al*., 2010).

The Mwea Irrigation Scheme is located in the lower slopes of Mt. Kenya, in Kirinyaga County of Kenya. It is bounded by latitudes $37^0$13'E and $37^0$30'E and longitudes $0^0$32'S and $0^0$46'S. Annual average precipitation for Mwea is 950 mm, with the long rains falling between March and May, while the short rain period is between October and December.

The scheme traverses three agro-climatic zones, with maximum moisture availability ratios ranging from 0.65 for zone III toward the highland slopes, to 0.50 for the vast area covered by zone IV, and to 0.4 for the semi-arid zone V (Sombroek *et al*. 1982). Moisture availability zones are based on the ratio of the measured average annual rainfall to the calculated average annual evaporation. The area is generally hot, with average temperatures ranging between 23 and 25^0C, having about 10^0C difference between the minimum temperatures in June/July and the maximum temperatures in October/March.

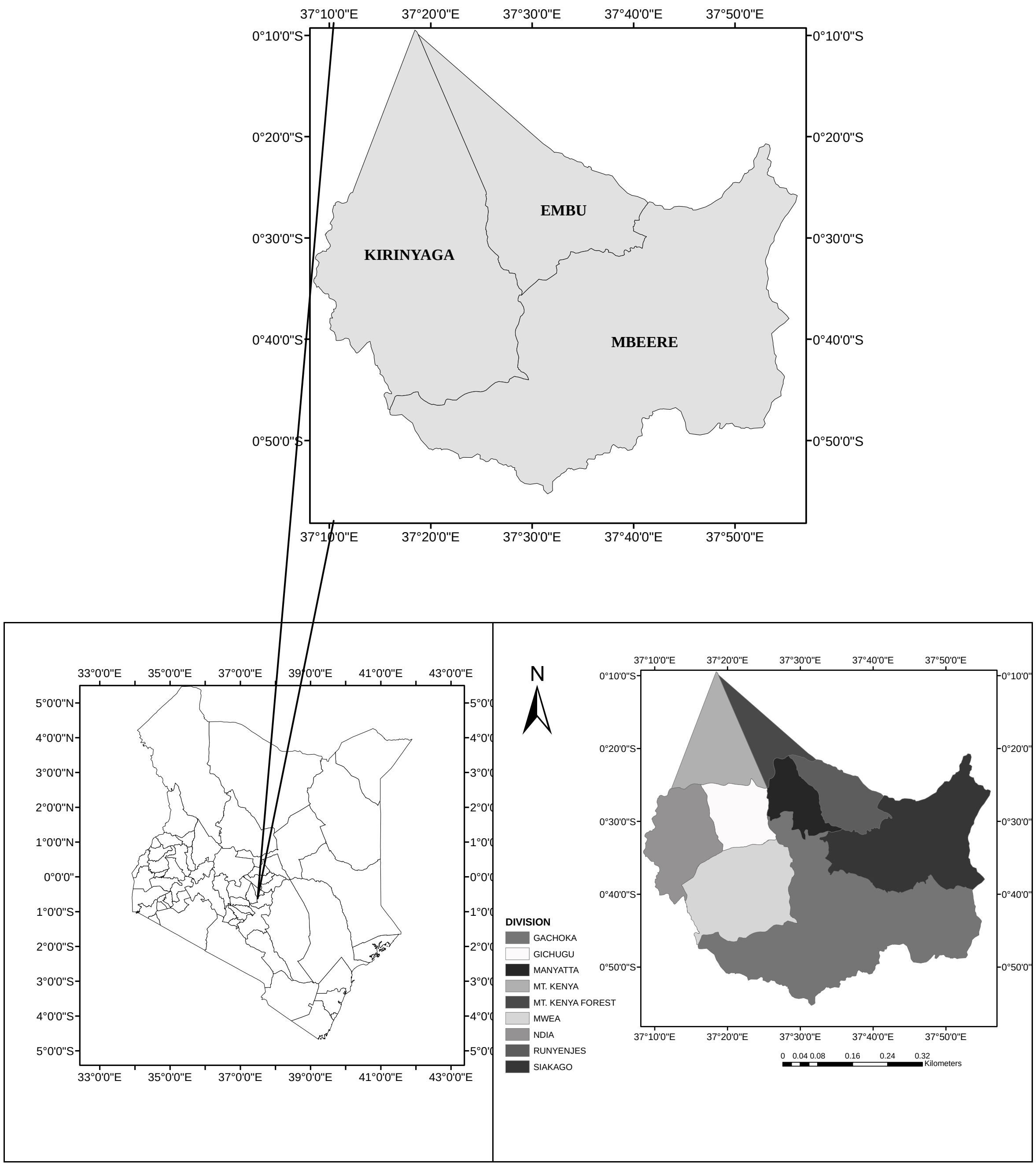

Figure 3. 1: Map showing location of the study area in Kenya
(source; mweamucsa.blogspot.com/p/about-mwea.html).

The predominant soils of the rice-growing areas of Mwea are vertisols (Sombroek *et al*. 1982). These are characterized by imperfectly drained clays, very deep, dark gray to black, firm to very firm, and prone to cracking. The most appropriate season for rice cultivation in Mwea is from August to December, when temperatures are suitable for grain filling and with less risk of disease incidence (Mukiama and Mwangi 1989). However, this period is also when the river flows are at their lowest, coinciding with the dry season, further putting a strain on water available for irrigation. Rice production is also complicated by the staggered planting calendar implemented in the scheme (Ijumba *et al*., 1990) since available water is not enough to reach all farmers during the most appropriate season.

The scheme has a gazetted area of 30,350 acres. A total of 16,000 acres has been developed for paddy production. The rest of the scheme is used for settlement, public utilities, subsistence and horticultural crops farming. The scheme supports about 3,400 smallholder households, with a population density about 1.8 households ha-1. The main crop grown in the Mwea irrigation scheme is rice, and Mwea is responsible for 80% of the rice grown in Kenya (not counting out-growers). The scheme is famed for its production of an aromatic basmati rice variety, locally called pishori, which has become a brand name for the scheme (Mati *et al*., 2010).

3.2 Research design

This study adopted the use of survey design in a natural research setting. The research design enabled study of different groups of the population dispersed over the wide geographical area of Mwea division through a sampling approach. Preliminary diagnostic studies were conducted before the final data collection instruments were settled on. A range of data collection techniques were employed including use of questionnaires, interviews and observation (Zeisel, 1980; Bartlett *et al*., 2001).

3.3 Data collection

The data collection tools included use of questionnaire, interviews, GIS data in vector and raster format, scanned ground survey maps, GPS data and physical observations. The questionnaire and interviews were employed to obtain statistically useful information on rice production and effect of rice blast disease to the farmers. GIS data was used to derive thematic layers that were linked together by geography. The thematic layer approach allowed the organization of the complexity of the area into a simple representation to help facilitate the understanding of suitability analysis. The sampled GPS data was important in mapping and to compare with the primary sources of data such as the questionnaires and field observations to enhance validity and reliability of the results.

3.4 Sampling method

A structured questionnaire combined with interviews to the farmers, other stakeholders and organizations and physical observations were employed to collect primary data. These structured questionnaires were conducted face to face with the farmers with a view to establish the impact of rice blast disease to the socio-economic aspect of the farmers in the area.

Data collected included household characteristics (age, education and gender of head of household and average family size), farm characteristics (average size of farm, type of land tenure, rice variety cultivated, number of years of rice farming, use of inputs including labour) and farmers' perceptions on rice blast disease (knowledge of rice blast disease, years since rice blast disease was first observed, assets sold due to onset of rice blast disease, cause of rice blast disease and when the disease spreads, whether rice blast disease is changing and the reasons why this may be so, resource use and management due to rice blast disease).

A systematic random sampling approach was employed based on all the units in the sections including the out growers. A total of three hundred and twenty five questionnaires were targeted from the total population of 5,576 household (Figure 3.2). This number was based on Cochran's sample size formula for categorical data (Bartlett *et al.*, 2001). A list obtained from previous JICA survey work (2009) had fundamental information; i.e., member's name, land ownership, area and location of farm(s), and house address. All members were grouped according to their respective sections (Table 3.1). The first member was selected and every twentieth member was next to be selected from Mwea Section. The second member and every twentieth member was selected from Thiba Section. This selection method was applied in all the sections. However, total number exceeded the expectation, because some blocks like H1 had 48 members and 3 were selected for interview. H2 with 67 members 4 were selected. If selected member was not available next candidate in the list was selected (Table 3.1). Five selected enumerators and two guides from NIB were employed and trained to conduct the questionnaires in the local language (Kikuyu). They were briefed extensively on the intended use of the work and also provided invaluable input into the survey design

Due to financial constraints and the fact that some respondents were not patient enough to complete all the sections of the questionnaire, the above target could not be realized. A total of three hundred and two questionnaires were fully filled and used for the data analysis and this formed a good representative of the target population.

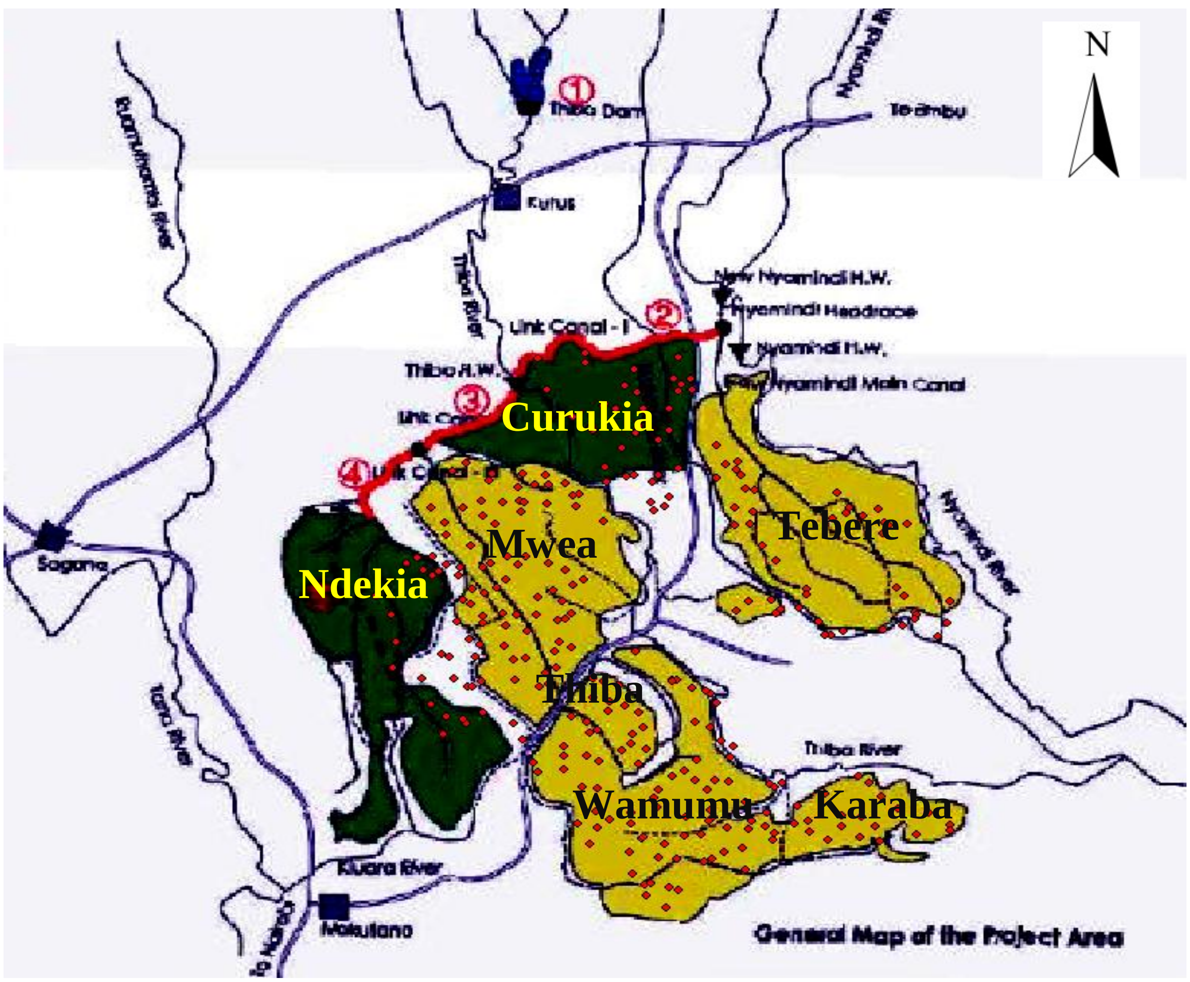

Figure 3.2: Study area; Irrigation schemes and the sampled farm units

Table 3. 1: Number of Members and Interviewees by Block

Block Name	No. of Members	No. of Interviewees	Block Name	No. of Members	No. of Interviewees	Block Name	No. of Members	No. of Interviewees
H1	48	3	M1	67	4	K8	17	1
H2	67	4	M2	28	4	T2	16	2
H3	76	5	M3	33	3	T5	93	5
H4	58	4	M4	87	3	T6	45	2
H5	116	7	M5	43	3	T7	71	5
H6	78	5	M6	47	3	T8	115	6
H7	53	4	M7	37	3	T11	81	0
H8	59	4	M8	22	1	T13	55	3
H18	75	5	M9	48	1	T15	24	0
H19	70	5	M10	18	2	T16	81	4
H20	76	5	M11	34	1	T17	13	1
W1	90	5	M12	63	4	T18	58	4
W2	139	7	M13	51	4	T19	73	0
W3	117	7	M14	65	5	T20	84	5
W4	102	5	M15	31	1	T21	56	1
W5	111	3	M16	87	6	T22	46	6
W6	141	8	M17	106	7	T23	29	2
W7	94	9	K1	133	7	T25	10	1
MUGAA	110	7	K2	105	6	CUMBIRI I	140	8
NDEKIA I	123	9	K3	103	6	CUMBIRI II	170	8
NDEKIA II	280	17	K4	92	5	KANDONGU	155	9
NDEKIA III	159	12	K5	106	6	KIANDEGWA	101	2
NDEKIA IV	162	11	K6	73	5	Total	5,576	325
NGOTHI	80	4	K7	80	5			

3.5 Data analysis

Descriptive statistics analysis of means and frequencies was used to summarize the household characteristics, the farm characteristics and the farmers' perceptions of rice blast disease. The data was then subjected to a chi square Test of Independence and nonparametric analysis of variance (ANOVA). This was conducted at 5% probability level. The analyses were done using SAS Version 9.1. The qualitative data from the questionnaire was used to report key findings under each main theme or category, using appropriate verbatim quotes to illustrate those findings.

From the questionnaire, farmers' response on whether they had been affected by rice blast disease and the total production per acre was used to develop an attribute table with GPS points. The GPS points were interpolated to create a geographical distribution map of rice blast disease.

3.6 Rice blast disease mapping

The data used was obtained from the questionnaire response by the farmers on whether rice blast disease had ever affected their farms, their response and amount of produce harvested per acre. At the first, a database was set up using Global Positioning System (GPS) and Geographical Information Systems (GIS). All the farmers units were referenced by GPS during the field work. Rice blast disease cases were created and pointed with point symbol on the map. The statistical maps displaying rice blast disease density and its geographical distribution in the study areas were produced through interpolation and displayed using ArcGIS 10 software and Geostatistics extension of the software. Interpolation was done between the sample point to obtain and predict values for unknown locations. Among the different interpolation techniques, the Inverse Distance Weighted (IDW) method was used, that is a simple interpolation technique that can often yield satisfactory results. The basic premise of inverse distance is that data points are weighted by the inverse of their distance to the estimation point. This approach has the effect of giving more influence to nearby data points than those farther away. Additionally, the inverted distance weight can be raised to further reduce the effect of data points located farther away.

3.7 Suitability analysis

3.7.1 Parameters for suitability analysis

The study area was extended to the whole of Kirinyaga and Embu Counties. Literature review of various references, interviews with local agronomists and researchers at Mwea Irrigation and Agricultural Development Centre (MIAD) and desk search of available data helped in identifying the critical requirements for suitable rice growing areas. The factors identified were related to climate (humidity and temperature), soil (soil texture, soil pH, soil drainage) and topography (slope).

Climatic information on temperature and humidity was derived from the Exploratory Soil Survey Report (UNEP/GRID, 1982) which shows the principle Agro-Climatic Zones of Kenya based on a combination of both moisture availability zones (I-IV) and temperature zones (1–9). Thematic maps were developed for each of the parameters. Data on soil properties was obtained from the Kenya soil survey (KSS). This coverage showed the soil physical and chemical properties of Kenyan soils. The polygons consisted of various soil mapping units linked to an attribute table of soil properties. Three soil parameters of soil texture, soil pH and soil drainage were obtained from an attribute table using Arc GIS 9.3 software and thematic maps were developed for each of the parameters. All the maps were geo-referenced to the Universal Transverse Mercator (UTM) coordinate system. Slope information was obtained from Digital Elevation Model (DEM) using GIS software package ArcGIS 9.3. The source of DEM was Shuttle Radar Topographic Mission (SRTM) which was 90m spatial resolution. The overall study flow chart that was followed is illustrated in (Figure 3.3).

3.7.2 Assigning weight of factors and multi criteria evaluation (MCE)

The purpose of weighting was to express the importance or preference of each factor relative to other factor effects on crop yield and growth rate. Factors established were the most relevant as identified with help of subject experts. Suitability levels for each of the factors were defined and used as a base to construct the criteria maps (Figure 4.3). The suitability levels for each factor were ranked as: Highly suitable-S1, Moderately suitable-S2, Marginally suitable-S3, Not suitable-N, based on the structure of FAO (1976) land suitability classification. According to the FAO (1976) guide line for irrigated rice and local expert's opinion, a specific suitability level per factor for production of irrigated rice crop was defined (Table 3.2).

