EXPLORING IMPROVED NUTRIENT OPTIONS FOR INCREASED RAINFED LOWLAND RICE PRODUCTION IN EASTERN AND NORTHERN UGANDA

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DECLARATION

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

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DEDICATION

This piece of work is dedicated to my dear wife Sylvia and to our children Keisha, Jeremy and Gabriel.

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GENERAL ABSTRACT

Although rice is increasingly becoming an important crop in Uganda, yields continue to decline due to poor soil fertility, weed problems and intermittent rainfall. Poor soil fertility has been ranked as the most important abiotic stress limiting rice production. The main objective of this study was to develop nutrient options for the improvement of rice production in eastern and northern Uganda. The specific objectives were: 1) to establish the current nutrient status, nutrient management practices and household characteristics that affect the use of fertilizer and other agro-inputs in lowland rice growing areas in eastern and northern Uganda; 2) to determine the effect of nursery management practices, age of seedlings at transplanting and split application of nitrogen fertilizer on the yield of four rice cultivars; 3) to determine the nutrient use efficiency and indigenous nutrient supply in lowland rice fields; 4) to assess yield responses of four rice cultivars to varying rates of inorganic fertilizers. Objective one was implemented through a survey to document soil fertility status and factors determining use of fertilizers and agro-inputs. Objective two was studied by applying di-ammonium phosphate (DAP) and fungicide in the nursery and transplanting seedlings at either 14 or 30 days after seeding using the following treatments: control (no chemical + 30-day old seedling), DAP+ 14 day old seedlings, DAP + 30 days old seedlings, fungicide + 30 day old seedlings, DAP + fungicide + 14 day old seedlings. Effect of split application of N on yield was determined by setting up an experiment using split plot design with five N-fertilizer treatments: 1) control (no fertilizer added); 2) 23 kg N ha^{-1} applied at planting; 3) 23 kg N ha^{-1} applied in two splits; 4) 46 kg N ha^{-1} applied at planting; 5) 46 kg N ha^{-1} applied in two splits. Objective three was studied using the omission plot technique with five treatments laid out in a randomised complete block design with four replicates: control (no fertilizer), NPK, PK (-N), NK (-P) and NP (-K). Agronomic efficiency (AE), recovery efficiency (RE), internal use efficiency

(IE) and gross return over fertilizer (GRF) were calculated. Appropriate N, P and K rates for site specific nutrient management (SSNM) were also calculated. For objective four, yield responses to different fertilizer options were determined using six fertilizer treatments: 20-20-0, 40-20-0, 60-30-0, 80-20-0, 80-40-0 and 120-40-0 kg ha^{-1} N- P_2O_5- K_2O. A split plot design was used with treatments as main effects and varieties as sub plots. All experiments were set up between 2013 and 2014. The omission experiments were set up using a local variety Bedinego while the other experiments were set up with four rice varieties; K 5, K 85, GSR 007 and WITA 9. Data was collected on plant height, number of tillers, number of panicles, grain yield and rice biomass dry weight at harvest. Profitability analysis of the different fertilizer treatments was also done. Determinants of use of agro-inputs were examined using a binary probit model. Analysis of variance (ANOVA) was performed for the different treatments and means separated using the least significant difference (LSD) at P=0.05. Results showed that male farmers dominated lowland rice production (90.7 %) and only 12 % of farmers used inorganic fertilizers at a rate of 10-50 kg ha^{-1}. Farmers' occupation and fertilizer prices were the main determinants for fertilizer use while age, household size, gender and training in agricultural production determined the use of agrochemicals on rice fields. Generally, the nutrient status at farmers' fields was low. All the sampled fields had medium levels of organic matter (2-4.2 %), over 80 % of farms had low levels of Olsen P (5-15 mg kg^{-1}) and all farms had medium to high levels of nitrogen and over 50 % of the farms had high levels of K (0.6-1.2 cmoles kg^{-1}). Common weeds in farmers' fields were *Cyperus difformis, Kyllinga erecta* Schum. and *Cyperus rotundus* L., *Cynodon dactylon* (L.) Pers., *Echinochloa colona* (L.) Link.). The parasitic weed *Ramphircarpa fistulosa* (Hochst.) Benth was found mainly in Butalejja and Bugiri districts. Applying DAP and transplanting 14 day old seedlings resulted in the highest yield (average yield= 3.4 t ha^{-1}). Generally, applying fertilizers and fungicide in the

nursery and transplanting 14 day old seedlings resulted in a yield increase of 0.6-0.8 t ha^{-1}. The interaction between split N applications and variety was significant for yield. When 23 kg of N was applied at once to all varieties, GSR 0057 yielded better than WITA 9 but its yield was similar to K 5 and K 85. Application of 46 and 23 kg of N ha^{-1} at once had significantly lower harvest indices (HI= 0.31 and 0.32 respectively) than the control and split application of 23 and 46 kg of N ha^{-1}. The full NPK treatment in omission trials had 73, 40, 23 and 25 % higher yield than control, PK (-N), NK (-P) and NP (-K) treatments respectively. The average AE, RE and IE of N were 9.4 kg kg^{-1}, 31% and 36.9% respectively. The average indigenous supplies for N, P and K were 52, 9.7 and 87.2 kg ha^{-1} respectively. The calculated appropriate nitrogen, phosphorus and potassium doses required to achieve 5 t ha^{-1} rice yield were 63, 12.6 and 24.5 kg ha^{-1} respectively. The gross return over fertilizer cost (GRF) for NPK, PK, NK and NP treatments were $1,275.3, 1039,1057 and 1008 ha^{-1} respectively. Yield in the different nutrient regimes generally increased with increase in amounts of fertilizer applied and variety K 85 out yielded all other varieties irrespective of treatment and season. The highest average yield (3.4 t ha^{-1}) was recorded in plots which received 120-40-0 (N, P and K respectively) while the lowest yield was recorded in 20-20-0 NPK (average yield= 1.3 t ha^{-1}). Generally, 120-40-0NPK recorded the highest net returns and profits of 29.0 % and 26.8 % in 2013A and B respectively. Improving nursery management has greater prospects for increasing rice yields in smallholder farms at minimal costs. The low nutrient use efficiency observed implies that maximum benefits from fertilizer use will only be realized if farmers can adopt good agricultural practices. Incentives to increase use of external inputs on rice production coupled with supportive policies for availability of affordable agro-inputs and improved technologies (including new varieties) can lead to increased rice production in Uganda.

CHAPTER 1: INTRODUCTION

1.1 Background

Agriculture plays an important role in Uganda's economy (Statistics U. B. O. S, 2011). About 73% of the people in Uganda depend on agriculture for their livelihood majority of whom (68%) depend on subsistence farming. In 2013, the agricultural sector contributed 21% of Gross Domestic Product (GDP), and 90% of total export earnings (Statistics U. B. O. S, 2014). In addition, agriculture is the major source of raw materials for industry and food for the population.