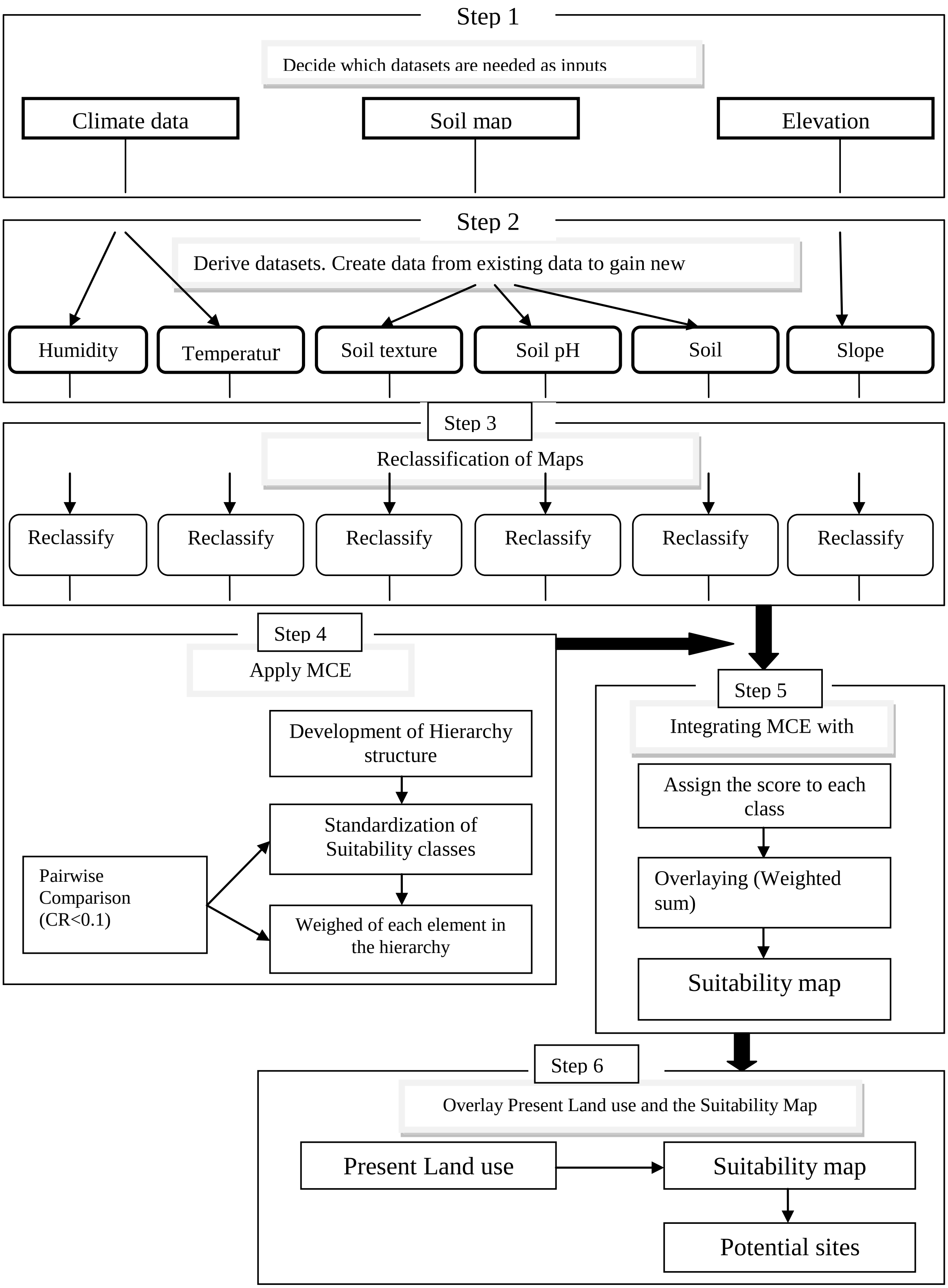

Figure 3. 3: Flowchart of the methodology followed in the suitability analysis study

Table 3. 2: Suitability levels of the six parameters for production of irrigated rice crop

Scale	**Topography**	**Humidity**	**Temperature**	**Soil PH**	**Soil texture**	**Soil drainage**
Very low suitability	60–100%	< 15	< 18	< 4.0	Sand	E-excessively drained
Low suitability	30 – 60%	15 – 25	> 35	> 8.4	Sandy loam	S-somewhat excessively drained
Moderately low suitability	15 – 30%	25 - 40	19 - 18	4.0 – 5.0	Silt loam	V-very poorly drained
Moderate suitability	8 – 15%	40 - 50	34 - 35	7.8 – 8.4	Loam	W-well drained
Moderately high suitability	5 – 8%	50 - 65	21 - 20	5.1 – 5.5	Silty clay	M-moderately well drained
High suitability	2 – 5%	65 - 80	31 - 33	7.4 – 7.8	Clay loam	P- poorly drained
Very high suitability	0 - 2%	> 80	22 - 30	5.6 – 7.3	clay	I-imperfectly drained

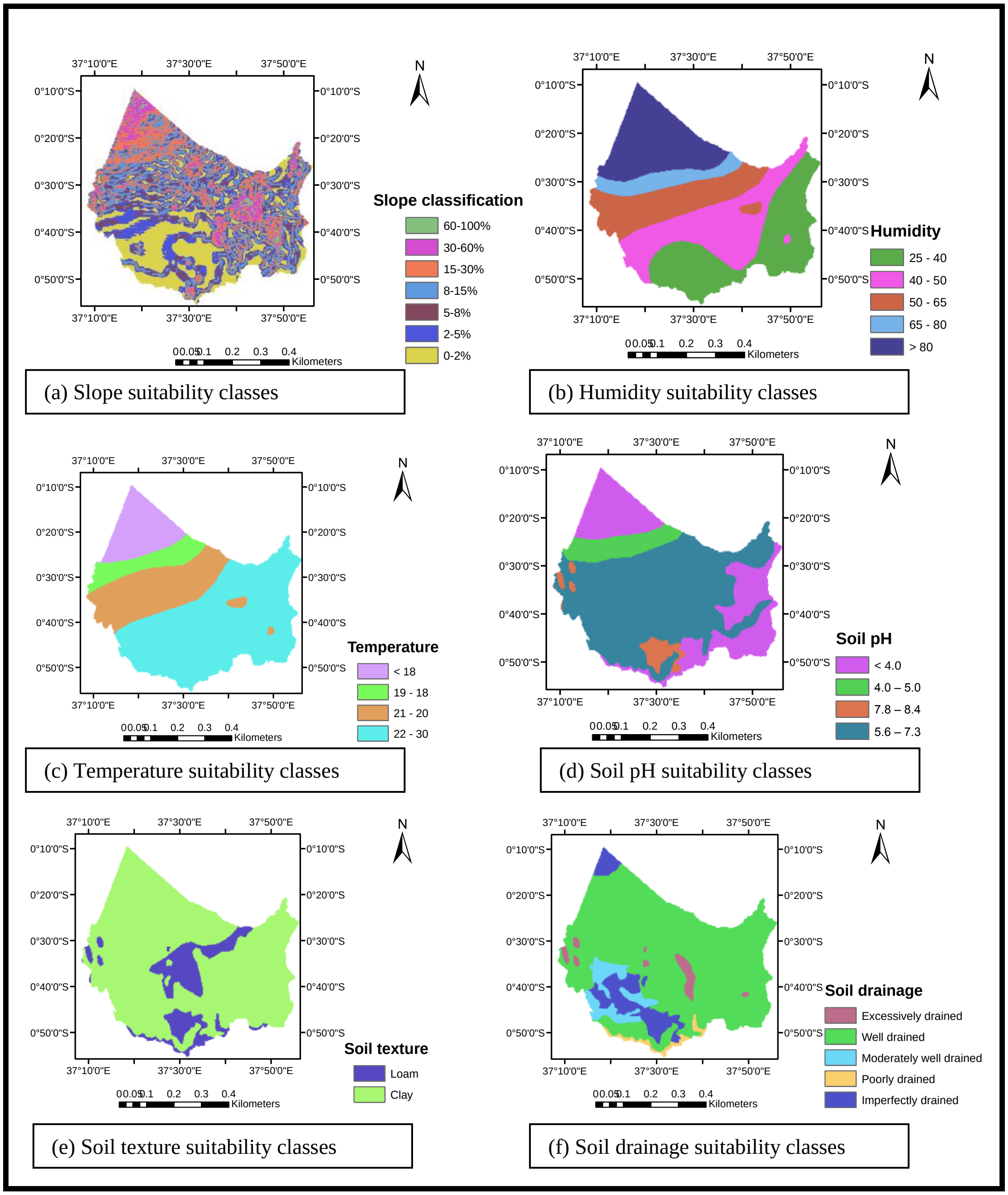

Figure 3. 4: Reclassified factor maps showing suitability levels of each parameter

In the procedure for MCE using weighted linear combination, it was necessary that the weights sum to 1. The MCE method used, weighted linear combination, requires that all factors must be standardized (Eastman, 1999) or transformed into units that can subsequently be compared (Malczewski, 1999). In this study, the factor maps were ranked according to Saaty's underlying scale with values 1 to 7 by discussion with local crop specialist and from literature reviews as shown in (Table 3.3).

Table 3. 3: Seven-point weight scale for pair-wise comparison

Description	**Scale**
very low suitability	1
low suitability	2
moderately low suitability	3
moderate suitability	4
moderately high suitability	5
high suitability	6
very high suitability	7

Using Pairwise Comparison Matrix, factor weights were calculated by comparing two factors together. The PWCM were applied using a scale with values from 9 to 1/9 introduced by Saaty (1980). A rating of 9 indicates that in relation to the column factor, the row factor is more important. On the other hand, a rating of 1/9 indicates that relative to the column factor, the row factor is less important (Mustafa *et al*., 2011). In cases where the column and row factors are equally important, they have a rating value of 1. Table 3.4 shows pairwise comparison matrix for the research.

Table 3. 4: Seven-point weighing scale for pair-wise comparison

scale	Topography	Humidity	Temperature	Soil PH	Soil texture	Soil drainage	Weights	Ranking
Topography	**1**	7	1/3	5	1/3	3	0.1843	3
Humidity	1/7	**1**	1/5	1/3	1/5	1/5	0.0355	6
Temperature	3	5	**1**	7	5	5	0.4153	1
Soil PH	1/5	3	1/7	**1**	1/5	1/ 5	0.0497	5
Soil texture	3	5	1/5	5	**1**	1	0.1865	2
Soil drainage	1/3	5	1	5	1	**1**	0.1287	4
CR=0.08							∑=1	

In the diagonal, elements were assigned the value of unity (i.e., when a factor is compared with itself). Since the matrix is symmetrical, only the lower triangular half actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half (for example, because the rating of temperature relative to topography is 3, the rating of topography relative to temperature will be 1/3).

In order to prevent bias through criteria weighting the Consistency Ratio was used

$CI = (\lambda max - n) / (n - 1)$ Eq. 1

$CR = CI / RI$ Eq. 2

A key step in the making of several pairwise comparisons is considering the consistency of the pairwise judgements. Example: If A compared to B = 3 and B compared to C = 2 then A compared to C should = 3x2 = 6. If it wasn't, some inconsistency would occur.

With AHP, we can measure the degree of consistency; and if unacceptable, we can revise pairwise comparisons. The degree of consistency was obtained through the following steps;

Step 1: Multiplying pairwise comparison matrix by relative priorities

Step 2: Dividing weighted sum vector elements by associated priority value

Step 3: Computing average (denoted λmax) of the values from Step 2.

Step 4: Computing consistency index (CI)

Step 5: Computing consistency ratio (CR)

CI = 0.1035

RI = 1.24

CR = 0.1035/1.24

= 8.3% < 10%

Standard Rule states: If CR <= .10, consistency is acceptable!

Once the composite layers and their weights were obtained, the MCE procedure within Arc GIS 9.3 was applied to produce the map of suitable areas. The suitability map for rice crop was identified by weighted overlay using spatial analyst tools in ArcGIS 9.3.

3.7.3 Present land use under rice cultivation

For this research, in order to generate the present Land use under rice growing, ground survey map of the scheme area and outgrowers main blocks was obtained from MIAD and JICA. The map was scanned and digitized using Arc GIS 9.3. In order to use these types of data in GIS it was necessary to align it with existing geographically referenced data, the map generated and georeferenced to Arc_1960_ UTM_Zone_36N of WGS 1984.

3.7.4 Overlay present land use/cover and the suitability map

The present land use/land cover map under rice cultivation and the suitability map for rice crop were overlaid to identify differences as well as similarities between the present land use and the potential land use. For rice crop, a cross table between the map of suitable areas and the land use/land cover map was obtained. In this way, we obtained useful information concerning the spatial distribution of different suitability levels were obtained. This phase allowed the fine-tuning of our results, because the resultant layer provided the information about how the rice crop was distributed across the various land suitability zones.

CHAPTER FOUR

4.1 RESULTS AND DISCUSSION

4.1.1 Socio-demographic characteristics of farmer respondents

The sample size of farmer respondents handled during the survey was 302 of whom 19.1% were female while 80.1% were males. The average number of family members was 6.0 per household. Average number of adults above 18 years was 2.19 per household for males, 1.99 for female and 1.79 for children below 18 years. The research study revealed that 47.4% of the respondents had primary level education, 14.9% did not attend school at all, 32.5% had secondary education, while those with diploma/certificate training and University were 3.6% and 1.7%, respectively (Figure 4.1). Education level is key to shaping and influencing farmer's productivity. Highly educated farmers have always demonstrated better means of crop production and adoption of new technologies as opposed to poorly educated farmers (Thirtle *et al.*, 2003*)*. The majority of respondent household heads were in the age range of 30's to 70's, while none of the respondents was older than 95 years. The age distribution among the sample is shown in Figure 4.2 below.

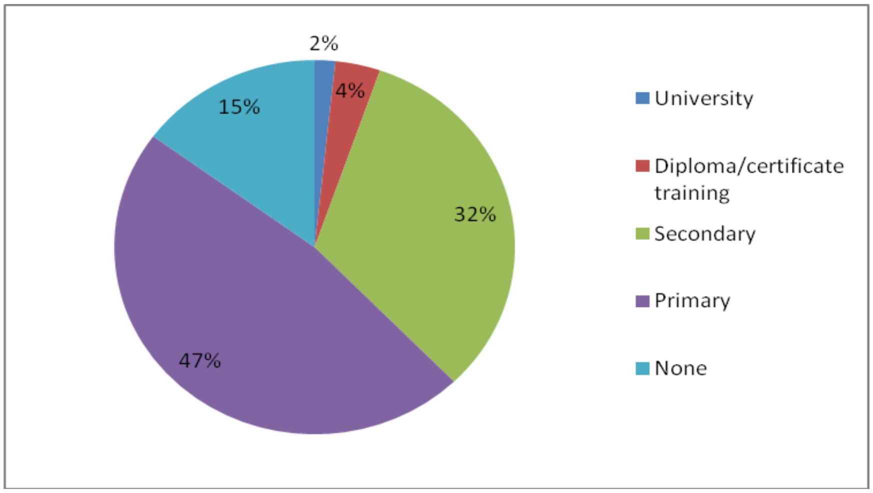

Figure 4. 1: Education level of the farmers

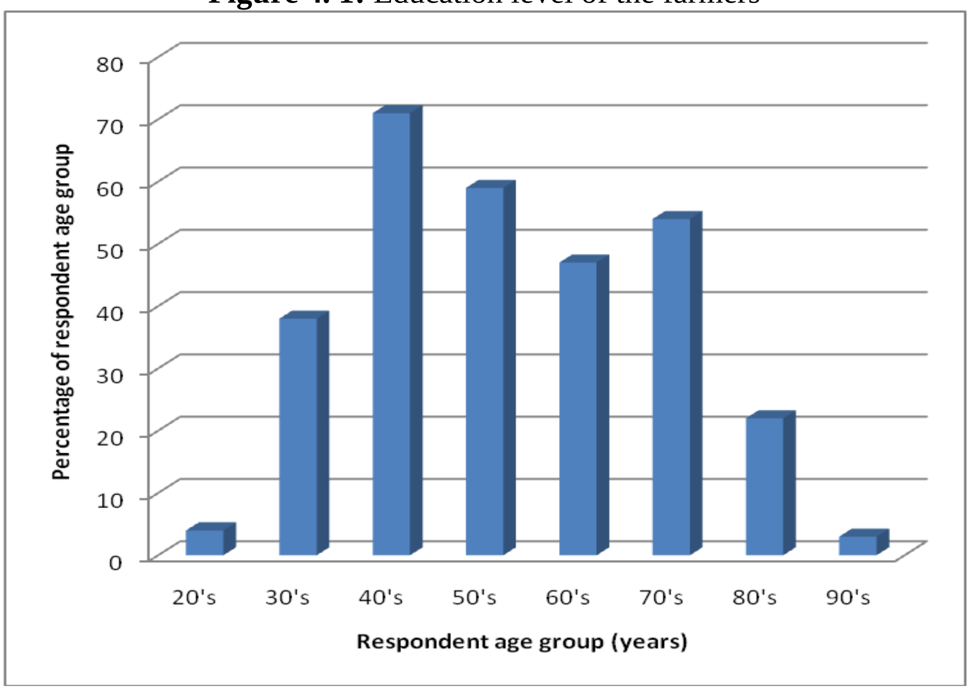

Figure 4. 2: Age distribution of farmer respondents

4.1.2 Household Economic Status

The survey revealed that farming was the main economic activity (73.4% of the respondents) of virtually all the respondents selected for this assessment (Table 4.1). Most of the respondents (12.8%) are engaged as casual labourers, while 7.4% and 3.1%

were engaged in business and formal employment, respectively. Among them, formal employment had the highest income earning per annum of Ksh118,884 followed by farming with Ksh67,040. The current debt was of Ksh36,487.68 on average. The mean weekly expenditure on food was Ksh1,114.60. The distribution of this expenditure is shown in Figure 4.3. Meanwhile, 228 families on average spent Ksh26,603.07 for education per annum.

The average number of domestic animals owned by household were as follows: (1) Cattle (2.47/HH); (2) Goats (1.29/HH); (3) Sheep (0.44/HH); (4) Poultry (14.2/HH); (5) Donkey (0.28/HH); (6) Others (0.26/HH) (Table 4.2). The total assets owned by the respondents are indicated in the (Table 4.3).

Table 4. 1: Distribution and Average annual income of each social economic activity practiced by the respondents

Activity	**No. of people**	**% in total adults**	**Average annual income (Ksh)**
Farming	719	73.4	67,040
Formal employment	30	3.1	118,884
Business	73	7.4	55,969
Casual labour	125	12.8	39,932
Others	33	3.4	41,900

Table 4. 2: The average number of domestic animals owned by household

No	**Animals**	**Total number**	**Average per HH**
1	Cattle	745	2.47
2	Goats	389	1.29
3	Sheep	134	0.44
4	Poultry	4288	14.20
5	Donkey	84	0.28
6	Others	78	0.26

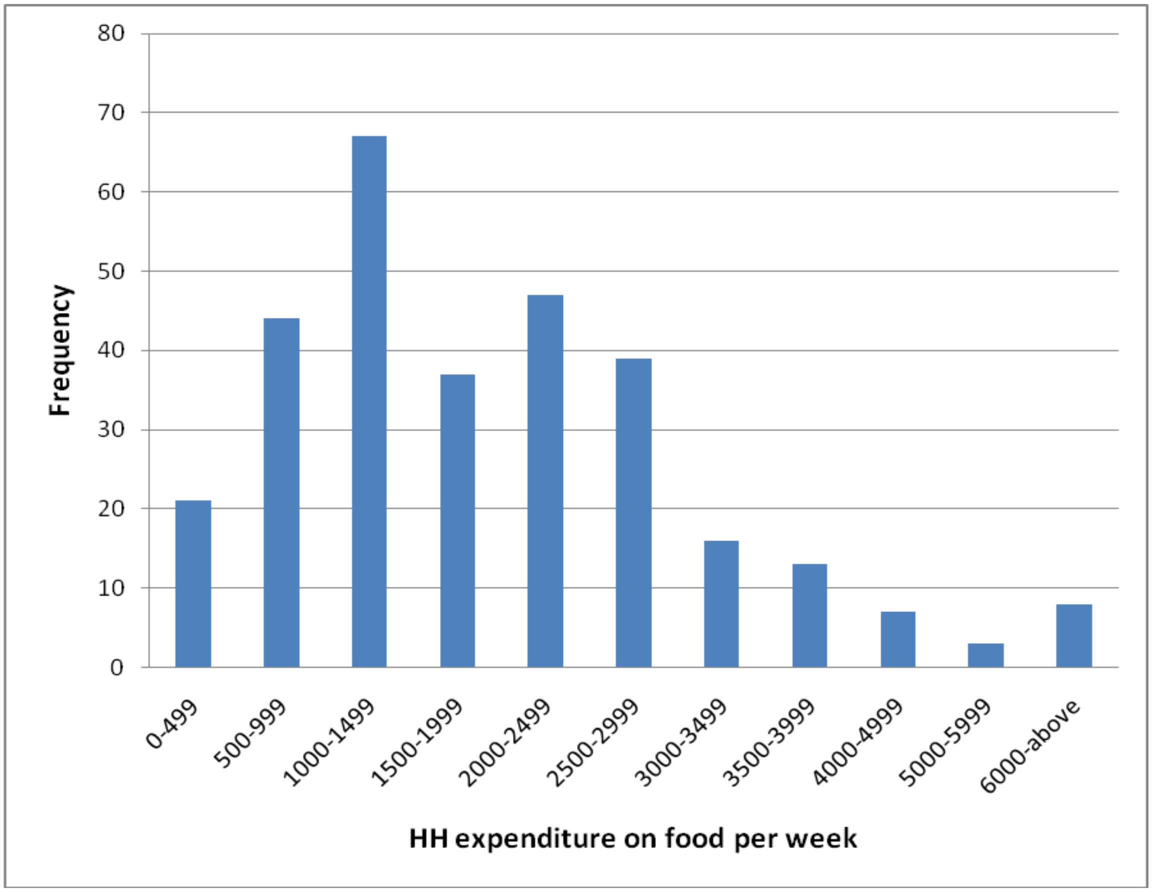

Figure 4.3: The average household food expenditure per person in a week in Ksh.

Table 4. 3: Assets holdings in total number

No	Items	Total number
1	Car	24
2	Motor Cycle	72
3	Tractor	9
4	T.V.	238
5	Bicycle	402
6	DVD	139
7	Mobile phone	699
8	DSTV	4
9	Radio	148
10	Carts	49
11	Water tank	4
12	Solar panel	3
13	Water pump	14

Given that each household had an average of 2.47 cattle, milk was expected to be readily available in the region, hence 91.8% of the households enjoyed tea with milk in the morning, 4.6% preferred porridge and 2.9% took tea without milk. Majority of the households 62.2% took rice in the morning as the main side dish while 23.3% prefer bread in the morning. At lunch 54.1% of the household took rice, 26.4% preferred githeri and 17.9% usually took Ugali. 57.7% of the household took vegetables as the lunch main side dish followed by beans/black beans (njahi) 33.6% (Table 4.4). During supper, majority of the household took ugali (44.4%) as compared to rice (40.1%). 14.6% of the household preferred githeri at supper. The main side dish at supper was vegetables 62.3%, followed by beans/ black beans (njahi) 24.5% and meat 12.3% (Table 4.4).

Most of the farmers, 58%, indicated that their lives and that of their household is not getting better economically (Figure 4.4). This is an indication that rice farming in the area was not very profitable and thus all the stakeholders should be involved in making rice growing a profitable economic activity so as to benefit the local farmers and improve their economic status.

Table 4. 4: Livelihood focused on daily food habit

	Percentage household			**Percentage household**	
Staple food	**Lunch**	**supper**	**Main side dish**	**Lunch**	**supper**
Githeri	26.4	14.6	Fish	1.5	0
Rice	54.1	40.1	Meat	6.8	12.3
Ugali	17.9	44.4	Vegetables	57.7	62.3
None	1.3	0.3	Beans/ black beans (njahi)	33.6	24.5
Others	0.3	0.7	Others	0.3	0.9

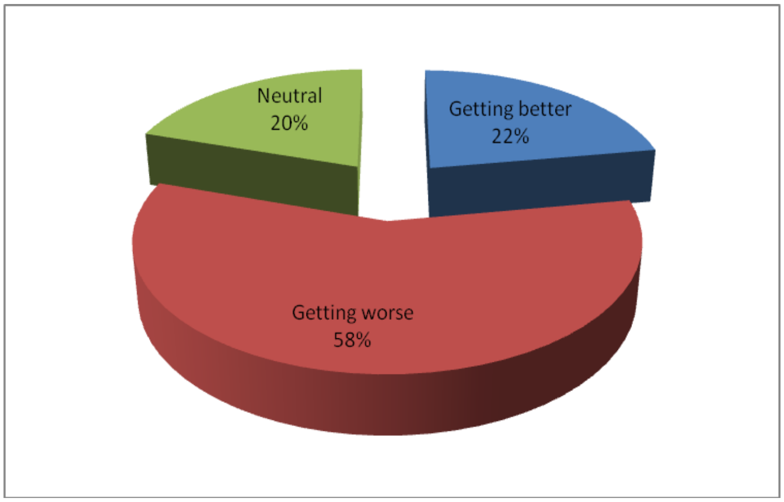

Figure 4. 4: : Livelihood status of the respondents and their household

4.1.3. Land Tenure

The average land holding was 2.83 acre per household, ranging from 0 to 15.25 acres. However, there were two peaks of the land size ownership, one at about 1.5 acre and the other at 4.5 acres (Figure 4.5). There were 38 farmers who leased rice field in 2010 with an average leased land size of 2.38 acres per farmer.

The common tenure system in the region was land owned but not titled (59%). Most of the farmers were given land in the scheme which was owned by the government through National Irrigation Board (NIB) and the government has not yet issued titles to the farmers up to date. The Land tenure system in the schemes was not favorable to farmers as they did not own land titles making it impossible for them to access credit. On the other hand women were key players in rice production, but yet they did not own land (NRDS Government of Kenya, 2009). Farmers who had title deeds (21%) were outgrowers who cultivate rice in their own farms around the schemes (Table 4.5). Most of the farmers 26% acquired their land in the years between 1970-1979, 24% acquired their land in between the years 1950-1959 and 1960-1969 (Figure 4.6). A higher number of the farmers 37% received their land as inheritance from their deceased or still living relatives. When asked how much they are willing to pay to rent-in per season, 66% of the farmers were willing to pay Ksh 30,000 per acre in one year while 25% were willing to pay Ksh 35,000 per acre in one year.

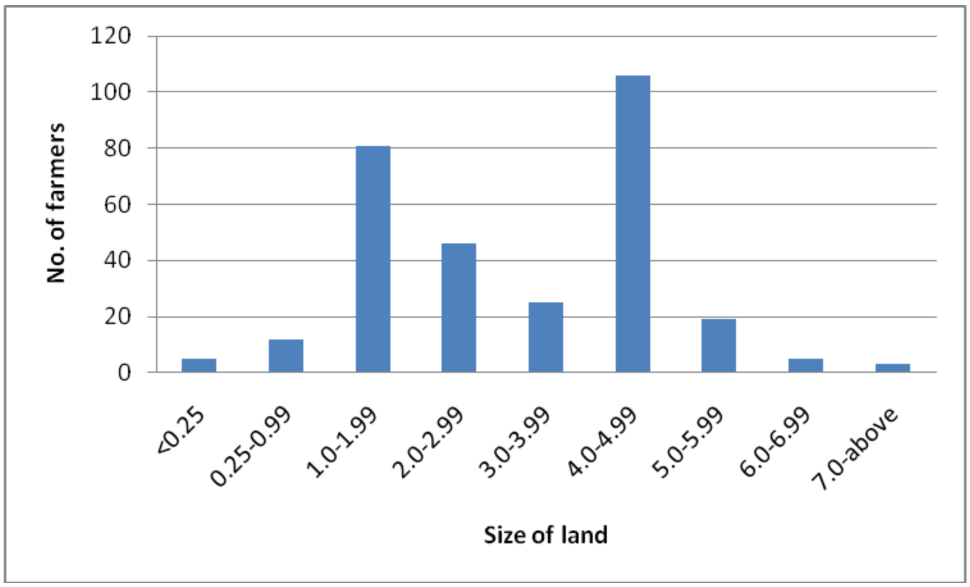

Figure 4. 5: Land size owned in acres for rice cultivation

Table 4. 5: Land tenure system

Tenure system	Frequency	Percentage
Title deed	72	21
Owned but not title	207	59
Leasehold	4	1
Government land	13	4
Rented -in	3	1

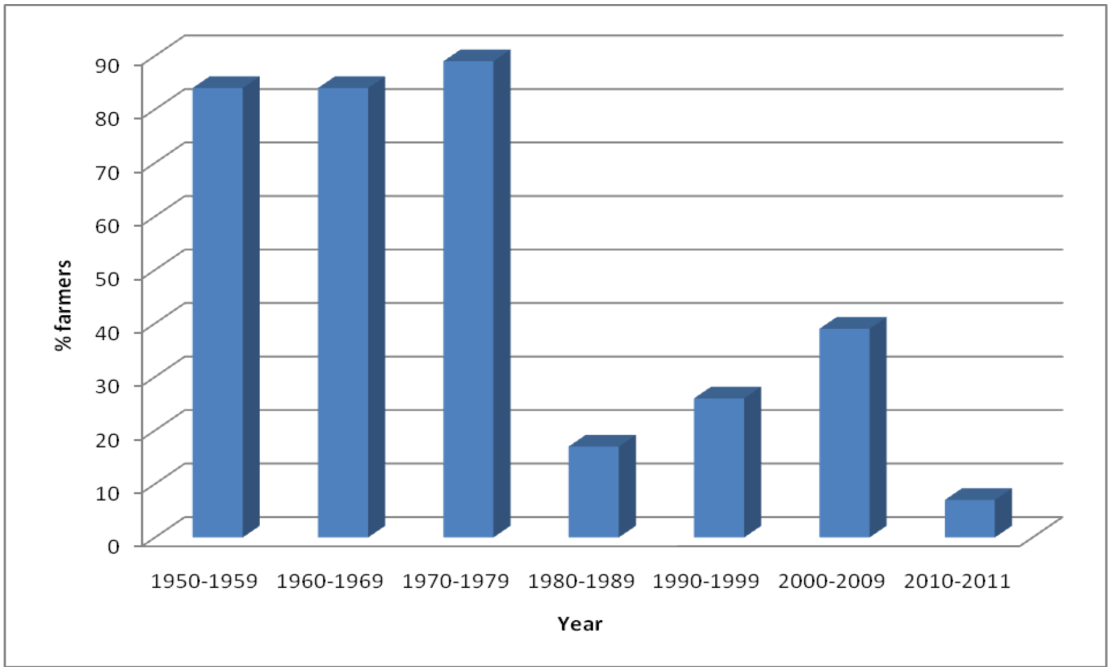

Figure 4. 6: Year of acquisition of the land under rice cultivation

4.1.4. Rice production

4.1.4.1 Land preparation and seed source

There were several methods of initial land tillage, i.e. Hired tractor private, Hired tractor from National Irrigation Board/Government of Kenya, Use of own tractor, Own oxen, Hired oxen, Family manual labour, Hired labour and farmers cooperative tractor. From the survey 72% of the farmers used hired private tractors in the initial land tillage, 18% used the farmers' cooperative tractor, 6% use hired labour while 2% and 1% used hired tractor from NIB and own Oxen, respectively. In the second tillage/puddling and leveling, animals were mostly used (90%), tractor rotavater 3%, own labour 4% and hired labor 3% (Table 4.6). The sowing date of the rice seedlings in the field from the nursery was commonly done in July and it continued till August. There was another small peak of sowing in November, and it belonged to the third group of the irrigation distribution schedule of the scheme area.

Table 4. 6: Land preparation methods during the first and second tillage

First land tillage method		**Second tillage/puddling and leveling**	
Tillage method	**Frequency**	**Tillage method**	**Frequency**
Hired tractor private	220	Tractor rotavator	10
Hired tractor NIB/GoK;	6	Animals	274
Own tractor	1	Own labor	12
Own oxen	4	Hired labor	8
Hired oxen	0	Others	2
Family manual labor	0		
Hired labour	15		
Farmer Cooperative tractor;	55		
Others	3		

Although seed source varied, majority of the farmers (83%) sourced their seeds from Mwea Irrigation and Agriculture Development Centre (MIAD), 9% got rice seeds from Mwea Rice Growers Multi-purpose Co-operative Society (MRGM) a rice grower society in the area who provided seeds on credit which the farmer later payed back in the form of harvested rice. A considerable number (6%) use their own seeds and very few farmers (1%) obtained their seeds from private seeds companies (Figure 4.7). The average amount of seeds used in one acre was 22.5kgs which cost between kshs 80 to Kshs 100 per kg. 97% of the farmers transplanted their seedlings randomly and only 3% of the famers transplanted their seedlings in line.

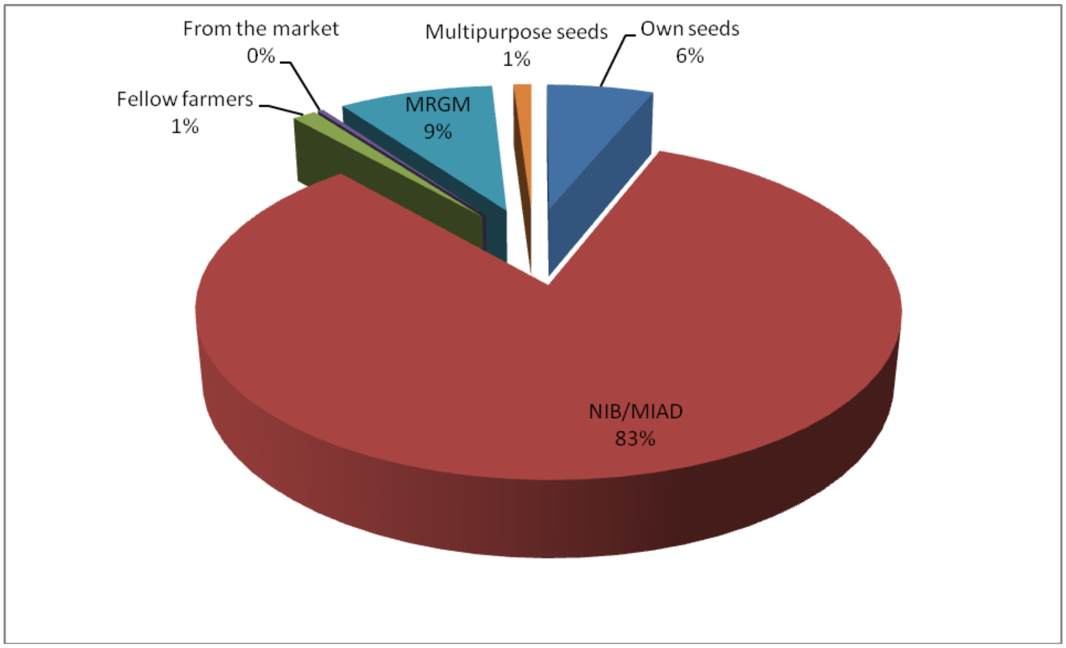

Figure 4. 7: Farmers source of seeds

4.1.4.2. Input use for rice cultivation

Fertilizers were commonly used by the farmers (Table 4.7). Majority of the farmers used DAP for (87.4%) the basal application and SA for top-dressing (89.9%). On average one bag (50kg) of DAP was used for basal application per acre and in a similar way another bag (50kg) of SA was used for top-dressing in one acre. This signifies that the farmers spend about Kshs 5,000 on fertilizers alone per acre. Organic fertilizers were greatly used during land preparation. This reduces the need for a lot of synthetic fertilizers during the growing period. Most of the farmers applied dry (47.6%) and fresh (46.6%) animal manure during land preparation (Table 4.8). Due to various pests and diseases the farmers used kshs740 on average per acre in one cropping season to buy chemicals and foliar fertilizers.