Rice (*Oryza sativa* L.) is one of the most important cereals in the world together with wheat and maize. Rice is a staple food for nearly one-half of the world's population and is grown in 112 countries around the world. Global rice production has risen steadily from around 200 million metric tons (MT) of unmilled rice in 1960, to over 678 million MT in 2009 (Sreepada and Vijayalaxmi, 2013). Rice is becoming increasingly important in Africa. From the year 2000 to 2010, the harvested area in Sub-Saharan Africa (SSA) has increased by 53% whereas production increased by 47% (Seck *et al*. 2013). Nigeria and Madagascar are the leading rice producers in Africa each with a planted area of 2,345,000 and 1,230,000 hectares respectively. Tanzania is the leading producer in East Africa with over 621,000 hectares planted to rice while Uganda is in second position with 140,000 ha planted (EUCORD, 2012). Rapid population growth and urbanization in SSA has seen the rice consumption grow more rapidly than production (Balasubramanian *et al.*, 2007). Domestic rice production in Africa covers only 60% of the regional rice consumption (Africa Rice Center, 2008) the rest of the rice demands being offset by imports.

Rice is one of the emerging crops grown currently in Uganda. It plays an important role both as a food and a cash crop in the country. The crop was ranked fourth among the cereal crops after maize, finger millet and sorghum and occupied a total of 138 thousand hectares of land with an estimated output of 181, 000 tons (Statistics, U. B. O., 2010). It is becoming a staple food countrywide, especially in urban areas. The per capita consumption of rice is estimated at 8 kg. In 2012, the country's rice import requirements were estimated at 60,000 tons (EUCORD, 2012). Uganda is therefore a net importer of the commodity and will continue to do so in the near future unless there is an improvement in domestic production**.** Most of the rice grown in Uganda is rain fed (95 %) of which, 60 % is lowland (Haneishi *et al.*, 2013). The eastern region produces more than 67% of all the rice produced in Uganda. According to Odogola, (2006), Uganda has tremendous potential for increasing its rice production. However, the rice production sector is facing biotic, abiotic and socio-economic challenges. Biotic factors include weeds, insect pests (stem borers, African gall midge, and rice bugs), diseases (blast, brown spot, rice yellow mottle virus), rats and birds. Abiotic stresses include low soil fertility and variable rainfall, with drought and flood occurrences in the same season. In addition to biotic and abiotic factors, socio-economic factors affect rice production including unfavorable input and output pricing policies at the national level, limited access to credit and inputs (e.g. seed, fertilizers, pesticides, markets, and market information) and poor rural infrastructure and transport system (Balasubramanian *et al.*, 2007). Given that rice is a major cereal crop that has great potential for increasing productivity in Uganda, there is an urgent need for strategic efforts to enhance its production for household food and income security (Kijima *et al.*, 2010).

1.2 Problem statement and justification

Rice yields in rainfed lowland rice fields in Uganda are still low, averaging at about 1.5- 2 t ha^{-1} compared to the potential yield of over 5 t ha^{-1}. The major contributing factor to low yields in Uganda is declining soil fertility and poor cultivation practices (Kijima *et al.*, 2010). Decline of soil fertility is generally seen as the most important constraint to crop production in Uganda. Most agro-ecosystems remove more nutrients than are provided by external inputs making it a fundamental biophysical root cause for declining food security in the smallholder farms. Declining soil fertility is compounded by poor cultivation practices used by majority of the farmers. For example, many lowland rice farmers in Uganda transplant 25-40 day old seedlings instead of 14-20 day old seedlings which give optimum yield. Transplanting old seedlings result in lower numbers of productive tillers and eventually low yields. Farmers apply fertilizer based on blanket recommendations rather than according to plant requirements resulting in reduced N- use efficiency (Linquist and Sengxua, 2003). In addition, mineral fertilizer application rates used by smallholder farmers on rice lack scientific basis (Nhamo *et al*., 2014).

Although the use of fertilizers and other agro-chemicals is still low among lowland rice farmers in Uganda, there is no clear documentation of the factors influencing their use. Whereas there are some reports on soil fertility and factors influencing fertilizer use in maize (e.g. Kaizzi *et al.*, 2006; Nkonya *et al.*, 2005) and banana (e.g. Wairegi and van Asten, 2010) growing areas, reports on soil fertility in lowland rice in Uganda are limited. Major gaps still exist on the status of nutrients, supply of nutrients from indigenous sources, nutrient use efficiencies of the different rice varieties grown, yield gaps of the different varieties, fertilizer recommendations and the general understanding of soil fertility in lowland rice growing ecosystems in Uganda. There is thus need to establish the nutrient status and to develop nutrient management options for the improvement of lowland rice production systems in Uganda.

The study established the current nutrient status in lowland rice growing ecologies, determined the indigenous nutrient supply and nutrient use efficiencies of nitrogen, phosphorus and potassium, determined fertilizer requirements for different yield targets, and tested appropriate inorganic fertilizer options.

1.3 Objectives

The main objective of this study was to develop nutrient options for the improvement of rainfed lowland rice production in eastern and northern Uganda.

The specific objectives of the study were:

1. To establish the current nutrient status, nutrient management practices and household characteristics that affect the use of fertilizers and other agro-inputs in lowland rice growing areas in eastern and northern Uganda.
2. To determine the effects of nursery management practices, age of seedlings and nitrogen split applications on yield of four rice varieties.
3. To determine the nutrient use efficiency and indigenous nutrient supply in rainfed lowland rice fields.
4. To assess the yield responses of four rice cultivars to varying rates of inorganic fertilizers.

1.4 Hypotheses

1. Farmers' fields are relatively low in organic carbon, nitrogen, phosphorus, potassium, calcium and magnesium.
2. Transplanting young and vigorous seedlings and split application of N-fertilizers increases yields in smallholder farms.
3. Nutrient use efficiency and indigenous nutrient supply are low in rainfed lowland rice systems.
4. Yields of rainfed lowland rice production systems in eastern and northern Uganda can be improved by appropriate combinations of inorganic fertilizers.

CHAPTER 2: LITERATURE REVIEW

2.1 Soil fertility decline in Africa

Debates over factors limiting agricultural growth in Africa have generally focused on adverse natural resources (poor soils, low and variable rainfall) and environmental decline, unfavorable conditions in international markets, macroeconomic policies that have undermined agriculture, inefficiencies in state support for agriculture, lack of technologies appropriate to African conditions and limited domestic demand (Wiggins and Leturque, 2010). At smallholder farmer level, unsustainable cultivation practices have led to accelerated depletion of the natural soil base available for food production (Hossner and Juo, 1999). Poor cultivation practices have resulted in decrease of soil fertility, reduction of soil organic matter (SOM), and increase in occurrence of acidic soils (Buckles, 1998). Decline in soil fertility as a result of land degradation decreases farmland productivity (Amede, 2003). Several decades of nutrient depletion have transformed originally fertile lands that yielded 2 to 4 t ha-^{1} of cereal grain, into infertile ones where cereal crops yield of <1 t ha^{-1} are common. As a result, soils have deteriorated significantly, especially in terms of phosphorus levels and SOM.