Table 4. 7: Fertilizer use by the farmers in rice cultivation

Fertilizer use	Kind of fertilizer	Frequency %
Planting fertilizers	DAP	87.4
	NPK	4.5
	UREA	1.5
	SA	3
	MOP	3.6
Top dressing fertilizers	DAP	4
	NPK	2.5
	UREA	1.4
	SA	89.9
	MOP/CAN	2.2

Table 4. 8: Organic fertilizer use by the farmers in rice cultivation

Organic fertilizer type	No. of farmers	Percentage
None	1	0.5
(dry) manure	99	47.6
(fresh) animal manure	97	46.6
Ash	2	1.0
Compost	6	2.9
Crop residual	3	1.4

4.1.4.3. Labour usage for rice production

Farmers in Mwea region highly depend on hired labour in rice cultivation. Bird scaring is the most expensive activity because it has a constant cost, whether one has 2 acres or half an acre of land farmers have to employ a person to scare birds for about one and half months before harvesting. Planting/sowing also requires a lot of money due to the intensive labour requirements. In summary the total family labour, hired labour and mechanization expenditure in one acre is Kshs. 32,494 (Table 4.9).

Table 4. 9: Average expenditure on family labour, hired labour and mechanization costs for rice production per acre for the main crop in one season

Expenditure Item	Activity	Costs per acre (Ksh)
Land Preparation	Clearing field	1,429
	Repairing Bunds	585
	Repairing canals	649
	1st ploughing	3,466
	2nd ploughing	1,211
	1st harrowing	1,590
	2nd harrowing	1,790
Farm management	Planting/sowing	4,060
	Soil covering	1,133
	1st weeding	1,782
	2nd weeding	1,725
	water management	1,235
	Scaring birds	5,062
	Harvesting	3,632
	Post harvest activities	2,012
Agricultural materials	Fertilizer and chemicals application	495
	Other expenses	638
Total		**32,494**

4.1.4.4. Harvest and sales of rice

The average yield per acre of basmati variety was 21.7bags (1,953kgs) and BW196 variety was 26.03 bags (2,343kgs), IR2793-80-1 variety did not give a good picture because very few farmers grew it in very small portions of land (Table 4.10). Some farmers (35%) were not satisfied with the yields they obtained and a bigger percentage 51% were contented and said that the yields were average. Only 14% of the farmers interviewed were of the opinion that their yields were above average. One acre of rice can produce about 30 bags (2,700kgs) if proper practices are adhered to. Majority of the farmers (82%) who were not satisfied by their yields indicated that inadequate rains were the main reason for the poor yields, crop disease (4%) and low temperatures (3%) were also mentioned as the cause of poor yields.

Basmati variety is generally a cash crop in the region of which of the total harvested rice 87.7% was sold and the rest 12.3% was left for consumption. BW196 was usually grown for consumption. The farmers indicated that BW196 is very heavy and provides a lot of energy compared to basmati but due to lack of aroma and poor cooking qualities most of the people especially in urban areas do not like it. 62.4% of BW196 produced was kept for consumption and only 26.0% was for commercial purposes. Interestingly, much of the BW196 was sold to the local farmers who do not cultivate the variety (Table 4.10). In the year 2010, the average sale per bag of basmati variety was ksh 4,473 while that of BW196 was 3,500. This clearly explains the reason for the choice of basmati over BW196 variety (Table 4.10). Majority of the farmers 82% sold their rice to traders and 13% sold their rice to cooperative association in the area (Figure 4.8). The farmers either took their rice to the market or traders came to their gate.

Table 4. 10: Average yield and sale of rice in 2010 cropping season

Variety planted	Average harvest per acre 90kg bags	Percentage Amount consumed	Percentage Amount sold	Average unit price per 90 Kg bag
Basmati370	21.7	12.3	87.7	Ksh 4,473
IR2793-80-1	3.1	76.47	23.53	Ksh 2,500
BW196	26.03	62.43	37.57	Ksh 3,500

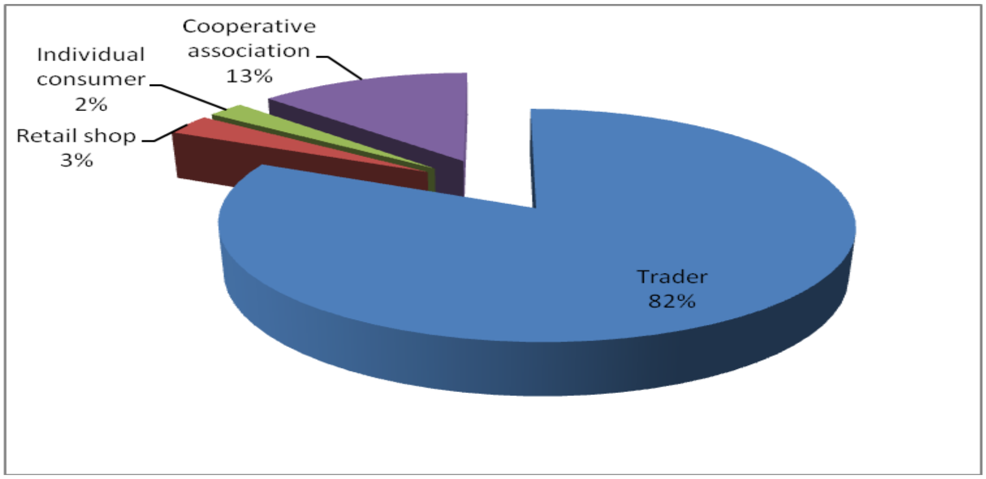

Figure 4. 8: Farmers marketing channels and their preference level among the farmers

4.1.4.5. Profit calculation

Profit in rice growing was obtained by subtracting the average expenditure of rice growing from the average sales of rice produced in one acre. The average expenditure included the family labour, hired labour, mechanization costs and all farm inputs i.e. seeds, fertilizer, chemicals and foliar fertilizers. The total sales were obtained by multiplying the average yield per acre of each variety by the average unit price per 90kgs bag. The profitability of the two common varieties is as shown in Table 3.11. Farmers indicated that in cultivating the two varieties the expenditure

Table 4. 11: Relative average profitability of rice growing for the year 2010

Variety	Average sales	Average expenditure	Average profit
Basmati	97,064	40,259	56,805
BW196	91,105	40,259	50,846

was almost the same but there was a little difference because the variety BW196 required more fertilizer than the basmati variety while basmati required more chemicals. In the average profit calculation it was assumed that the average expenditure was similar in the two varieties. From the table above it can be said that though BW196 was more productive than basmati, it had less returns. The difference in profitability was ksh 5,959 per acre. It was also noted that the market demand for basmati was very high compared to BW196. This clearly justifies the reason why 98% of the farmers in mwea region grew basmati rice.

4.1.5 Choice of varieties

Rice farming in Mwea region was the main source of livelihood and the choice of variety greatly depended on the market value of the variety. Out of the 302 farmers interviewed 38 farmers grew BW196 variety but in smaller quantities compared to Basmati370. 98% of the total interviewed farmers grew Basmati370 as the main variety while only 2% grew BW196 as main variety. The other varieties were cultivated in very small portions of land compared to Basmati370 and BW196 varieties (Figure 4.9). All the farmers who grew Basmati370 gave their reason for variety choice as for sale. They usually left a small portion for consumption. This was because Basmatic370 fetches higher market prices compared to the other varieties.

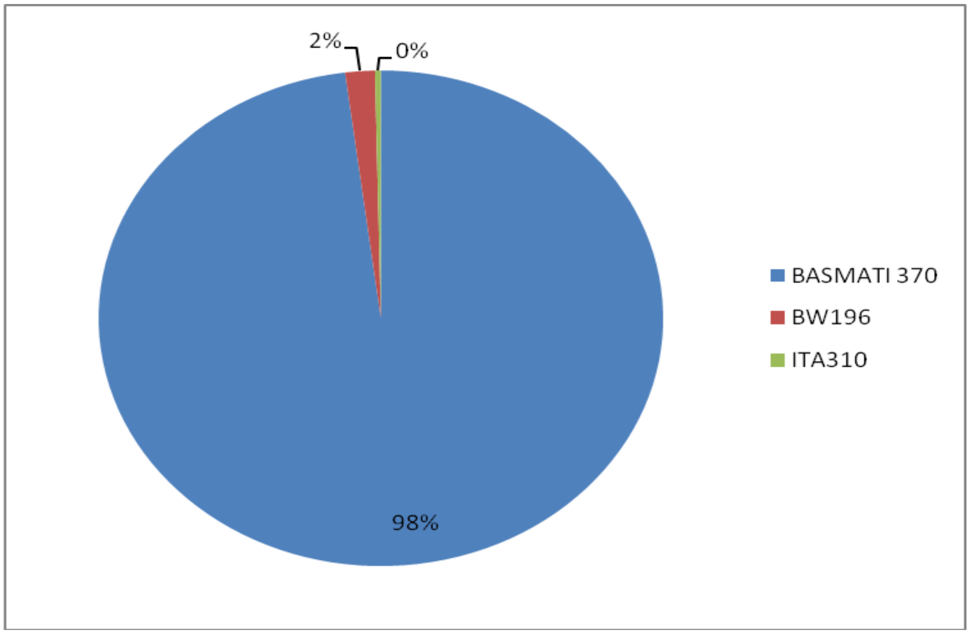

Figure 4. 9: Percentage choice of varieties by the farmers

Table 4.12 illustrates the perceptions of the farmers interviewed on the characteristic attributes to an ideal rice variety for cultivation. These were ranked from the most ideal characteristic to the least. Good prices for sale were the most desired characteristic followed by high yielding. Therefore a method that focuses on getting farmers to adopt a technology just because it is high yielding may not meet the needs of farmers. Good prices for sale is an important factor because most of the farmers carry out rice farming as a commercial enterprise and thus any intervention that will increase the prices will be highly acceptable in the area.

Table 4. 12: Ranking of the rice characteristic preferred by the farmers according to importance

Rank	Rice characteristic
1	Good prices for sale
2	High yielding
3	Early maturity
4	Low input requirement
5	Aroma
6	Good taste
7	Pest and diseases resistance
8	Weed resistant
9	Easy hand threshing
10	Long grains
11	Many tillers
12	Does not brake easily when milling
13	Non sticky when cooked
14	Flood resistance
15	Difficult to shatter when in the field
16	Long shelf life
17	Long plant height
18 (others)	Good ratoon

4.1.6. Farmers perception on rice blast disease

From the research findings almost all the farmers (98%) had awareness and knowledge of rice blast disease (Figure 4.10). Out of the 98% with knowledge and awareness 76% had been affected by the disease, while 24% had never been affected (Figure 4.11). A chi square Test of Independence was performed to examine the relationship between farmers' knowledge on rice blast and rice blast infection. The relationship between these variables was significant, X^2 (1, N = 290) = 6.05, p =.014. Farmers' with knowledge and awareness were less likely to be affected by the rice blast disease than farmers without the disease knowledge and awareness.

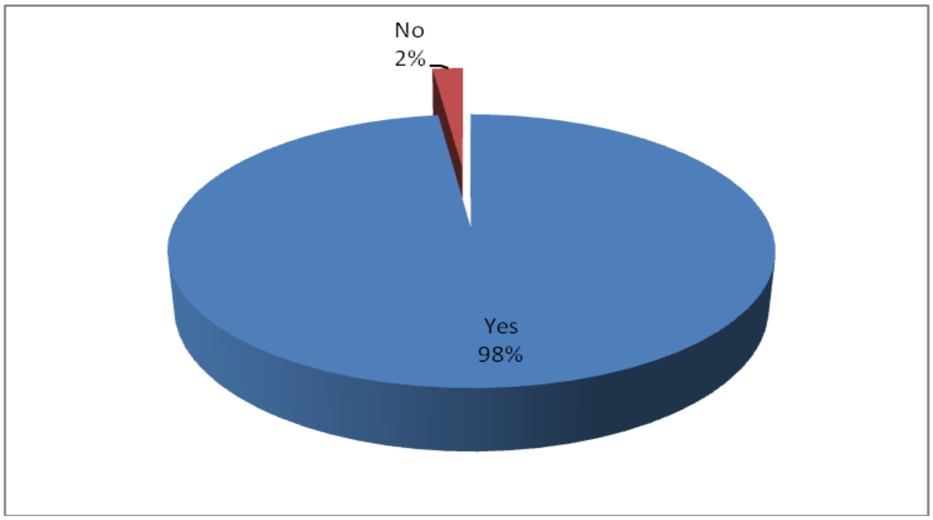

Figure 4. 10: Farmers awareness on rice blast disease

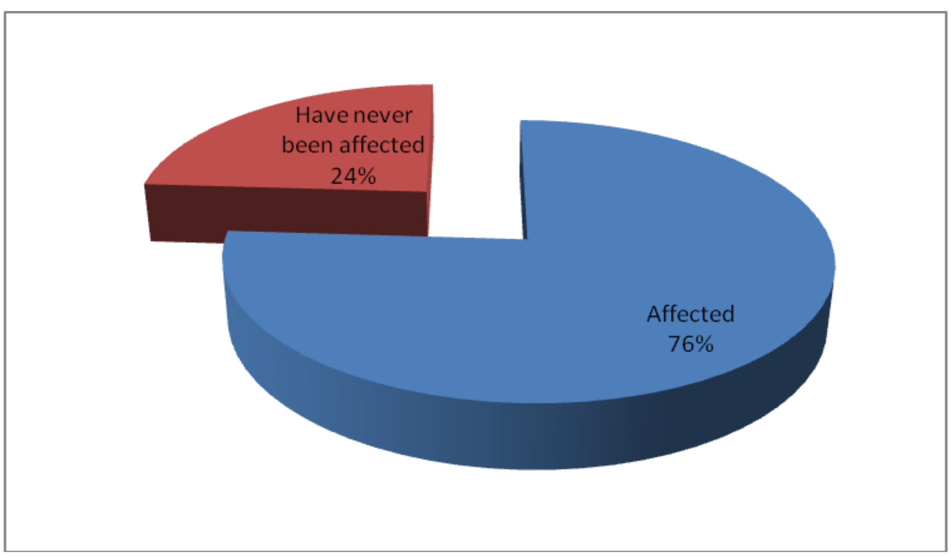

Figure 4. 11: Percentage farmers that have been affected by the rice blast disease

Different local names of the disease were identified but the majority of the farmers 93% still refered the disease as blast, other names were 'kivuruto' and 'mbaa'. Farmers attributed rice blast disease to a range of different causes, including excessive use of nitrogen fertilizer, water shortage, and lack of proper drainage canals and due to climate change. The disease resulted in yield losses as high as 70–80% while predisposing factors (high mean temperature, relative humidity higher than 85–89%, presence of dew, drought stress and excessive nitrogen fertilization) favored epidemic development (Piotti *et al*. 2005). Farmers' knowledge on the type of blast in their farm units was diverse. 52% of the farmers found leaf blast, 42% panicle blast, while 6% and 2% observed neck and stem blast, respectively (Figure 4.12). The way the farmers were able to identify the above mentioned type of blast varied widely. Some of the common answers were; reddish brown spots on leaves, empty panicles, whitish panicles, yellow leaves, black necks and majority indicated that extension workers from MIAD identified the type of blast in their farm units. The fungus *Pyricularia oryzae* attacks at all stages of the crop and symptoms appear on leaves and nodes (Seebold *et al.* 2004).The symptoms are more severe in case of neck blast that is characterized by the infection at the panicle base and its rotting (Bonman *et al.* 1989).

The interviews also revealed that rice blast disease was the most destructive disease compared to other diseases. The farmers mentioned that it was possible to harvest nothing when inffected by the disease. Surprisingly 76% of the farmers had never observed any other disease or pest in their farm while 24% indicated they had been affected by rice blight, leaf miner, stem rot and leaf rust. According to **S**hahijahan *et al* (2010) paddy blast is generally considered as the principal disease of rice. 87% of the farmers were first affected by rice blast in the year 2009 and 7% were first affected by the disease in the year 2010. The rest had earlier realized the disease in the year 2003 to 2008 (Figure 4.13). From the findings the month of October had a high disease prevalence compared to the other months (Figure 4.14).