Soil nutrient mining has been estimated to average 660 kg of nitrogen (N), 75 kg of phosphorus (P) and 450 kg of potassium (K) per hectare per year during the last 30 years from about 200 million hectares of cultivated land in 37 countries in Africa excluding South Africa (Smaling *et al.*, 1997). In many parts of SSA where poor soil conservation methods prevail, long term productivity of soil is projected to decline considerably unless soil management practices improve. It now requires a major investment to restore soils to a sufficient level of fertility for sustainable crop production (Chukwuka and Omotayo, 2009). In 1999 FAO estimated that smallholder farmers in Uganda apply an average of 1 kg of NPK ha^{-1}. This is among the lowest fertilizer application rates in SSA; where the average fertilizer application is 12.8 $kgha^{-1}$ (Heisey and Mwangi, 1996). Whereas there are some reports on soil fertility in maize (e.g. Kaizzi *et al.*, 2006; Nkonya *et al.*, 2005) and bananas (e.g. Wairegi and van Asten, 2010) growing areas, reports on soil fertility in rainfed lowland rice in Uganda are limited. There is thus need to establish the nutrient status and possible nutrient recommendations for lowland rice production systems in Uganda.

2.2 Use of inorganic and organic fertilizers to improve soil fertility

Applying fertilizers is the most direct way to overcome soil-fertility depletion, and indeed it has been responsible for a large part of the sustained increases in per capita food production that have been recorded in Asia, Latin America, and the temperate region, as well as in the commercial farm sector in Africa (Buresh *et al., 1997*). Although most smallholder farmers in Africa appreciate the value of fertilizers, they are seldom able to apply them at the recommended rates and at the appropriate time because of high cost, lack of credit, delivery delays, and low and variable returns (Naab, 2003).

The exclusive use of organic inputs as external nutrient sources has been advocated as a logical alternative to expensive fertilizers in Africa due to the fact that cattle manures or green manures contain carbon and all essential nutrients (Onyango *et al*., 2003). Organic inputs however contain low nutrient concentrations in comparison with inorganic fertilizers. For example, animal manures and plant material contain 1- 4% N (10- 40 g N kg^{-1}) on a dry weight basis, while inorganic fertilizers contain 20- 46% N (200- 460 g N kg^{-1}) and are already dry. In addition, organic inputs are very low suppliers of phosphorus because of their low concentrations (Onyango *et al*., 2003). On-farm research in western Kenya illustrated the potential of combining inorganic and organic sources of P in a moderate P-sorbing oxisol with pH 5.1. The integration of locally available organic resources with commercial P fertilizers may be the key to increasing and sustaining levels of P in smallholder farms in Africa.

2.3 Nutrient problems in lowland rice production

Low soil fertility is an increasing constraint to productivity in the East African region (Nandwa and Bekunda, 1998). It is estimated that 17.5, 6.9, 20.5, 3.5 and 4 Kg nutrient of N, P_2O_5, K_2O, Mg and Ca respectively are removed per ton of rice grain and straw at harvest (Dobermann and Fairhust, 2002). Because fertilizers are in most cases either expensive or not readily available, farmers apply insufficient amounts of fertilizer to their crop leading to continuous soil mining. Pender *et al.* (2001) estimated that less than 10% of smallholder farmers in Uganda apply inorganic fertilizers, albeit applying low rates of about 1 kg NPK per hectare. Wortmann and Kaizzi (1998) while estimating nutrient balances for small scale farming systems, found low or negative nutrient balances for N, P and K. At household level, Nkonya *et al.* (2005) found only 5% households with a positive total N, P, K balance while 95% of households were unsustainable. Their studies were however focusing on cropping systems and household levels and were not crop specific.

2.4 Roles of soil microbes in soil fertility

Soil microorganisms are an important part of the soil. They are important contributors in many biochemical processes and play a major role in maintaining soil fertility and crop yields. Changes in the activity and diversity of soil microbes may reflect changes in soil quality. It has been shown that different soil management practices affected the structure and activity of soil microorganisms (Islam *et al.*, 2009).

Soil microbial biomass is considered to act both as the agent of biochemical changes in soil and as a repository of plant nutrients such as nitrogen (N) and phosphorus (P) in agricultural ecosystems. In paddy fields, in which N fertility had been sustained over a long period of time, about 60%−70% of N absorbed by rice plants was derived from native soil N rather than fertilizer N (Zhang and Wang, 2005). A study by Zhang and Wang (2005) on nutrient uptake of rice and characteristics of soil microorganisms in long-term fertilization experiments for irrigated rice reported that soil microbial carbon was maximum in the NP or PK treatments. Soil microbial biomass N showed a marked increase in the NPK treatments and the control, where no nutrient was applied, compared to PK, NP and NK treatments. They concluded that fertilization influenced microbial biomass and community diversity. Islam *et al.* (2009) while evaluating the effect of fertilizer applications on soil microbial community structure in rice based cropping systems using Fatty acid methyl esters (FAME) analysis, found the relative abundance of gram-negative bacteria to be highest in control which did not receive either chemical fertilizer or compost manure and lowest in NPK plots while abundance of gram-positive bacteria were higher in compost amended plots than control and NPK plots. They concluded that the microbial community structure in a rice-based cropping system under long term experiments varies with different fertilizer treatments and that there are positive effects of compost amendments on microbial diversity which could result in greater productivity of the cropping system. It is evident that fertilization has an effect on soil microbes.

2.5 Site- specific nutrient management

Doberman *et al.* (2002) suggested that plant nutrient uptake, rice yields and hence profit, can be significantly enhanced by applying fertilizers on a cropping season and field specific basis done by more rigorous site specific methodologies of nutrient management. Site specific nutrient management (SSNM) was defined by Dobermann and White (1999) as the dynamic, field specific management of nutrients in a particular cropping to optimize the supply and demand of nutrients according to their differences in cycling through soil-plant systems. According to Dobermann *et al.* (2002), SSNM established for rice tries to account for regional and seasonal differences in the climatic yield potential. It also explains the differences between fields with respect to indigenous nutrient supply and within-season dynamics of nitrogen demand. Further, the SSNM approach developed for rice uses crop based estimates of indigenous nutrient supply instead of relying on soil tests which are poor predictors of indigenous nutrient supply or rice grain yield (Dobermann *et al.*, 2003). The SSNM approach is used to predict field specific fertilizer rates. A modification of the QUEFTS model (Jansen *et al.*, 1990) is used to work out the field specific NPK recommendations for rice in the trial sites (as detailed by Dobermann *et al.*, 2002).