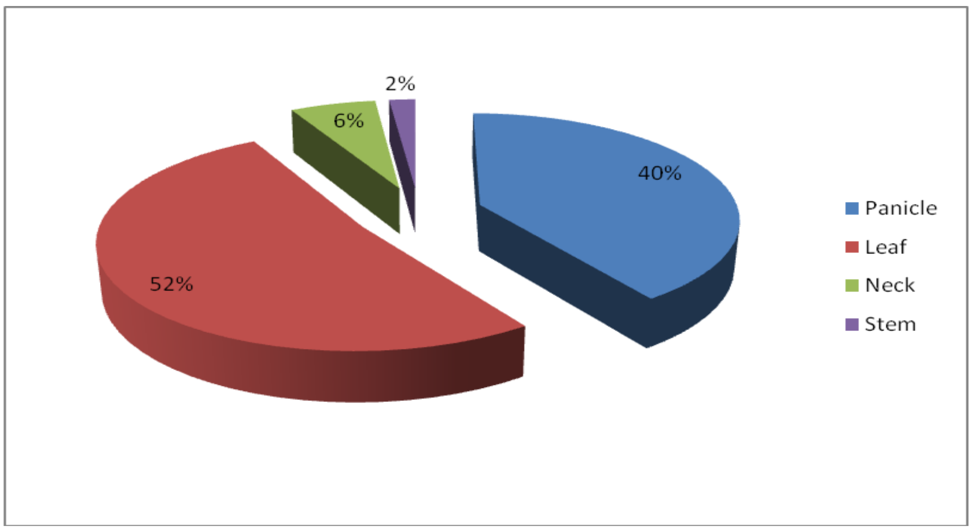

Figure 4. 12: Type of rice blast disease observed in various farm units

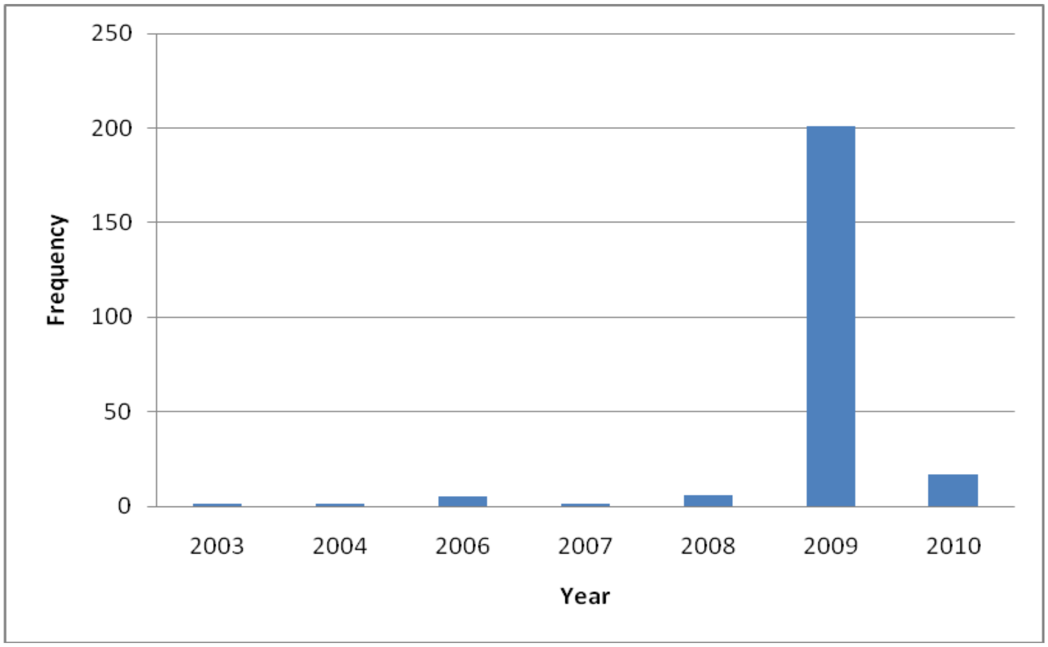

Figure 4. 13: The frequency of incidences of rice blast disease by year

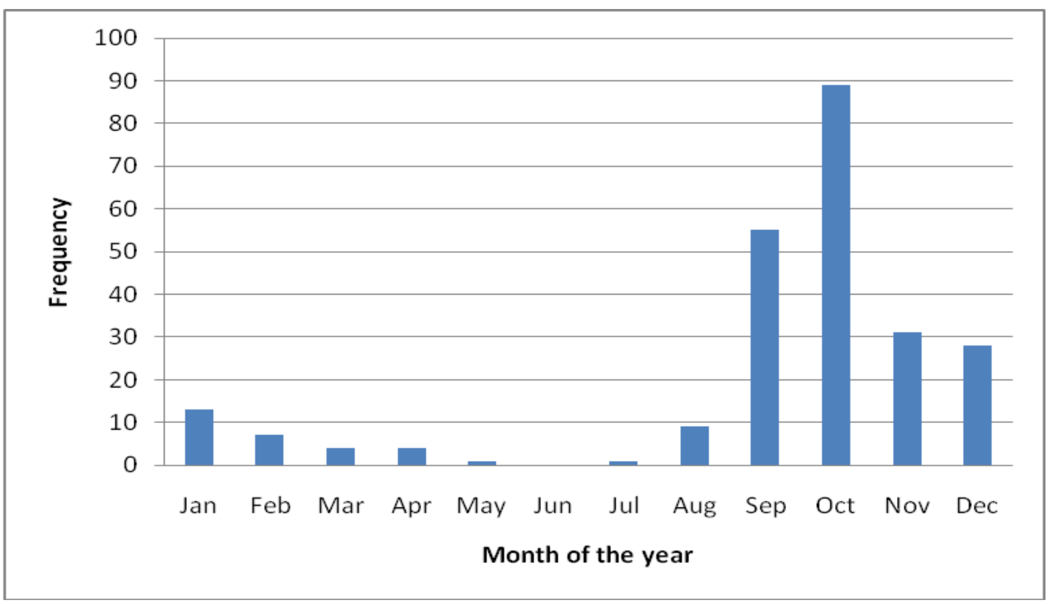

Figure 4. 14: The prevalence of rice blast disease by month of the year

Rice blast disease seems to be a new disease in Mwea region as indicated earlier. The effect of the disease in production has become a concern to the region and also to the nation which rely on this region for production of rice to its population. In this research the progression of rice blast disease in the farm units since the year 2006 to 2010 and its effect to the total production per acre was observed. It was noted that during the year 2009 when rice blast occurrence was at 55.5%, the average number of rice bags (90kg) that were produced in an acre dropped to 10.5 from 21.9 produced in the previous year. This indicated that the total loss in production due to rice blast disease in 2009 was 47.9% compared to the previous year (Table 4.13). In the year 2010 rice blast disease occurrence dropped to 6.2% and the average production in an acre went back to normal. Heavy yield losses have been reported in many rice growing countries. For example 75, 50 and 40 percent grain loss may occur in India (Padmanabhan, 1965), Philippines (Ou, 1985) and Nigeria (Awodera and Esuruoso, 1974). In rice-growing areas, a blast outbreak could cause the loss of about 35–50% of rice yield, and in a serious outbreak of the disease, up to 100% of yield could be lost (WARDA, 1999).

Farmers in Mwea region have three different planting groups. According to the farmers the grouping was done due to the shortage of water. To determine which group you will be allocated depends on the area you are in and when you pay the water charges. It was educative to see how rice blast disease progressed from 2006 to 2010 in various planting groups. It emerged that in the year 2006, 2007, 2008 and 2010 the farmers in the third planting group were the most affected by rice blast followed by farmers in planting groups two and least affected were farmers in planting group one. In 2009, farmers in planting group two were the most affected followed by farmers in planting group three (Figure 4.15).

Table 4. 13: The percentage rice blast occurrence and the average production in an acre

Year	% rice blast occurrence	Bags (90kg) produced in an acre
2006	6.8	22.9
2007	6.3	22.2
2008	9.7	21.9
2009	55.5	10.5
2010	6.2	22.4

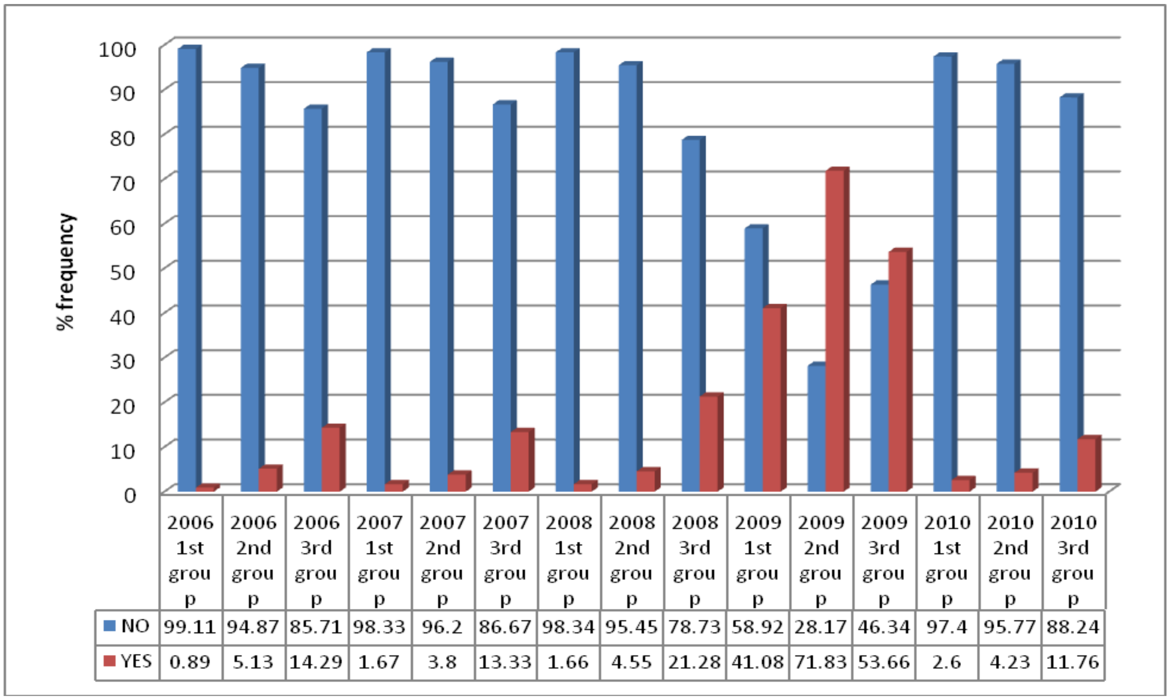

Figure 4. 15: Percentage rice blast incidences in the various planting groups from 2006 to 2010.

Various rice varieties are usually susceptible to rice blast disease. From this study 97% of the farmers interviewed indicated that Basmati370 was highly susceptible to rice blast disease. It was also noted that BW196 according to the survey was resistant to the disease. Only 2% of the respondents were of the opinion that the variety was susceptible (Figure 4.16). In the earlier discussion farmers mostly considered the variety that would fetch good market prices and thus they preferred growing Basmati370 that was highly susceptible to the disease than a resistant variety such as BW196. In China with the incorporation of resistance genes, rice blast is no longer a serious problem for the widely grown hybrid indica Rice. However, it has remained a serious problem for glutinous rice (32% losses), japonica rice (5-12% losses) and upland rice (losses could reach to 20-50%) (Youyong *et al.* 2000).

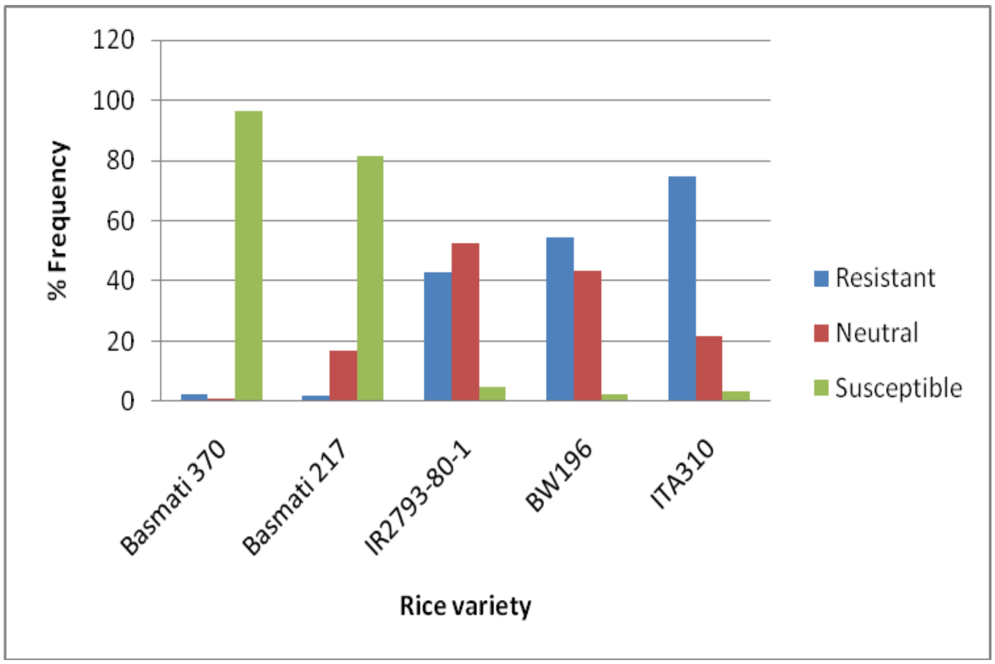

Figure 4.16: Rice blast disease susceptibility level among various rice varieties.

4.1.7. Control strategies used by farmers against rice blast disease and factors influencing them

A range of different methods had been tried by the respondents in their attempts to control rice blast disease and with some measures of success. These included: burning diseased-straw and stubble (3%), chemical use (82%), abandon field (1%). Split applications of nitrogenous fertilizer and use of resistance varieties were strategies that had less than 1% usage (Table 4.14). However, by the time of the surveys, majority of rice farmers (86%) had abandoned attempts at controlling rice blast disease using the aforementioned methods because they were found to be ineffective. A few (4%) indicated that the control methods were too expensive and laborious given the rate of infection of the rice, and households did not have enough labour to carry them out. Farmers considered that hired labour was too expensive. Only 8% of the farmers who were using chemicals thought the method worked very well (Table 4.15). Of the farmers who were not practicing any control method 37%, indicated that they had not been affected by the disease. In China farmers growing susceptible varieties use fungicide to control blast, making as many as three to eight spray applications per season (Li Jiarui, 1994). The use of resistant varieties is the most economic and effective way of controlling rice blast, especially in resource-poor farmers' fields (Séré *et al.* 2011). Therefore considerable effort should be directed toward developing and identifying blast-resistant cultivars in order to provide farmers with low-cost blast management.

A chi square test of independence was used to analyze the data with rice blast disease infection as one variable and the control methods as the second variable. There was a significant effect, X^2 (5, N= 299) =202.32, p = .001. Whether to control or not was influenced by the education of the farmer and the current income from rice. Farmers with a higher income from rice were more likely to attempt methods of controlling rice blast disease than farmers earning a lower income from rice. Surprisingly, however, farmers with higher levels of education were less likely to control the disease than farmers with lower levels of education ($p < 0.01$). This is perhaps because higher education is associated with greater opportunities for generating alternative sources of income, and as such, those farmers who are more highly educated, may have opted to diversify to other sources of income rather than attempt to control rice blast disease.

Most farmers surveyed obtained information on control strategies either from extension workers 50%, fellow farmers 23% or from training workshop 20%. A smaller number received information from visiting researchers 3% and from the local leaders 2% (Table 4.16). This indicated that farmers prefered to get their information through some form of personal contact. Kenya Agricultural Research Institute (KARI) has focused on rice research while the Ministry of Agriculture provides extension service. KARI and its partners have the capacity to conduct rice adaptability trials. The scientists based at research institutions have experience in rice breeding, agronomy, crop protection and socio-economics (NRDS Government of Kenya, 2009).

Table 4.14: Percent usage of various rice blast control methods

Control method	Frequency	Percentage
Burning diseased-straw and stubble	8	3
Use of resistance strains	1	0
Chemical use	218	82
Apply compost	0	0
Avoid farm activities when plants are wet	0	0
Abandon field	2	1
Split applications of nitrogenous fertilizer	1	0
Others (Not using any control method)	37	14

Table 4.15: Farmers perception on how the use of chemical to control rice blast disease worked

Perception of the method	Frequency	Percentage
Worked very well	19	8
Worked satisfactorily	57	24
Worked - but not well	101	43
Did not work	56	24
I don't know	4	2

Table 4.16: Farmers source of advice on the appropriate method of rice blast disease control

Source of advice	Frequency	Percentage
Fellow farmers	54	23
Extension workers	119	50
Training workshops	47	20
Radio	0	0
Local leaders	5	2
Visiting researchers	7	3
Newspaper/pamphlet	0	0
Others	4	2

From the analysis the brand names of chemicals being used by the farmers were; Topsin, Goldazim, Rodazim and Bavastin. These chemicals were readily available in the market and most of the extension officers from MIAD/NIB trained the farmers on how to use these chemicals. In 2009 when the area was highly affected by the disease the government through NIB provided some of these fungicides to the farmers free of charge. It again emerged that MIAD/NIB were the main source of advice to the farmers on the products to use (Figure 4.17)

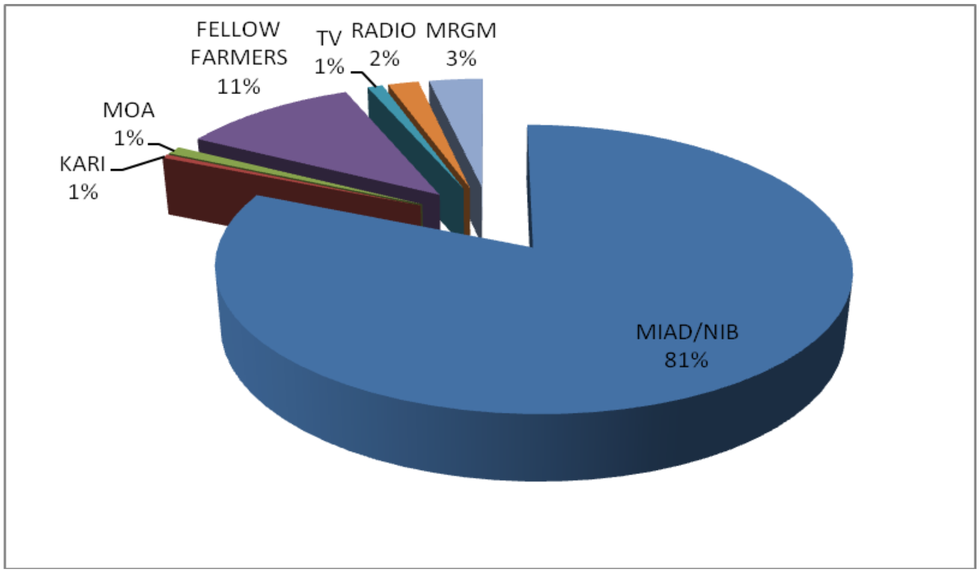

Figure 4.17: Farmers source of advice on which product to use in controlling rice blast disease

It was surprisingly to note that 51% of the farmers interviewed were of the opinion that no group/institution was carrying out any research activity in tackling rice blast disease. 49% of the farmers with the knowledge of a group/institution indicated that MIAD/NIB led the list with 93% in trying to tackle the disease, Ministry of agriculture followed with 4%, farmers group with 3% while KARI, Agrovets and MRGM with 1% each (Figure 4.18).