2.6 Factors influencing adoption of fertilizers and other agro-inputs

Adoption was defined by Feder *et al*. (1985) as the extent of use of a new technology in a long-run equilibrium when a farmer has all information about the new technology and its prospective benefits. Technology adoption is normally measured as a binary variable designating usage or no usage of the technology (Kaliba *et al*., 2000). Factors influencing the acceptance and usage of new agricultural technologies are categorized as farm and farmers' associated attributes (farmer's education, age, or family and farm size); technology associated attributes (e.g., the kind of characteristics a farmer likes in an improved rice variety) (Adesina *et al*., 1992); and the farming objective (CIMMYT, 1988). Croppenstedt *et al.* (1996) identified plot size, previous experience with fertilizer, supply of fertilizer, farm size, amount of rainfall, household size, the ratio of the price of the main crop to the cost of the fertilizer and access to credit as the main factors influencing adoption. In addition, Minot *et al.*, (2000) while studying demand of fertilizer among farmers in

Benin Republic and Malawi discovered in Benin Republic that education of household head, size of farm plot, household head expenditure, farm size, maize plot, rice plot, and number of cattle owned had significant effects on fertilizer demand. In Malawi, they found that household size, education of household head, ethnicity, price of maize, farm size, household head expenditure, club membership, and vegetable plot affected fertilizer demand. Akpan *et al*., (2012) found other factors such as gender, extension agent visit and the distance to fertilizer selling point as significant factors affecting fertilizer use intensity among arable crop farmers in Abak agricultural zone in Akwa Ibom state, Nigeria. In Uganda, reports on the factors determining use or no use of fertilizers and other agro-inputs by rice farmers are still scanty. Such reports would guide policies on how to increase yields through adoption of agro-inputs. Previous adoption and use of new technology studies have utilized a variety of econometric models the most commonly used being maximum likelihood estimation techniques including tobit (Adesina and Zinnah, 1993; Adesina and Baidu-Forson, 1995; Nkonya *et al.* 1997), logit (Green and Ng'ong'ola, 1993), Sain and Martinez, 1999), and probit (Negatu and Parikh, 1999; Kaliba *et al.*, 2000). This is because adoption of a technology is generally considered as a binary variable indicating use or no use of the technology (Kaliba *et al.*, 2000). In most cases, the binary variable definition is based on whether a household used or did not use the technology.

2.7 Effect of good nursery management practices on rice yields

Although rice is an increasingly important crop in Uganda (Hyuha *et al*., 2007), the yield gap between the harvested yields at farmers' fields and the potential yields is considerably high. Many factors are responsible for the yield gap including declining soil fertility, low yielding varieties, drought, flood occurrences, and poor agronomic practices. According to Lal and Roy (1996), the success of transplanted rice cultivation depends on the seedlings. Adequate nutrition, optimum seeding densities and transplanting seedlings at the appropriate age are the key practices for producing vigorous rice crop stands after transplanting. Most farmers do not appreciate the benefit of raising healthy and vigorous seedlings as well as transplanting young seedlings. By making a small investment in raising healthy and vigorous seedlings in the nursery, farmers could harvest an additional yield of up to 2 t ha^{-1} (Panda *et al*., 1991). Several studies have indicated that application of nitrogen and phosphorus in the nursery results in higher yields than the unfertilized control. For example, Ros *et al*. (1997) recorded a 50 and 100% increase in dry matter when N and P were applied in the nursery. Similarly, Rajagopahan and Krishnarajan (1987) applied di-ammonium phosphate (DAP) and single super phosphate (SSP) to the nursery at 50 kg Pha^{-1} and produced the highest grain yields of 4.9 t ha^{-1} corresponding to a 21% yield increase.

The age of seedlings at transplanting is also an important factor contributing to good performance of rice. Farmers all over the world transplant seedlings at different ages, but most often transplant 25 to 50 day old seedlings in lowland rice (De Datta, 1981; Singh and Singh, 1999). Several researchers have reported increases in rice grain yields when rice seedlings are transplanted at less than 25 days old (Ashraf *et al*., 1999; Nandini and Singh, 2000; Thanunathan and Sivasubramanian, 2002). Most farmers in Uganda transplant 25-40 day old seedlings resulting into lower numbers of productive tillers leading to low yields. Besides, limited research has been conducted to optimize nutrient requirements for the nursery and to establish the optimum age of transplanting. Given the low rates of fertilizer use, improving nursery management to produce healthy and vigorous seedlings presents an opportunity to increase yields at minimal production costs.

2.8 Improving nutrient use efficiency in lowland rice cropping systems

The N fertilizer source, the N application time, or both usually dictate at which end of the efficiency spectrum N fertilizer use by rice resides. The rice recovery efficiency for fertilizer N is on average 30-40%. Recovery efficiency is generally defined as the total N accumulation in the aboveground biological yield (grain + straw) per unit of applied N fertilizer (Cassman *et al*., 1993). Nitrogen fertilizer is typically applied in at least two or more split applications in most production systems (Cassman *et al*., 1993).

It is clear that farmers could improve efficiency and profit by improving the recovery rate of applied nutrients, especially N, through better crop management in general, without major increases in investment in fertilizers (Wopereis *et al*., 1999). The most important constraints that resulted in low N recovery rates in Senegal River delta were: timing of N fertilizer application that did not coincide with critical growth stages of the rice plant; use of relatively old (>40 days) seedlings at transplanting; unreliable irrigation water supply; weed problems; and late harvesting. Similar results were obtained by Haefele *et al*. (2000, 2001) for the Senegal River delta and Segda *et al*. (2004) for the Bagré irrigation scheme in Burkina Faso. Farmers in Burkina Faso and Senegal lacked knowledge on the importance of N as the main yield-limiting factor, optimal timing and right quantity and method of fertilizer application. They also didn’t have sufficient information on optimal sowing dates to avoid yield loss due to cold- or heat-induced sterility Segda *et al*., 2004). Working with Senegalese and Mauritanian farmers, improved nutrient management (application of 20 kg P/ha and 150 kg N/ha in three splits at early tillering, panicle initiation and booting) increased yields by about 1 t/ha (Haefele *et al*., 2000; Haefele *et al*., 2001). Farmers growing rice in the lowlands in Uganda not only lack the blanket fertilizer recommendation, but also do not have the knowledge on application of N in splits to increase N use efficiency and yield. A few farmers who apply fertilizers apply it basally, hence they do not register the benefits of split N applications. There is need to optimize N application to improve N use efficiency and achieve better yields.

CHAPTER 3: SOIL NUTRIENT STATUS AND NUTRIENT MANAGEMENT PRACTICES IN LOWLAND RICE GROWING AREAS OF EASTERN AND NORTHERN UGANDA

3.1 Abstract

Rice is increasingly becoming an important crop in Uganda. However, yields continue to decline due to poor soil fertility, weed problems, intermittent rainfall and limited use of fertilizers. Poor soil fertility has been ranked as the most important abiotic stress limiting rice production. A survey was carried out in five districts in Uganda in 2013 to document soil fertility status, soil fertility management practices by farmers, knowledge and perceptions on soil fertility in lowland rice production systems and factors determining use or no use of fertilizers and agro-chemicals among lowland rice farmers. Primary data was collected by administering a structured questionnaire to 150 rice farmers from Kaliro, Namutumba, Bugiri, Butalejja and Lira districts. Soil samples were collected from rice fields of each interviewed household and analyzed for pH, total carbon, total nitrogen, available P and exchangeable Ca, Mg, and K. Weed samples were also taken for identification. Determinants of use of agro-inputs were examined using a binary probit model. Results showed that male farmers dominated lowland rice production (90.7%) and only 12% of surveyed farmers used inorganic fertilizers at a rate of 10-50 kg ha^{-1}. All the sampled fields were moderately acidic, with medium levels of organic matter (2-4.2%), while over 80% of farms had low levels of olsen P (5-15 mg kg^{-1}) and all farms had medium to high levels of nitrogen. Over 50% of surveyed farms had high levels of K (0.6-1.2 cmoles kg^{-1}). The most common weeds found in farmers' fields were *Cyperus difformis, Kyllinga erecta* Schum., *Cyperus rotundus* L., *Cynodon dactylon* (L.) Pers., *Echinochloa colona* (L.) Link.). The parasitic weed *Ramphircarpa fistulosa* (Hochst.) Benth was identified mainly in Butalejja and Bugiri districts. Majority of the farmers

ranked declining soil fertility, pests and diseases, weed problems and insufficient rain as the major constraints to rice production. Farmer's occupation and fertilizer prices were the main determinants for fertilizer use while age, household size, gender and training in agricultural production determined the use of agrochemicals on rice fields. Farmer training on rice production, soil fertility and incentives to increase use of external inputs on rice production can lead to increased rice production in Uganda. For this to be realized, supportive policies for availability of affordable agro-inputs need to be put in place.