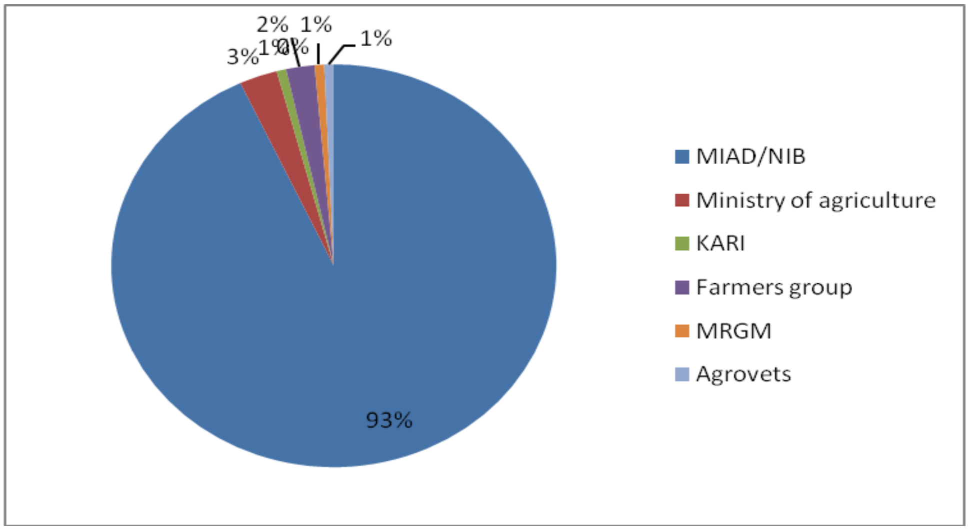

Figure 4. 18: The role of Group/Institution helping farmers in tackling rice blast disease

Majority of the farmers interviewed (72%) did not engage themselves in any other socio-economic activity even after being affected by the rice blast disease. 15% opted to growing horticultural crops, 7% engaged in trading activities while 2% started livestock rearing, wage earning and Boda boda business (Table 4.17).

Due to the loss of produce by the rice blast disease, 74% of the farmers liquidated their assets to meet other needs (Table 4.18). 37% of those farmers liquidated their assets to cater for school fees, 34% for domestic use e.g. purchasing of food stuff, 22% for buying farm inputs for the next planting seasons, 4% for paying debts/loans obtained to facilitate farming activities, while only one farmer liquidated her assets to start a grocery business in Mwea town. A chi-square test was performed and no relationship was found between economic status of the farmers and the rice blast disease infection, X^2 (2, N = 302) = 0.89, p =.64.

Table 4. 17: Other socio-economic activities introduced as a result of rice blast disease

Activity	No. of farmers	Percentage
No activities introduced	216	72
Growing other horticultural crops	44	15
Livestock rearing	7	2
Boda boda business	5	2
Trade	22	7
Wage earner	5	2

Table 4. 18: Assets type and value per year liquidated due to the effect of rice blast disease

No.	Asset type	No. of farmers	Value per annum (Ksh)
1	Land	4	280,000
2	Tractor	1	800,000
3	Motor vehicle	2	220,000
4	Motor cycle	1	50,000
5	Ox cart	2	20,000
6	Ox plough	1	3,000
7	Livestock	71	20,650
8	Trees	1	1,000

4.2. Rice blast disease mapping

During the survey the farmers were spatially sampled within the study area. The sample size was geographically representative of the study area. The farmers were asked whether they had been affected by rice blast disease (Table 4.19) and the total production per acreage. Rice blast effect on production for the year 2009 was used to produce the density map of rice blast disease in Mwea region. The reason for the use of year 2009 was because rice blast disease was highly recorded in the area during that year and was the main contributor of yield loss.

Table 4. 19: Geographically referenced and frequency of farm units affected by rice blast disease among the sampled farmers in the study area

Rice blast occurrence in the farm units	No. of farmers	Percentage
Have been affected by rice blast	226	76.09
Have never been affected by rice blast	71	23.91

Figure 4.19 shows the rice blast disease cases created and pointed with point symbol on the Mwea region map. The GPS points were interpolated to create a geographical distribution map of rice blast disease (Figure 4.20). Interpolation is a way to make a SWAG (Scientific Wild Ass Guess) and is common in biological studies and in studies of disease where samples are infrequent and randomly placed. A simple interpolation method called IDW (Inverse Distance Weighting) was applied. The "inverse" part comes from the first law of Geography; more distant things are less likely to be related than close things. IDW estimates cells value by averaging the values of sample data points in the vicinity of each cell. The closer a point is to the center of the cell being estimated, the more influenced, or weight, it has in the averaging process. This method assumes that the variable being mapped decreases in influence with distance from its sampled location (Lukaszyk, 2003).

To create the density map of rice blast disease within Mwea region, the production per acre by the farmers was linked to the GPS points and interpolated using ArcGIS 10

(Figure 4.21**).** In this analysis an assumption was made that the rate of production per acre is directly influenced by the intensity of rice blast disease. An objective scale was developed, this scale was used to measure the preference from worst to best which was based on rice production in the farm units. Having the information from the survey analysis that an average production per acre was normally 21.7 bags (90kg) a disease density scale was developed as shown in (Table 4.20**)**. The scale was used to reclassify the interpolated map and a disease density map was created (figure 4.22).

Table 4. 20: Rice blast disease density scale as per total acreage production

Rice production in 90kgs bags per acre	**Rice blast disease density scale**
0-4	Very high density
4.1-8.0	High density
8.1-12.0	Moderately high density
12.1-16.0	High density
16.1-20.0	Moderately low density
20.1-24.0	Low density
24.1- above	Very low density

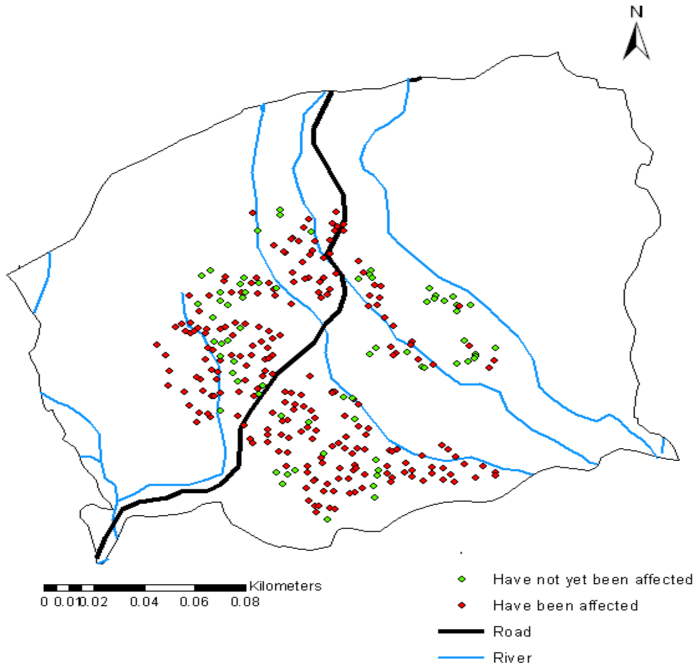

Figure 4. 19: Mwea map showing location of the sampled farm units and cases of rice blast disease

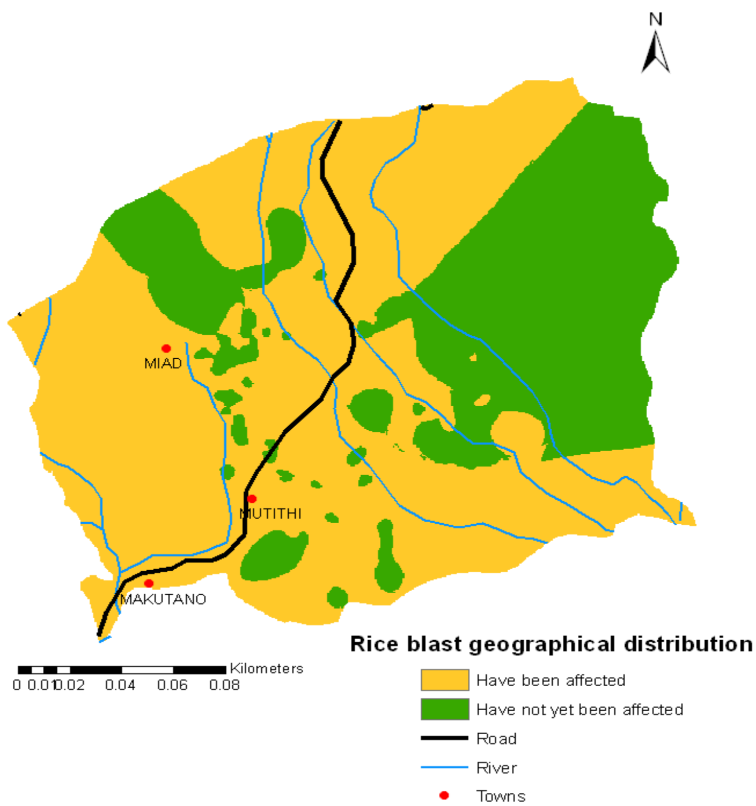

Figure 4. 20: Geographical distribution of rice blast disease in Mwea region

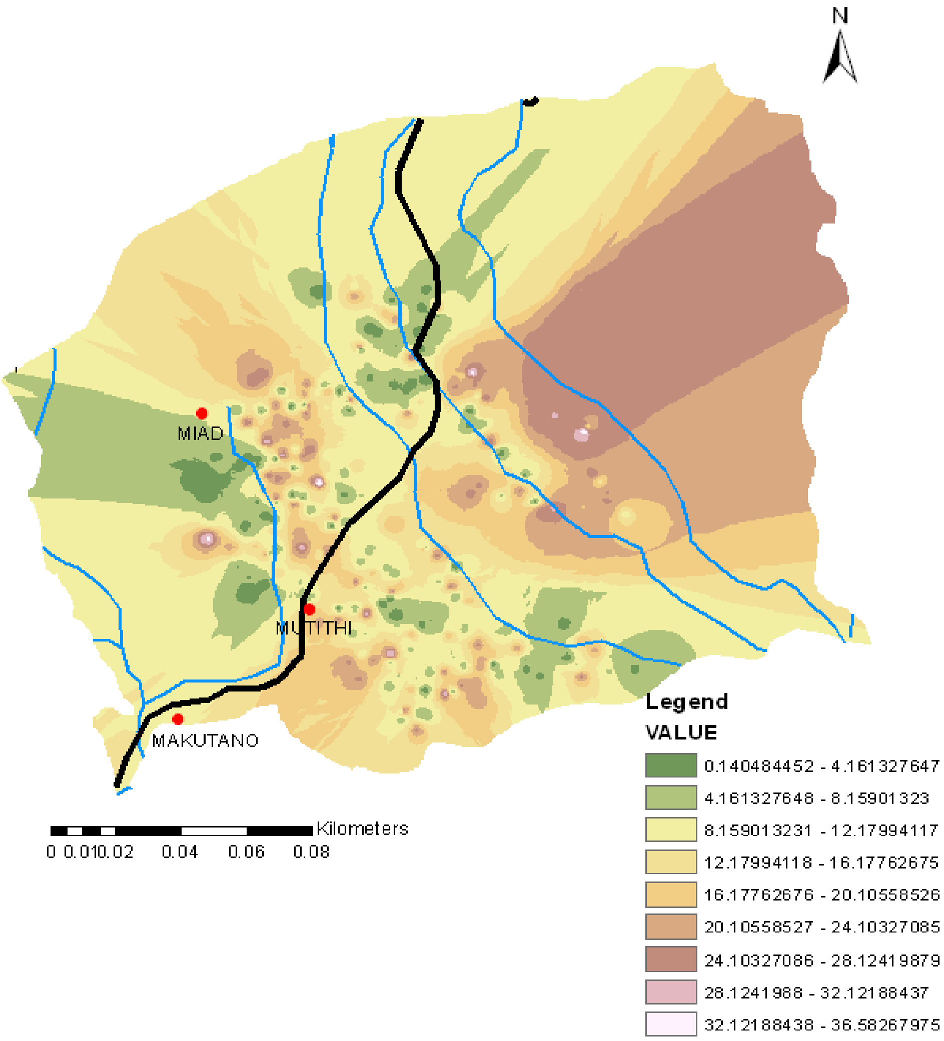

Figure 4. 21: Rice blast disease density out put

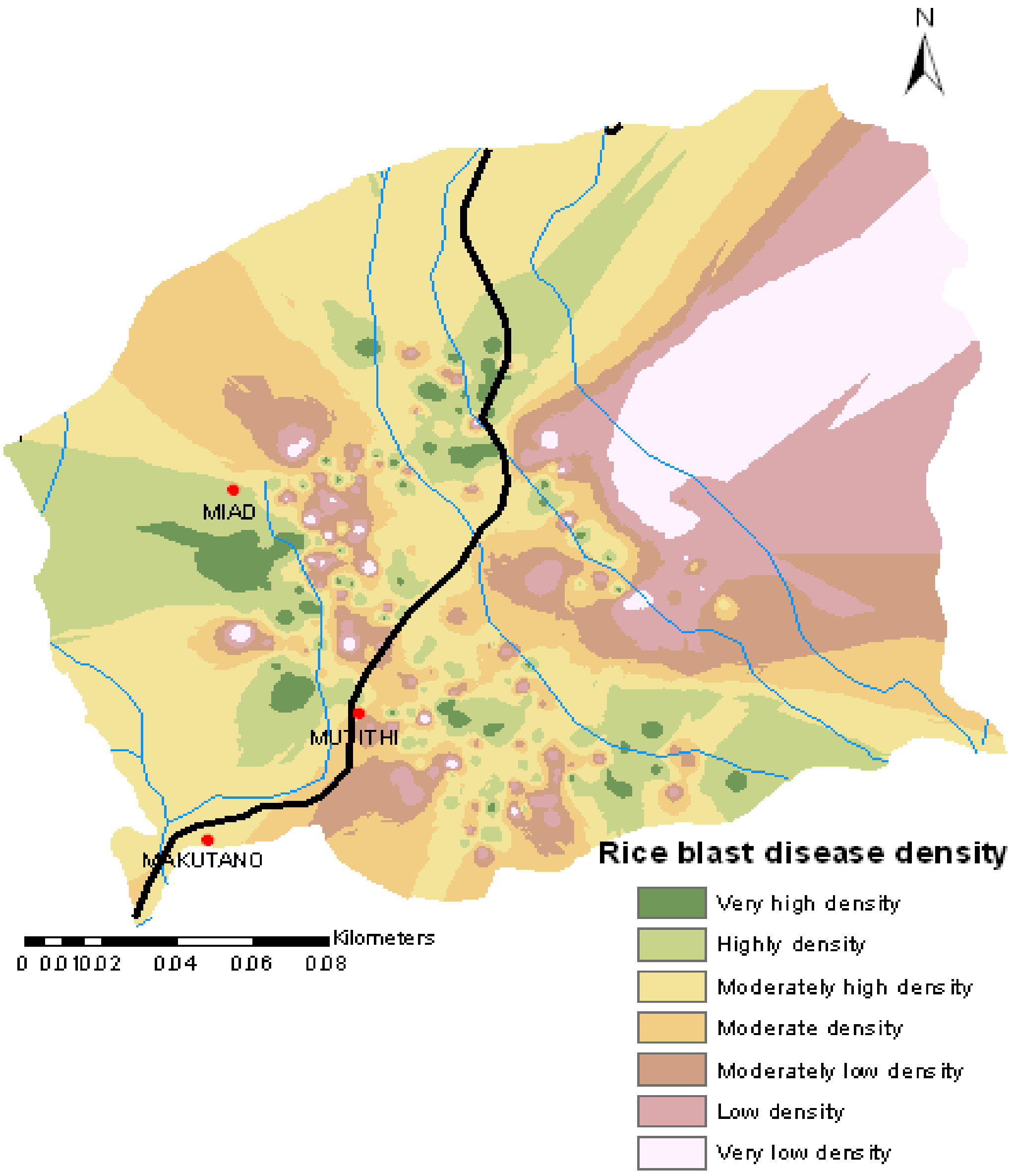

Figure 4. 22: Rice blast disease density

The statistical maps (Figure 4.22) shows rice blast disease density and its geographical distribution in the study area. Interpolation was done between the sample points to obtain and predict value for unknown locations. The results indicated that 33.4% of the study area had a moderately high density and only 13.7% of the study area was under very low density.