3.2 Introduction

Rice is becoming increasingly important in Africa. Over the past three decades, the harvested area in Sub-Saharan Africa (SSA) has increased by 105% whereas production increased by 170% (FAO, 2010). Thirty-eight percent of planted area in Africa is upland, 33% rainfed lowland, 9% deep water and mangrove and 20% irrigated wetland. In reality, with the exception of Senegal and Madagascar more than 80% of the rice produced in Africa comes from rainfed lowlands (Balasubramanian *et al.,* 2007). Similarly, in Uganda most of the rice grown is rainfed (95%) of which, 60% is lowland (Haneishi *et al.,* 2013) yielding average of 1 t ha^{-1} compared to the potential yield of over 5 t ha^{-1}. Although area under rice production and average yields have increased in Uganda over the past 30 years, productivity per unit area has stagnated since the 1980s (FAO, 2010). Abiotic, mainly poor soil fertility, acidity/ alkalinity and drought, and biotic stresses including weeds, pests and diseases are the contributing factors to low rice productivity (Rodenburg and Johnson, 2009). Of these stresses, poor and declining soil fertility has been ranked as the most important (Balasubramanian *et al.,* 2007; Nandwa and Bekunda, 1998; Nkonya *et al*., 2005). Likewise, application of weed management technologies on rice was reported to result in the highest yield gains compared to other agronomic technologies (e.g. Nhamo *et al.,* 2014; Rodenburg and Johnson, 2009). In Uganda, the biotic and abiotic stresses have been compounded by limited research on rice. Recent research works have focused on understanding rice farmers, varieties grown, harvested yield in farmers' conditions and regional shares of rice production in Uganda (e.g. Kijima *et al*. 2006). Not much effort has however been invested in understanding the soil fertility status, management of soil fertility by farmers and farmers' knowledge and perceptions on soil fertility and potential recommendations. In addition, whereas several studies have been conducted to document the factors determining fertilizer use among smallholder farmers in Nigeria (Apkan *et al.*, 2012), Zambia (Knepper, 2012), Kenya (Wanyama *et al.*, 2010) and Tanzania (Mussei *et al.,* 2001), few studies have been conducted in Uganda to understand the factors limiting fertilizer use among farmers (e.g. Nkonya *et al*., 2005). The objective of the study was to determine soil fertility status in smallholder farms, soil fertility management practices by farmers, knowledge and perceptions on soil fertility in lowland rice production systems, the perceptions of farmers on the relationship between rice yields and soil fertility trends and the factors determining use or no use of fertilizers and agro-chemicals (herbicides and fungicides) among lowland rice farmers.

3.3 Materials and Methods

3.3.1 Site description and sampling design

The study was conducted in eastern and northern Uganda between January and March 2013. Five districts that predominantly produce rice were surveyed i.e., Bugiri, Namutumba, Kaliro, Butaleja in eastern Uganda and Lira in northern Uganda. Five subcounties were selected randomly per district in eastern Uganda and two subcounties were selected purposively in Lira district (northern

Uganda). Fewer subcounties were selected in Lira because lowland rice is majorly grown in the two selected subcounties. All the selected districts experience bimodal rainfall pattern receiving a total rainfall ranging from an average of 1200 to 1350 mm per annum. Within each sub county, three parishes and two villages per parish were randomly selected. With the help of the area extension worker and the area local government leader, a sampling frame from the subcounty register was used to randomly select the respondents.

3.3.2 Household interviews

Face to face interviews were conducted using a pre-tested questionnaire (Appendix 6). A total of 150 farmers (30 per district) were randomly selected and interviewed.

The interviews were proceeded by soil and weed sampling from the interviewee's rice field. Data collected included varieties of rice grown, fertilizers applied (rates and time of application), yields, agronomic practices, cultural practices used to maintain soil fertility and trends in soil fertility. Secondary data obtained from national documents such as the 2002 Population and Housing Census report (Statistics U. B. O.S., 2002) was also used.

3.3.3 Soil sampling and analysis

Eight soil subsamples from a depth of 0-20 cm were taken on a grid of 20 m x 20 m in each interviewed farmer's field. The subsamples were mixed and one composite sample taken per farmer and labeled clearly. The samples were analyzed for pH, total carbon, total nitrogen, available P and exchangeable Ca, Mg, and K. Prior to analysis, soil samples were air dried, ground using a mortar and pestle, screened through a 2-mm sieve and subjected to analysis using routine procedures outlined by Okalebo *et al.* (1993). Soil pH was measured using the glass electrode method with a soil-to-water ratio of 1:2.5 (Gaines, 1979). Organic matter was measured using the potassium dichromate ($K_2Cr_2O_7$) method (Nelson and Sommers, 1982). Total N was determined by Kjeldhal digestion. Available P was measured by Bray P1 method (Bray and Kurtz, 1945). Exchangeable bases were determined from an ammonium acetate extract by flame photometry (K^+, Na^+) and atomic absorption spectrophotometry (Ca^{2+}, Mg^{2+}). Particle size distribution (texture) was determined using the Bouyoucos (hydrometer) method.

3.3.4 Data analysis and models used

Descriptive analyses using frequencies and means were performed using SPSS statistics 22. A decision to use fertilizer and agro-chemicals was modeled as a binary decision: a household either uses or does not use fertilizer and other agro inputs. A probit model was used to analyze the factors affecting the use of fertilizer and agro-chemicals among smallholder lowland rice farmers in eastern and northern Uganda.

3.3.5 Conceptual framework

The most appropriate maximum likelihood estimation (MLE) models for assessing technology adoption include the logit and probit model. The basic difference between the two models is that logit assumes that the dependent variable follows a logistic distribution while the probit model assumes a cumulative normal distribution. The interpretation of the same data, whether estimated by probit or logit, is very similar, with noticeable differences occurring only in the tails of the distribution (CYMMYT, 1993). In this study, the binary variable approach is used and the sample is divided into two categories: households that used fertilizer and other agro-chemicals and those that did not (use fertilizer = 1; don't use fertilizer = 0). The current study utilizes a probit model to analyze the factors affecting the use of fertilizer among lowland rice farmers in eastern Uganda. The probit model takes the basic form: $Yij = \mathrm{b}ij\ Xij + \mathrm{a}i$

i = 1 if farmer uses agro-inputs; *j* = 0 if otherwise

Where; *Y* = adoption of Agro=input/ inorganic fertilizer;

b = the parameters to be estimated; and a*i* = error term.