4.3 Suitability map for rice crop

The suitability map for rice crop, identified by weighted overlay using spatial analyst tools in ArcGIS 9.3, is shown in (Figure 4.23). The number of hectares available to each suitability class was as follows: highly suitable (S1) 105,769 ha, moderately suitable (S2) 203,259 ha, marginally suitable (S3) 61,588 ha and not suitable (N) 57,723 ha which represent 24.69%, 47.45%, 14.39% and 13.48% of land area, respectively. The results showed that highly suitable areas (S1) were found mostly in areas under current rice growing. These S1 areas were characterized by: slope level of 0-2%, soil pH level between 5.6 to 7.3, soil drainage imperfectly drained, texture class clay, humidity levels >80 and temperatures between 22-30^{0}C; these values are in agreement with those considered in the literature. Generally not suitable areas (N) were located in mountainous areas with slope level >50%.

According to a related study in the Tana delta, Kuria *et al.* (2011), found the number of hectares available to each suitability class in the Tana delta area to be distributed as follows: 67% is highly to moderately suitable, 14% is moderately suitable, and 10% is marginally suitable. About 9% of the study area classified as Eutric Fluvisol was found to be currently unsuitable for rice cultivation, due to some limitation factors such as partly sandy clay texture, saline, low water retention, and high hydraulic conductivity. Dengiz (2013) did a similar study in Çankırı-Kızılırmak district in the Central Anatolian region of Turkey and found that the land highly and moderately suitable for rice cropping covered an area of about 837.3ha (55.5%). Of the study area, 34% was unsuitable for rice, and those areas corresponded to adverse soil physical and chemical properties.

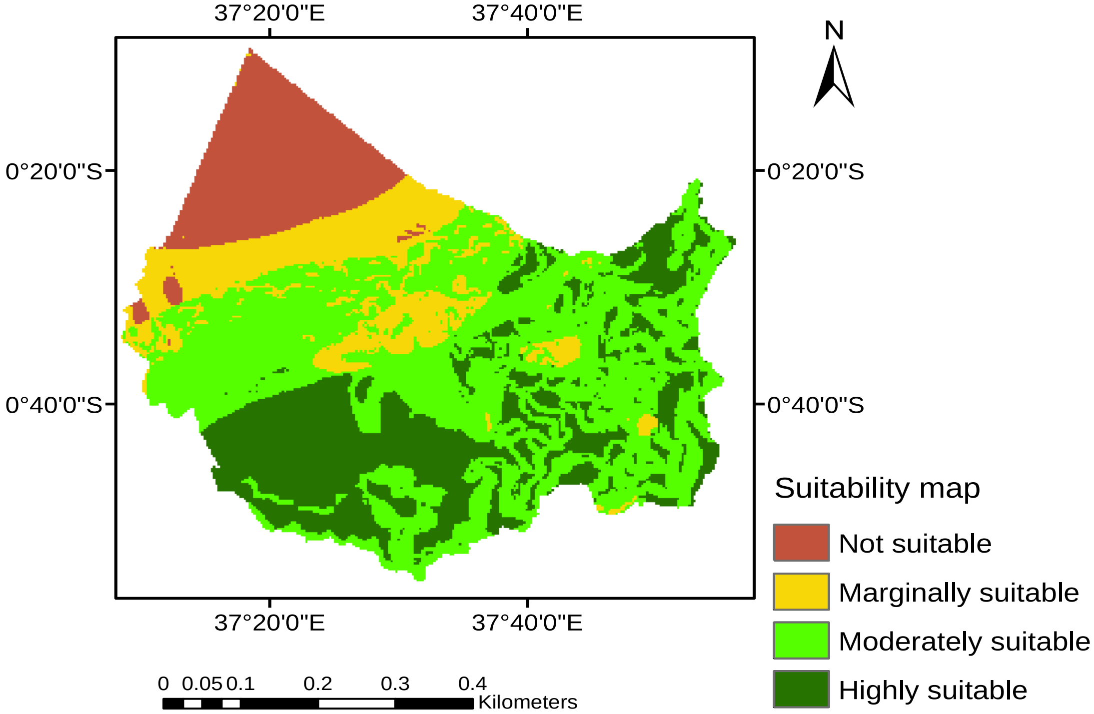

Figure 4. 23: Rice crop suitability map for Mwea region

4.4 Present land use under rice cultivation

Figure 4.24, shows 10 land use/cover types, within the study area. The rice cultivated area included both the outgrowers blocks and the scheme area. The game reserves and the Mount Kenya forest was classified under protected areas. The total area under rice growing area was 13,369 ha.

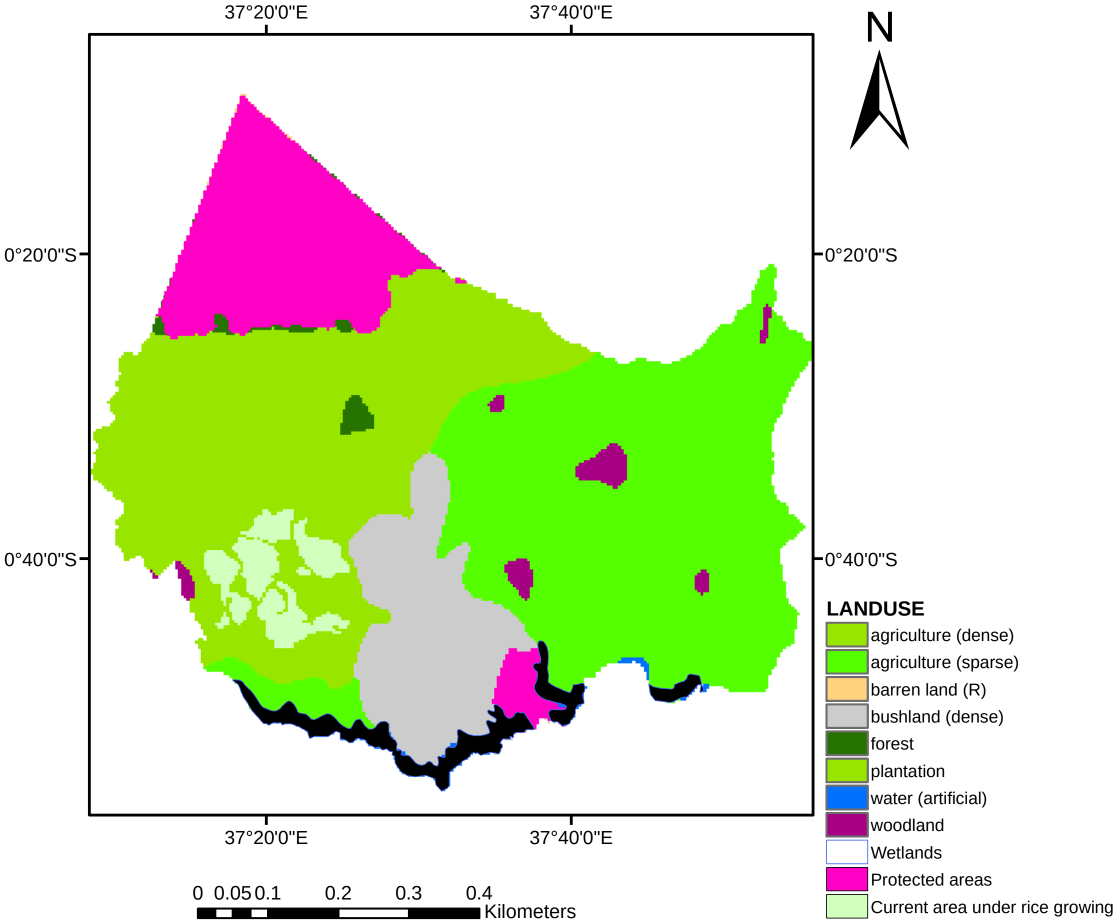

Figure 4. 24: The current land use/cover map of the study area.

4.5 Overlay present land use/cover

To improve the results, the current land use/cover map (Figure 4.24) and the suitability map for rice (Figure 4.23) were overlaid to identify differences and similarities between the present land use and the potential land use for the rice crop. This was done because of the identification and accurate description of current and potential production areas are essential for research and agricultural development (Corbett, 1996). The potential area map for rice growing after the overlay was presented in (Figure 4.25). The total potential areas for rice production was 86,364 ha (Table 4.21).

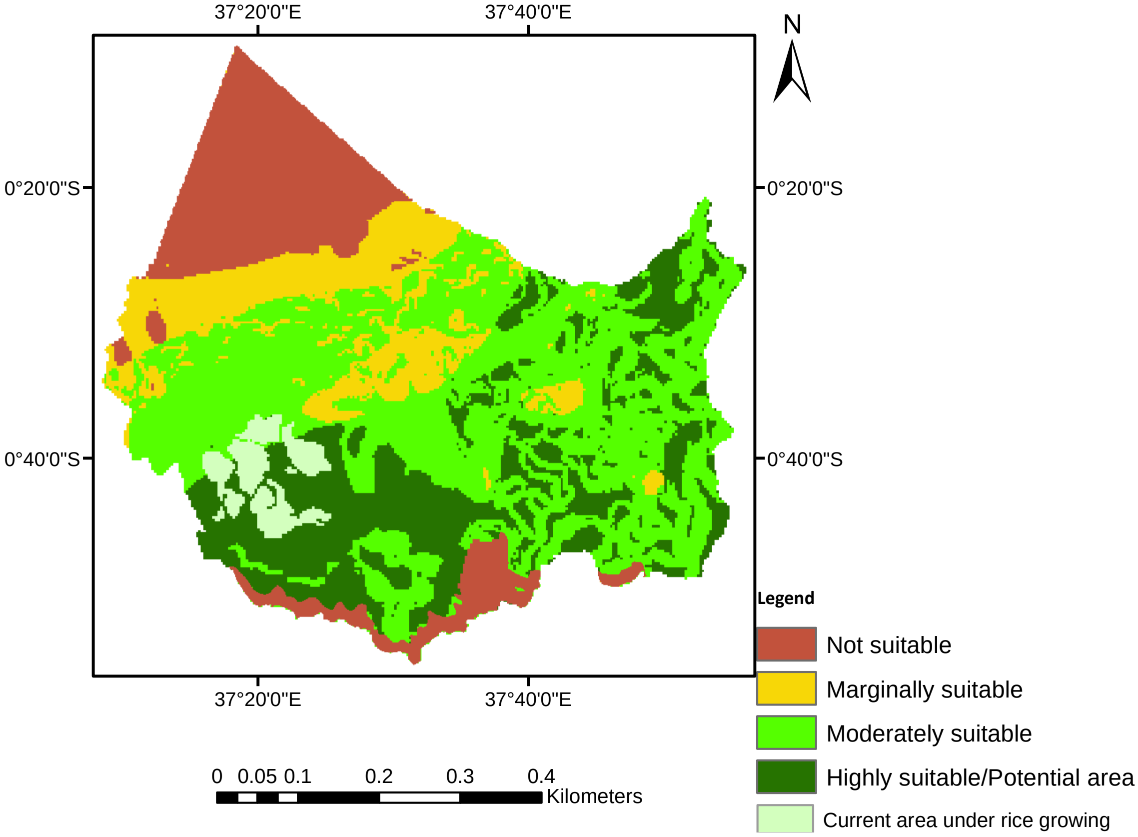

Figure 4.25: Map showing potential areas for rice growing based on current land use / cover map

According to the present land use/cover map (Figure 4.5), the area cultivated with rice was 13,369 ha. The proportion of current rice production areas within the identified suitable areas is shown in Table 4.22. The analysis revealed that in the study area, 23.08% (3,011 ha) of total rice crop was under moderately suitable areas and 77.92% (10,036 ha) was under highly suitable areas. Thus, the average yield of the study area was highly effective since no areas were under the other two classes of marginally and not suitable areas. Therefore, economic levels of agricultural production can be achieved by (a) cultivating rice crop in highly (S1) and moderately (S2) suitable areas, (b) diversification of marginally (S3) suitable areas to crops other than rice that are more suitable in the pedo-climatic requirements.

Table 4. 21: Total potential area for rice growing

	Areas (Ha)
Suitable area for rice growing	105,769
Area under rice growing	13,369
Potential area for rice growing	86,364

Table 4. 22: Proportion of current rice production areas within the identified suitable areas

Suitability class	**Areas (Ha)**	**Proportion (%)**
Moderately suitable	3,011	23.08
Highly suitable	10,036	76.92

In this study, spatial analysis techniques was applied to identify suitable areas for rice crop. The results obtained from this study indicate that the use of GIS and application of Multi-Criteria Evaluation using AHP could provide a superior database and guide map for decision makers considering crop substitution in order to achieve better agricultural production. This approach has been used in some studies in other countries. However, in Kenya this approach has not been widely used in agricultural applications to identify suitable areas for rice crop. The study clearly brought out the spatial distribution of rice crop derived from digitizing data in conjunction with evaluation of biophysical variables of soil and topographic information in GIS context. This is helpful in crop management options for intensification or diversification.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study demonstrated that rice blast disease had a negative effect on the economic status of the people in Mwea region. The farmers indicated that in some seasons they harvested nothing due to rice blast disease. This led to the disposal of some of their assets to meet their needs and even some famers shifted from rice growing for other activities like trade (7%) and growing horticultural produce (15%) which in their opinion had better returns. Farmers who were economically well up, had an upper hand in controlling the disease because they were in a position to acquire the fungicides and reduce the infection. The disease seemed to affect every farmer equally despite their level of education or age.

Rice blast disease was ranked by the farmers as the most destructive disease (98%) compared to all the other rice diseases in the region (2%). According to the farmers the main cause of the disease was the use of excessive nitrogen fertilizer (58%). In a study conducted in Suakoko, Liberia, with 16 rice cultivars, the incidence of the blast increased when nitrogen was increased from 60kg N to 120kg N ha^{-1} (Awoderu, 1983). This indicates the risk of excessive use of nitrogen fertilizers. This is due probably to the injurious effect of ammonium accumulation in the cells of the plants treated with high nitrogen. The soluble nitrogen in the plants may serve as suitable nutrients for fungus growth (Ou, 1985).

The statistical maps displaying rice blast disease density and its geographical distribution in the study area were produced through interpolation. Interpolation was done between the sample points to obtain and predict value for unknown locations. The results indicated that 33.4% of the study area had a moderately high density and only 13.7% of the study area was under very low density.

The survey indicated that 58% of the farmers were of the opinion that their livelihood was getting worse. Although we can't argue on this trend in the absence of any previous baseline survey, it could safely be said that there were not as many cars (24), motorbikes (72), T.V. (238), mobile phones (699), etc. as in ten years ago. As per the eating habit and dish contents, their life condition may be considered well up. However, it could be assumed that the uses of the assets mentioned above require daily running costs and this accelerates obsession for more income. The need for higher income may lead to declining sense of livelihood, but must be highly appreciated because it may lead to higher production.

The main aim of land suitability analysis was to identify the suitable land parcels for growing rice in counties of Embu and Kirinyaga. Integrating MCE with GIS for spatial decision making process was an important technique. The parameters used for the evaluation of land suitability for rice growing were soil (drainage, texture and pH), temperature, slope, humidity and land use/ land cover.

The larger portion of the soils of the study area had a pH between 5.6 and 7.3 which accounts for 60%. Clay and clay loam soils were the dominant textural classes in the study area with area coverage of 85.9% and 14.1%, respectively. Furthermore, well and moderately well drained drainage classes accounted for about 81.8% and 6.4%, respectively. The study disclosed that, a larger portion of the study area fell under the slope classes class 0-2% and 2-5%, which covered 24.3% and 21.7% of the total area, respectively.

The weighted overlay analysis result for temperature indicated that 55.6% of the study area had very high suitability for rice growing. However, a larger portion of the study area was classified as having moderately low suitability for rice growing in terms of humidity which accounts for 28%.

According to the present land cover map, the rice cultivated area was 13,369 ha which included the outgrowers surrounding the irrigation scheme. The suitability analysis indicated that 75% of the study area currently being used was under highly suitable areas and 25% was under moderately suitable areas. The overall suitability analysis indicated that 24.69% of the study area was suitable for rice growing, 47.45% was moderately suitable, 14.38% marginally suitable and 13.48% was not suitable for rice growing. The potential area for rice growing was 86,364 ha accounting for 23.4% of the study area and out of this only 12% was currently under rice cultivation.

5.2 Recommendations

It is urgently recommended that there is need to minimize the impact on the rice blast disease. More research is needed to establish an effective level of nitrogen fertilizer in the management of the rice blast disease. The current emphasis on rice blast disease should be how to control the disease. Therefore, emphasis should be in developing rice cultivars with adequate levels of resistance/tolerance to the disease. Sound crop management practices would also go a long way to minimize the losses caused by the pathogen in Mwea region. Future directions for rice blast research and control in a hitherto low to moderate input production system in Mwea should focus on the development of sound and practical intergrated management programs for the disease and studying the effect of changing cropping practices on disease incidence/intensity (Fomba and Taylor 1994). Moreover there is need to conduct more studies on the genetic resistance and collate of farmers' indigenous knowledge and skills in the management of rice blast and other disease/pests.

Also important is the result of suitability evaluation must be brought into the reach of rice growers. Multidimensional approach of present research has put a number of recommendations forward to the stakeholders as follows.

(1) It is important to create the soil databases and land information system, including soil types, soil fertility, terrain, current land use status, climate, slope, soil erosion, land unit map. The database system should be created on the GIS software, allowing users to access, edit, update, overlay and analyze to create a new map which meets the requirements of the study problem. Application of other information sources like remote sensing images, Global Positioning System (GPS), etc should be encourage because it will help on bringing real time change in land use and management strategy.

(2) The model of present research work must be applied to determine land evaluation for other agricultural crops as well. Fundamental aspect of the research is

feasible in context of Mwea however, flexibility on selection of the criteria and sub-criteria for different crops and in other geographical locations should be offered. During the period of data collection, we encountered the necessity of soil improvement and soil protection for sustainable agricultural productivity. Soil management measure is also necessary tool for the farmers to harness potentiality of the land because of reduced fertility.

(3) Finally the outcome of the research need to be disseminated among local rice farmers and enable them understand about capacity and limitation in range of suitability of their farm holding. Land parcel use potential, limitations prevail and management measure should clearly be conveyed to land users, so that the real use of research will be seen.

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APPENDICES

Appendix 1: Sample form of Mwea baseline socio-economic questionnaire survey for Rice blast disease.
MWEA BASELINE SOCIO-ECONOMIC QUESTIONNAIRE SURVEY FOR RICE BLAST DISEASE.

Date of interview Date:________ Month:____________ Year:_____________ Interviewed by______________________________________

Date checked Date:________ Month:____________ Year:______________ Checked by__________________________________

Date entered Date:________ Month:____________ Year:_____________ Entered by___________________________________

Household Head Name:____ Household ID: ____________(assigned in advance)

District: _______________________________ Code: ______________ (assigned in advance)

Village: _______________________________ Code: ______________ (assigned in advance)

Division: ______________________________ Location: ___________________________

Sub-location: __________________________ Village: ____________________________

Block______________________________ Unit_______________________________________

Farm no_____________________________ Out grower area______________________________

Respondents Name:____

Contact (mobile phone number):____

GPS measurement
At the respondent's rice field (farm):
GPS Number:_Latitude: N ° ' "; Longitude: W ° ' "
Record Number:_____; Date and Time_____; Elevation: __m

1. Demography (August 2010 – July 2011)

A “household” includes all members of a common decision making unit (usually within one residence) that are sharing income and other resources. Members are those who were born to but should not have independent decision making unit apart from this household. Also include workers or servants as members of the household if they stayed in this household at least one month in the last 12 months. Use an extra sheet if necessary.

Person ID	Name	Sex 1=M 2=F	Age in years	Relation to head: See Code below	Marital status: See Code below	Highest grade completed See Code Sheet	Still in school now? 1=yes 2= no	Engaged in off-farm activities in the last 12 months? 1=Yes, 2=No		Number of months living at home in the last 12 months?	If less than 12 months (**D9<12**), why? See Code below
								Self-employment (business or self-employment activities)	Employment (salaried employment, paid farm labour, or other casual/wage labour)		
ID	**Name**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											

2. Land Tenure

Make sure to include all the parcels owned/operated (owned-and-operated, owned-but-not-operated, and not-owned-but-operated parcels) by the HH.

Unit No.	Tenure system See Code below	If LT1=1 (title deed), who owns the title deed? See Code below	How did this household acquire this parcel? See Code below	Year of acquisition?	If **LT6=2 (rented-in) or LT3=1 (rented-out)**					If you were to buy/rent-in this parcel w/o homestead**,**	
					Lease period in 2009 1=main season only 2=short season only 3=annual	How much Ksh did you pay to the land owner or receive from the tenant?	How many years have been renting-in/out this parcel continuously?	Relation with land owner/tenant 1=relative 2=friend 3=neighbor 4=other (specify)	Residence of land owner/tenant 1=same sub-location 2=same location 3=other	How much are you willing to pay to buy?	How much are you willing to pay to rent-in per season?
PNO	**LT1**	**LT2**	**LT3**	**LT4**	**LT5**	**LT6**	**LT7**	**LT8**	**LT9**	**LT10**	**LT11**
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											

Code for LT4:
1=title deed
2=owned but not titled (e.g., settlement scheme)
3=leasehold
4=government land/forest/road reserves
5=rented-in
6=other (specify)

Code for LT5:
1=HH head
2=spouse
3=head's parents
4=deceased husband
5=deceased parents
6=other relatives
7=seller
8=other (specify)

Code for LT6:
1=purchased
2=rented-in for fixed payment
3=received as gift
4=received as inheritance
5=borrowing from relatives
6=sharecropping-in
7=just walk-in
8=other (specify)

3. Rice production

(a) How long have you been in rice farming?_______________years
(b) What is the size of your farm? .... acres
(c) Total land planted with rice during the last planting season ____________________ acres

(d) Characteristics of Plots for Rice Production in 2010 cropping Season

Unit No.	Plot Facilities								Plot use in previous years				If rice was grown continuously since 2006, for how many years has rice been grown in this plot continuously?	After 2011, for how many years will the same plot be used rice cultivation continuously? If it is unknown, put 99.
	Bund		Leveling		Water Supply Canal		Drainage Canal							
	Is the plot bunded? See Code below	If Yes bunded (1 or 2), who constructed it? See Code below	Is the plot leveled? 1=Yes 2=No	If 1=Yes leveled, who did it? See Code below	Is the plot equipped with water supply canals? 1=Yes 2=No	If 1=Yes, who constructed it? See Code below	Is the plot equipped with drainage canals? 1=Yes 2=No	If 1=Yes, who constructed it? See Code below	2009 See Code below	2008 See Code below	2007 See Code below	2006 See Code below		
LID	**RT1**	**RT2**	**RT3**	**RT4**	**RT5**	**RT6**	**RT7**	**RT8**	**RT9**	**RT10**	**RT11**	**RT12**	**RT13**	**RT14**

Code for RT1
1=Yes, big bund
2=Yes, mini bund
3=No

Code for RT2, RT4, RT6, and RT8
1=NIB
2=Cultivator him/herself
3=A farmer other than the current cultivator
4=JICA
5=others

Code for RT9, RT10, RT11, and RT12
1=fallow
2=virgin land
3=grazing
4=maize
5=rice
6=cereals other than maize/rice
7=legumes
8=root/tuber
9=vegetables
10=fruits
11=banana
12=other crop (specify)

(e) Land Preparation and Sowing for <u>Rice Production</u> in 2010 cropping season

Name of the rice variety	Unit ID	**Ploughing**		**Harrowing before sowing**		**Soil-covering after sowing**		**Plot Maintenance at the beginning of cropping season 2010**						**Sowing/Planting**	
		Did you plough before sowing? See code below	If 4=by tractor, how much Ksh did you pay for it?	Did you harrow before sowing? See code below	If 4=by tractor, how much Ksh did you pay for it?	Did you harrow before sowing? See code below	If 4=by tractor, how much Ksh did you pay for it?	Bund		Water Supply Canal		Drainage Canal		How did you sow? 1=broadcast 2=dibbling with hoe 3=dibbling with stick 4=transplant (random) * 5=transplant (line) *	Amount of seed used (kg)
								Did you repair the bund? See code below	If 5, 6=paid, how much Ksh did you pay for it?	Did you repair the water supply canals? See code below	If 5, 6=paid, how, how much Ksh did you pay for it?	Did you repair the drainage canals? See code below	If 5, 6=paid, how, how much Ksh did you pay for it??		
VName	**LID**	**RT15**	**RT16**	**RT17**	**RT18**	**RT19**	**RT20**	**RT21**	**RT22**	**RT23**	**RT24**	**RT25**	**RT26**	**RT27**	**RT28**

Code for RT15, RT17, RT19
1=No (no ploughing, no harrowing, or no soil-covering)
2=by hand/foot
3=by animal
4=by tractor (once)
5=by tractor (twice)

Code for RT21, RT23, RT25)
1=No (no bund, no water supply canals, or no drainage canals)
2=No repairing
3=by him/herself
4=by a group of cultivators
5=by hired labor
6=by tractor

* Only if transplanting is the principal method in the plot questioned.

4. Family and Hired Labour Use for Rice Production in 2010 cropping season

Unit No.	Activity Specify if the code is 12, 15, 16, or 17.	Activity Code See below	Family Labour Use For Rice Production in the Planting season 2010									Exchange Labour			Hired labour		
			Adult Men			Adult Female			Children (under 18 years old)								
			Num ber	Days	Hours a day	Num ber	Days	Hours a day	Num ber	Days	Hours a day	Num ber	Days	Hours a day	Num ber	Days	Cost (Ksh)
LID	**RL1**	**RL2**	**RL3**	**RL4**	**RL5**	**RL6**	**RL7**	**RL8**	**RL9**	**RL10**	**RL11**	**RL12**	**RL13**	**RL14**	**RL15**	**RL16**	**RL17**

Code forRL1
1=clearing field
2=repairing bunds
3=repairing canals
4=1st ploughing
5=2nd ploughing
6=1st harrowing
7=2nd harrowing
8=sowing/planting
9=soil covering
10=1st weeding (manual)
11=2nd weeding (manual)
12=water management (opening/closing channel, watering, pumping, etc.)
13=scaring birds
14=harvesting
15=post harvest activities (threshing, bagging, transporting outputs, etc.)
16= chemical application (fertilizer, pesticide, herbicide, etc.)
17=other (specify)

5. Input Use for rice in the cropping Season(s) 2010

(If the farm is under production for two season please indicate input use within the two season including the ratoon)

Planting Season 1=1st planting season 2=2nd planting season 3=ratoon	Variety Name	Acres under this variety	**Seed Use**				**Fertilizer Use**						**Organic Fertilizer Use**			Expenditure for hiring labor for fertilizer application (Ksh)	Other costs (herbicide, foliar, etc.) (Ksh)
			Seed Type 1=local 2=improved 3=mixed	Qty	Unit Code Sheet	Unit Price	Planting fertilizer			Top dressing fertilizer							
							Type Code below	Qty	Unit Code Sheet	Type Code below	Qty	Unit Code Sheet	Type Code below	Qty	Unit Code Sheet		
PS	**VName**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**

Code for C8 and C11
0=none
1=DAP
2=NPK
3=UREA
4=Ammonium sulfate
5=other (specify)

Code for C14
0=none
1=(dry) manure
2=(fresh) animal manure
3=ash
4=compost
5=household waste
6=crop residual
7=other (specify)

6. Harvest and Sales of rice in 2010 cropping season

(If the farm is under production in two season please indicate total harvest and sales for the two season including the ratoon)

Planting Season 1=1st planting season 2=2nd planting season 3=ratoon	Variety Name	Variety Code See Code Sheet	**Total Harvest**				**Amount Consumed**		**Amount Sold**			**For the sales**			
			Qty	Unit See Code Sheet	Is the yield 1=average 2=above average 3=below average	If the yield is 3=below average, why? See Code below	Qty	Unit See Code Sheet	Qty	Unit See Code Sheet	Unit Price (Ksh)	When did you sell?		To whom did you sell? See Code below	Where did you sell? See Code below
												Month	Year		
PS	**CName**	**CID**	**C17**	**C18**	**C19**	**C20**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C28**	**C29**

Code for C23
1=rain shortage
2=heavy rain
3=flood
4=low temperature
5=insect
5=animal
6=birds
7=crop diseases
8=other (specify)

Code for C32
1=trader
2=retail shop
3=individual consumer
4=cooperative association
5=supermarket
6=institution (e.g. school)
7=company
8=other (specify)

Code for C33
1=farm gate
2=in the village
3=local market

7. Choice of varieties and seed source

(a) What variety of rice are you cultivating? (Rank the varieties according to the size of cultivating area)

Rice varieties	**Rank**	**Reasons**
1. Basmati 370		
2. Basmati 217		
3. IR2793-80-1		
4. BW196		
5. ITA310		
6. Others (specify)		

(b) When selecting rice varieties to grow, what rice characteristics do you consider? (Rank the characteristics according to the importance)

Rice characteristics	**Rank**
1. High yielding	
2. Early maturity	
3. Does not broke easily when milling	
4. Aroma	
5. Weed resistance	
6. Good taste	
7. Good prices for sale	
8. Pest and diseases resistance	
9. Flood resistance	
10. Many tillers	
11. Difficult to shatter when in the field	
12. Easy hand threshing	
13. Long shelf life	
14. Non-sticky when cooked	
15. Low input requirement	
16. Long grains	
17. Low plant height	
18. Others (specify)	

(c) According to you which varieties are susceptible to rice blast disease? (Please indicate the resistance of varieties to rice blast). 1) Resistance, 2) neutral 3) susceptible

Rice varieties	Chose 1), 2) or 3)
1. Basmati 370	
2. Basmati 217	
3. IR2793-80-1	
4. BW196	
5. ITA310	
6. Others (specify)	

(d) Where do you get seeds from? (Tick as appropriate)

Seed source	Tick as appropriate
1. Own seeds	
2. NIB/MIAD	
3. Fellow farmers	
4. From the market	
5. Others (specify)	

8. FARMERS' PERCEPTION ON RICE DISEASE

(a) Do you know the rice blast disease? 1. Yes ☐ 2. No ☐

(b) If yes, what is its local name?.

………………………………………………………………

(c) Has rice blast disease ever affected your farm? 1. Yes ☐ 2. No ☐

(If yes, answer the following questions)

(d) What type of blast do you find in your farm? 1) panicle, 2) leaf, 3) neck, 4) stem

(e) How did you know you have the above mentioned rice blast in your farm?

____
____
____
____

(f) Have you ever observed any other diseases in your farm? 1. Yes ☐ 2. No ☐

(If yes, which ones)

………………………………………………………………………………

(g) What disease is more destructive in rice production? 1) Blast 2) others/none (specify)

(h) When did you first realize the existence of rice blast disease in your field? (Give year and season)

Year …………………, Planting season………………… Planting group…………………

(i) Have you ever realized rice blast disease occurrences in other farms? 1) Yes 2) No

(j) If yes indicate the month, year and distance of the farm from your farm.

Month	Year	Distance from your farm (see code sheet)

(k) Does the disease affect the rice crop in your farm throughout the growing season? (please tick as appropriate)

1. Yes ☐ 2. No ☐

(l) If No, Indicate which month(s) of the year the disease is prevalent

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec

(m) How has the rice blast disease progressed in your field for the last five years?

Year	Transplanting month	harvesting month	variety	Blast occurrence (yes or not)	Yield (bags)
2006 1st planting group					
2006 2nd planting group					
2006 3rd planting group					
2007 1st planting group					
2007 2nd planting group					
2007 3rd planting group					
2008 1st planting group					
2008 2nd planting group					
2008 3rd planting group					
2009 1st planting group					

2009 2nd planting group					
2009 3rd planting group					
2010 1st planting group					
2010 2nd planting group					
2010 3rd planting group					

(n) According to you what factors do you think might have led to the presence of the disease in your farm?

____
____
____
____
____

(o) Activities introduced as a result of rice blast disease (Tick as appropriate)

Activities introduced	**Tick where applicable**
1. No activities introduced	
2. Growing other horticultural crop	
3. Livestock rearing	
4. Boda boda business	
5. Trade	
6. Wage earner	
7. Others (specify)	

(p) Have you liquidated any assets due to the on-set of rice blast disease?

1. Yes ☐ 2. No ☐

(q) (If yes, what assets have you liquidated (type and value per year)?

type	value per year	reasons

9. Recognition about rice blast

Recognition of rice blast	Action to be taken	Reason
1. In your nursery		
2. In your paddy field at		

the early growth stage		
3 .In your paddy field at the flowering stage		
4. In your paddy field at the maturity stage		
5. In the neighbours nursery		
6. In the neighbours paddy field early growth stage		
7. In the neighbours field at the flowering stage		
8. In the neighbours field at the maturity stage		

10. FARMERS' TECHNOLOGICAL INTERVENTIONS ON RICE BLAST DISEASE

(a) What rice blast disease control methods have you been using?

Method *	Source of advice •	Year of start of use	Farmer's perception of method ♣	Cost of method (per growing season)	Method still being used (Yes / No)	If method stopped, reason for abandoning

** Burning diseased-straw and stubble = 1, Use of resistance strains = 2, chemical use = 3, Apply compost = 4, Avoid farm activities when plants are wet = 5, abandon field = 6, Split applications of nitrogenous fertilizer = 7, other (specify) = 8*

• Fellow farmer = 1, Extension worker = 2, Training workshop = 3, Radio = 4, Local leader = 5,
Visiting researchers = 6, Newspapers/pamphlet = 7, Other (specify) = 8

♣ Worked very well = 1, Worked satisfactorily = 2, Worked − but not well = 3, Did not work = 4
I don't know = 5

(b) If using chemicals what kind of chemicals do you use to control blast? Name of product____

(c) From whom did you learn about the product?__________ 1) MIAD/NIB, 2) KARI, 3) MoA, 4) fellow farmers, 5) TV, 6) Radio, 7) other (specify)

(d) If not using any control method, give reasons why.

____

____

____

____

(e) Is there any developmental activity by any Group/institution to tackle rice blast disease in your area? 1. Yes ☐ 2. No ☐

(f) If yes, which group/institution? (Tick where appropriate)

Group/institution	**Tick where appropriate**
1.MIAD/NIB	
2.Ministry of agriculture	
3.KARI	
5.Farmers group	
6.NGOs	
7.Others (specify)	

CODES

Rice variety code	Unit Code	Distance code
1. Basmati370 2. Basmati217 3. IR2793-80-1 4. BW196 5. ITA310 6. Sindano 7. Other (specify)	1=90 kg bag 2=50 kg bag 3=25 kg bag 4=10 kg bag 5=2 kg bag 6=kgs 7=grams 8=litres 9=crate 10=numbers 11=bunch (banana) 12=gorogoro 13=tones 14=debe 15=wheelbarrow 16=cart 17=canter 18=pickup 19=donkey load 20=donkey cart load 21=hand cart load 22=head load 23=other (specify)	1=0- 2.5km 2=2.5-5km 3=5-7.5km 4=7.5 – 10km 5=10 – 12.5 km 6=12.5 – 15 km 7=15 – 17.5km 8=17.5 – 20km 9=over 20km