Table 3.1 shows the exogenous variables used in the model and their hypothesized effects.

Table 3.1: Explanatory variables X_{is} included in the probit model

Variable	**Description**	**Measure**	**Hypothesized effects**
Improved variety	If the farmer planted Improved rice variety	1= Yes; 0=no	+
Education	Education	1=above primary education; 0=Primary education or none	+
Size of land	Land holdings (acres)	Size of land owned	+/-
Occupation	Occupation	1= Commercial farmer; 0=Subsistence	
No Knowledge	Knowledge on fertilizer availability and use	1=Had no knowledge; 0= Had knowledge	-
High price	High fertilizer prices	1= High prices; 0= Prices not a problem	-
Training _rice	Training in rice production	1=Had training in rice production; 0=Did not have training	+
Training soil	Training on soil fertility	1= Had training on soil fertility; 0=Had no training on soil fertility	+
Young farmer	Young rice farmers with reference to middle aged	1=Less than 30 years; 0=Otherwise	+
Old farmers	Older farmers with reference to middle aged farmers	1=Above 50 years; 0 = Otherwise	-
Decreased yield	Decreased rice yields	1=Yes; 0=Otherwise	+
Constant yield	Constant yields	1=Yes; 0=Otherwise	-
Gender	Gender of the farmer	1= male; 0= Female	+

3.4 Results

3.4.1 Demographic characteristics of rice farmers in eastern and northern Uganda

In general, the survey had 90.7% male respondents and only 9.3% female respondents. The number of male input users was significantly higher (P= 0.027) than female input users. The rest of the demographic characteristics were not significantly different between input and non-input users. More than 90% of farmers who used fertilizers and agro-chemicals were male, while 13% of those who did not use fertilizers were female (Table 3.2).

Table 3.2.: Demographic characteristics of rice farmers (percentages) in Namutumba, Bugiri, Kaliro, Butalejja and Lira districts in Uganda

		Total respondents	**Input users**	**Non input users**	**P-values**
All respondents		100 (n=150)	12 (n=18)	88 (n=132)	
Gender	Male	90.7	96.9	86.2	0.027
	Female	9.3	3.1	13.8	
Occupation	Subsistence farmers	93.4	94.3	92.2	0.968
	Other occupation	6.6	5.7	7.8	
Age	0-30 years	29.2	29.9	28.2	0.634
	31-40 years	35.1	34.5	35.9	
	41-50 years	23.2	19.5	28.1	
	> 50 years	12.6	16.1	7.8	
Marital status	Married	96	95.4	96.9	0.455
	Single/widowed	4	5.5	3.1	
Formal education	None	10.6	9.2	12.5	0.201
	Primary/ Junior	48.3	54	40.6	
	Secondary	36.4	31	43.9	
	Tertiary	4.6	5.7	3.1	
Family size		8.4 (3.65)	8.8 (3.55)	8.07 (3.82)	0.631

Standard deviations are in parenthesis where applicable

Most (93%) respondents were subsistence farmers, while the rest were either civil servants or commercial farmers. More than 60% of all respondents were below 40 years of age while more than 60% of the respondents had attained primary education. Education attained by farmers did not influence choice to use or not to use fertilizers and agro-inputs.

3.4.2 Importance of rice and rice production status in eastern and northern Uganda

Rice was ranked by respondents as the second most important cash crop after maize and the 5th most important food crop after maize, sweetpotatoes, cassava and beans respectively (Figure 3.1). The most popular rice variety grown by farmers was Supa (grown by 71% of respondents) followed by *Kaiso* (Figure 3.2). Other rice varieties grown included the K- series (K- 98, 5, 85) and NERICAS (4, 10). Supa was preferred by farmers as it has a high market demand because of two key attributes: (a) good aroma and (b) high yielding ability (Table 3.3). Likewise, Kaiso was preferred because of its high yielding and early maturity characteristics.

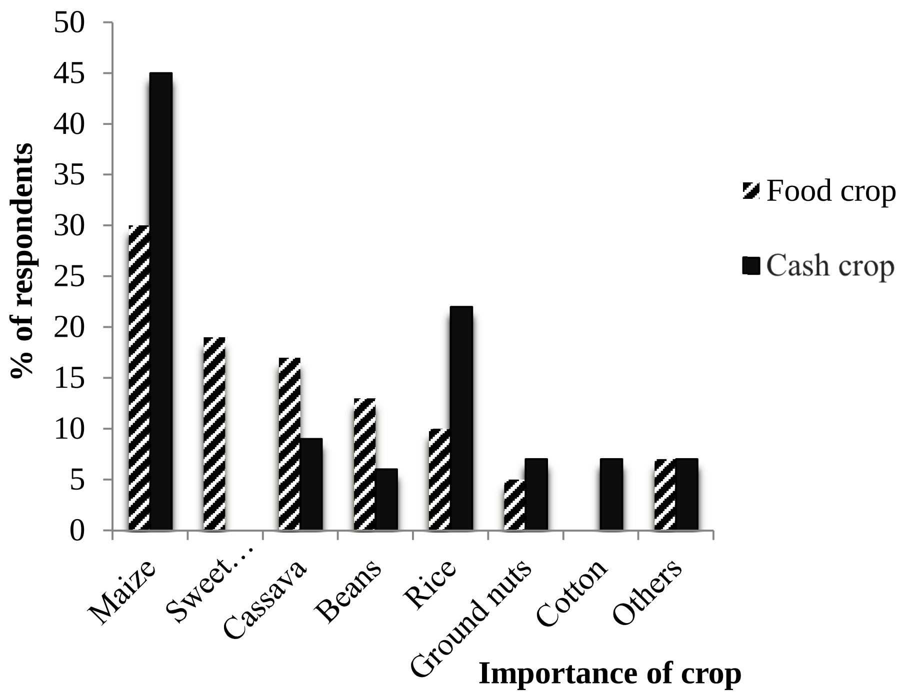
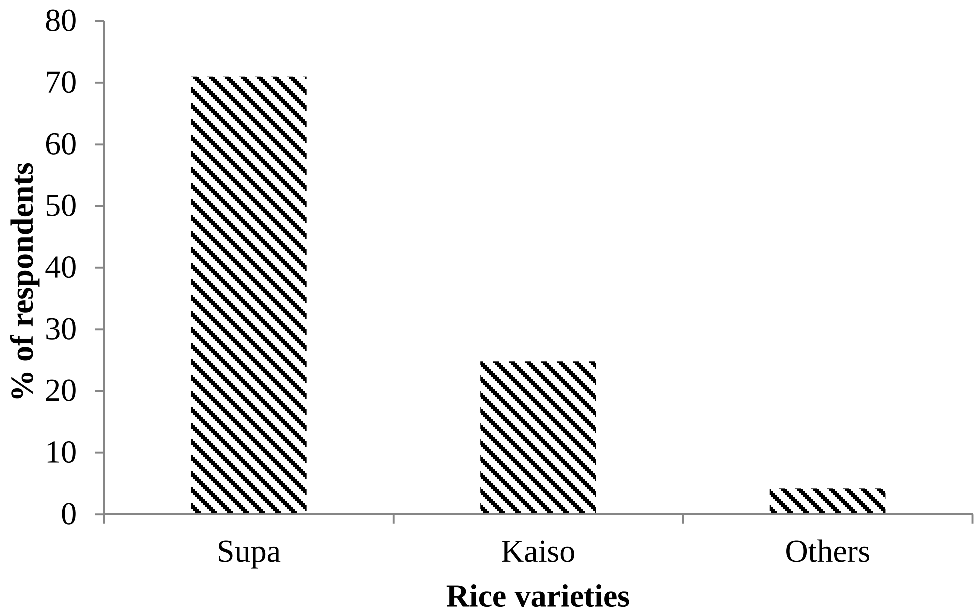


Figure 3.1: Importance of rice and other crop commodities for food and income security in Namutumba, Bugiri, Kaliro, Butalejja and Lira districts in Uganda

Though the majority of farmers in the sampled districts received minimal agricultural training, more trained farmers used fertilizers than their counterparts who never received training in rice production (Table 3.3). Significant differences were also recorded between time of sowing or

transplanting of the rice crop. There was a significant difference between input users and non-input users with respect to time of planting. Overall, most farmers (81 %) plant early (late march and early April (Table 3.4)



Other: K-98, K-5, NERICA 4, NERICA 10

Figure 3.2: Most grown rice cultivars in Namutumba, Bugiri, Kaliro, Butalejja and Lira districts in Uganda

Table 3.3: Farmer preference of two commonly grown rice cultivars, Supa and Kaiso (%) and reasons for preference, in eastern and northern Uganda

Reasons for preference	**Variety**	
	Supa	**Kaiso**
High market demand	27.4	3.4
Early maturity	19.2	23.7
High yielding	23.3	47.5
High grain quality	5.5	8.5
Easy to grow	6.8	5.1
Aromatic quality	6.8	0
Good milling recovery	2.7	5.1
Resistance to pest and diseases	8.2	0

Those who did not use fertilizers concentrated their planting around April meaning that they plant only one season in a year. Overall, 52% of all respondents practiced rice seedling transplanting while the rest practiced direct seeding. The farmers who transplanted their crop used fertilizers and agro-chemicals more than their counterparts who practiced direct seeding. Age of seedlings at transplanting varied between those who used fertilizers and those that did not use fertilizers with the majority transplanting 30 days old seedlings and some transplanting 14-21 days old seedlings. A few farmers, especially non input users, transplant seedlings older than 40 days (Table 3.4). There was a significant difference between input users and non-input users for training in rice production and time of sowing. More input users had participated in trainings in rice production that non-input users. More input users (74.2%) plant early compared to non-input users.

Table 3.4: Agronomic attributes in rice production and farming experience of farmers in Namutumba, Bugiri, Kaliro, Butalejja and Lira districts in Uganda in 2013

		Input users	**Non-input users**	**All sample**	**P-value**
Training in rice production		12.5	2.3	6.6	0.013
Time of planting	Early planting*	74.2	84	81.7	0.017
	Late planting**	25.8	16	18.3	
Method of rice establishment					0.071
	Transplanting	60.6	45.7	52.4	
	Direct seeding	39.4	54.3	47.6	
Age seedlings are transplanted					0.729
	14-21 days	34.2	39.1	36.7	
	30 days	63.2	53.7	58.2	
	45 days	2.6	7.3	5.1	
Source of water					0.050
	Rain water	81.3	92.0	87.4	
	Irrigation water	18.8	8.0	12.6	
Proportion of farmers with problems of soil erosion/ run off		89.1	92.0	90.7	0.545

***** late march, early April; ** May, June

3.2.4 Agricultural inputs used in rice production in eastern and northern Uganda

Only about 12% of the rice farmers sampled used inorganic fertilizers in rice production and none used organic fertilizers. The most used agro inputs in rice production were herbicides used by about 18 % of respondents (Figure 3.3). The most common inorganic fertilizers used were urea and di-ammonium phosphate (DAP) (Table 3.5) applied at a maximum rate of about 50 kgha^{-1} (Data not shown). This rate has its origins from extension messages given to farmer for maize so they apply it for rice as well. Inorganic fertilizers were purchased from input dealers around the villages where the farmers are located. Respondents maintained soil fertility by use of crop residues majorly straw (52.8%) while others managed soil fertility by leaving their fields under fallow between planting seasons for five months in total (Table 3.6). During this time, there is no water in the swamps and they are used as grazing lands as well. More than 99% of respondents did not carry out soil tests (data not shown).

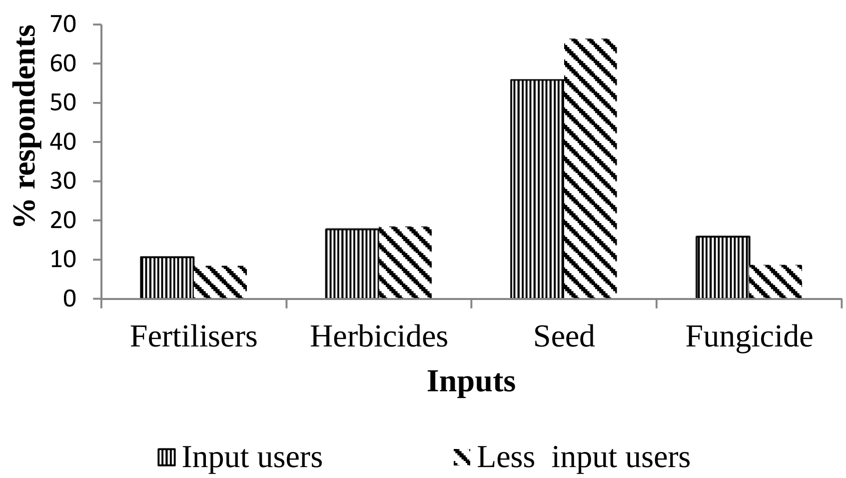


Figure 3.3: Commonly used agricultural inputs in rice production in eastern and northern Uganda

Table 3.5: Types of fertilizers used and percent usage in rice production in eastern and northern Uganda

Type of fertilizer	**Percentage**
Di-ammonium phosphate	38.9
Urea	33.3
Muriate of potash	5.6
Others (specify)*	22.2
Total	100.0

* included organic fertilizers

Table 3.6: Methods of maintaining soil fertility in farmers' fields

Method	**Percentage of respondents**		
	Input users	Non input users	All respondents
Crop rotation	7.7	12.3	10.3
Planting legumes	1.3	0.8	0.9
Fallowing	30.8	38.5	36.0
Crop residues	60.2	48.5	52.8

3.2.5 Rice yield trends and management of declining yields

Generally, most respondents indicated that their rice yields had declined over the previous five years. Majority (72.4%) of those who used agro-inputs and 57% of those who did not use were of the view that their yields were declining. Those who held the view that rice yields had been increasing attributed it to good soil fertility and presence of water. Those who considered it to be declining attributed it to poor soil fertility>, pests and diseases>, weed problems> and insufficient water in that order (Table 3.7). Both input users and non-input users ranked training on soil fertility management as the most urgent solution followed by provision of subsidies on inputs by government and other non-government organizations.

Table 3.7: Farmers' perceptions on rice yield trends (%) in eastern and northern Uganda

	Input users	Non input users	All Respondents
Trend			
Increasing	14.9	26.6	19.9
Decreasing	72.4	57.8	66.2
Constant	12.6	15.6	13.9
Factors contributing to the increasing trends			
High yielding varieties	3.2	16.2	10.3
Good soil fertility	35.2	18.9	26.5
Good agricultural practices	9.7	29.7	20.6
Favorable weather	22.6	8.1	14.7
Good timing of planting	9.7	16.2	13.2
Presence of water	19.4	10.8	14.6
Factors contributing to decreasing trends			
Lack of improved seed	5.9	5.8	5.6
Poor yielding varieties	4.2	4.5	4.2
Pests and diseases	24.4	19.9	21.8
Poor soil fertility	27.7	26.9	27.8
Insufficient knowledge of good production practices	5.9	3.2	4.2
Insufficient water	12.6	16.0	14.1
Weed problems	19.3	23.7	22.2

3.2.6 Indicators of soil fertility and ways of gauging soil fertility among rice farmers in eastern and northern Uganda

Farmers specified that they gauged soil fertility based on the yield output from the land (54.3%), appearance (color) of the soil (13.9%), type of vegetation on the land (7.9%) and color of the crop (9.3%) among others (Table 3.8). Farmers highlighted high crop yield (49.7%), vigorous crop (27.2%), dark green crop (12.6%) and high growth rate of the crop (7.3%) as indicators for good soil fertility. Indicators of poor soil fertility included stunted crop (41.1%), low yield (34.4%), and yellowing or purpling of the crop foliage (9.9%). Soil color, crop yield and growth rate were ranked as the most common indicators used by farmers to gauge soil fertility (Table 3.9).

Table 3.8: Indicators of soil fertility and ways of gauging soil fertility in eastern and northern Uganda

Ways of gauging soil fertility	Input users (%)	Non input users (%)	All sample (%)
Color of the soil	13.3	18.3	16.1
Type of vegetation on the land	11.7	9	10.3
Yield output from the land	27.4	25.9	26.6
Water holding capacity of soil	14.9	14.8	14.9
Color of the crop	11.7	11.4	11.2
Stoniness of the land	2.0	1.4	1.6
Crop height and growth rate	12.1	14.5	13.2
Soil hardness	6	3.1	4.7

Table 3.9: Indicators of soil fertility in northern and eastern Uganda

	Input users (%)	**Non input users (%)**	**All respondents (%)**
Indicators of good soil fertility			
Vigorous crop	21.4	22.1	21.7
Presence of particular weed species	1.3	3.7	2.5
Dark green crop	14.5	15.8	15.3
High crop yield	37.7	35.3	36.4
High growth rate of the crop	25.2	23.2	24.2
Indicators of poor soil fertility			
Stunted crop	39.7	34.9	36.6
Yellowing/ purpling of the crop	15.1	12.2	13.1
Low yield	36.5	37.2	37.3
Presence of some weeds	8.7	15.1	12.7
Poor response to fertilizer/ manures	0	0.6	0.3

3.2.7 Major production problems and factors limiting fertilizer use among rice farmers in eastern and northern Uganda

The most prominent rice production problems identified by farmers can be categorized as biophysical factors (pests and diseases, poor soil fertility and drought) and socio economic factors (labour shortage, lack of credit facilities, lack of market/ low prices produce and high prices of inputs) among others (e.g. Table 3.10). Farmers also indicated that the most important factors limiting fertilizer use were high purchase prices, lack of knowledge on their availability and use. A few farmers indicated that use of fertilizers was not cost effective while some indicated that the soils were still fertile (Figure 3.5).

Table 3.10: Production problems faced by farmers in eastern and northern Uganda and their management in 2013

	Input users (%)	**Non-input users (%)**	**All sample (%)**
Major production problems in rice			
Lack of improved seed	7.5	5.4	6.2
Low yielding varieties	2.6	2.7	2.6
High prices of inputs	6.8	5.4	6.2
Pests and diseases	17.7	16.7	17.2
Poor soil fertility	10.9	9.5	10.5
Inaccessibility of inputs	1.1	2.7	2.0
Inadequate knowledge in rice production	4.9	5.1	4.9
Drought	14.7	17.6	16.2
Lack of credit facilities	5.3	6.5	5.9
Lack of market	14.7	13.4	13.9
Limited labor	13.9	15.2	14.5
Ways of solving production problems			
Availing high yielding varieties	12.0	13.8	12.8
Increased Government incentives to reduce prices of inputs	25.6	19.0	22.0
Trainings on rice production	35.2	30.5	32.8
Improved accessibility to inputs	13.6	15.5	14.4
Construction of irrigation facilities	13.6	21.3	18.0

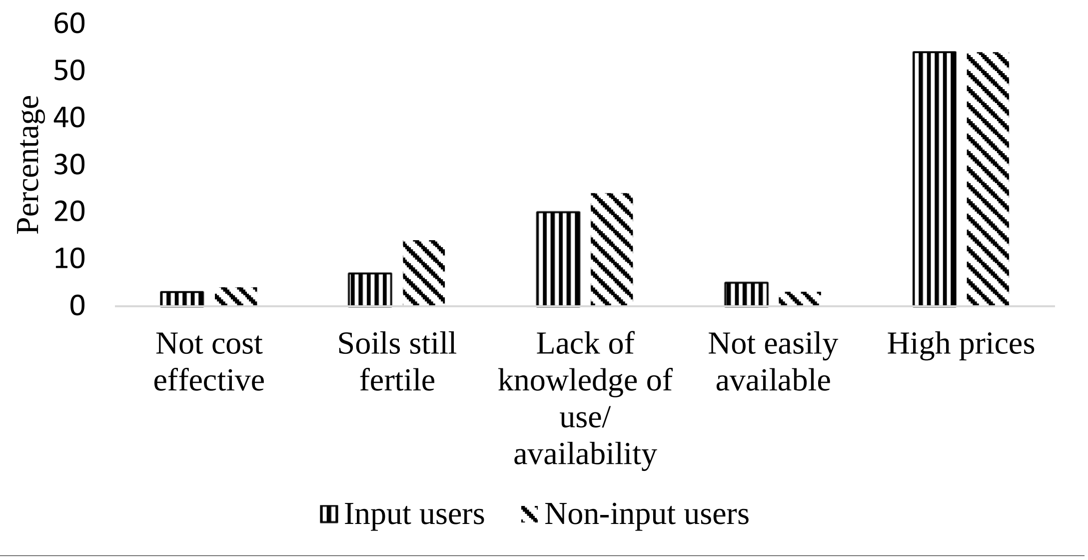


Figure 3.5: Factors limiting fertilizer use in lowland rice in eastern and northern Uganda

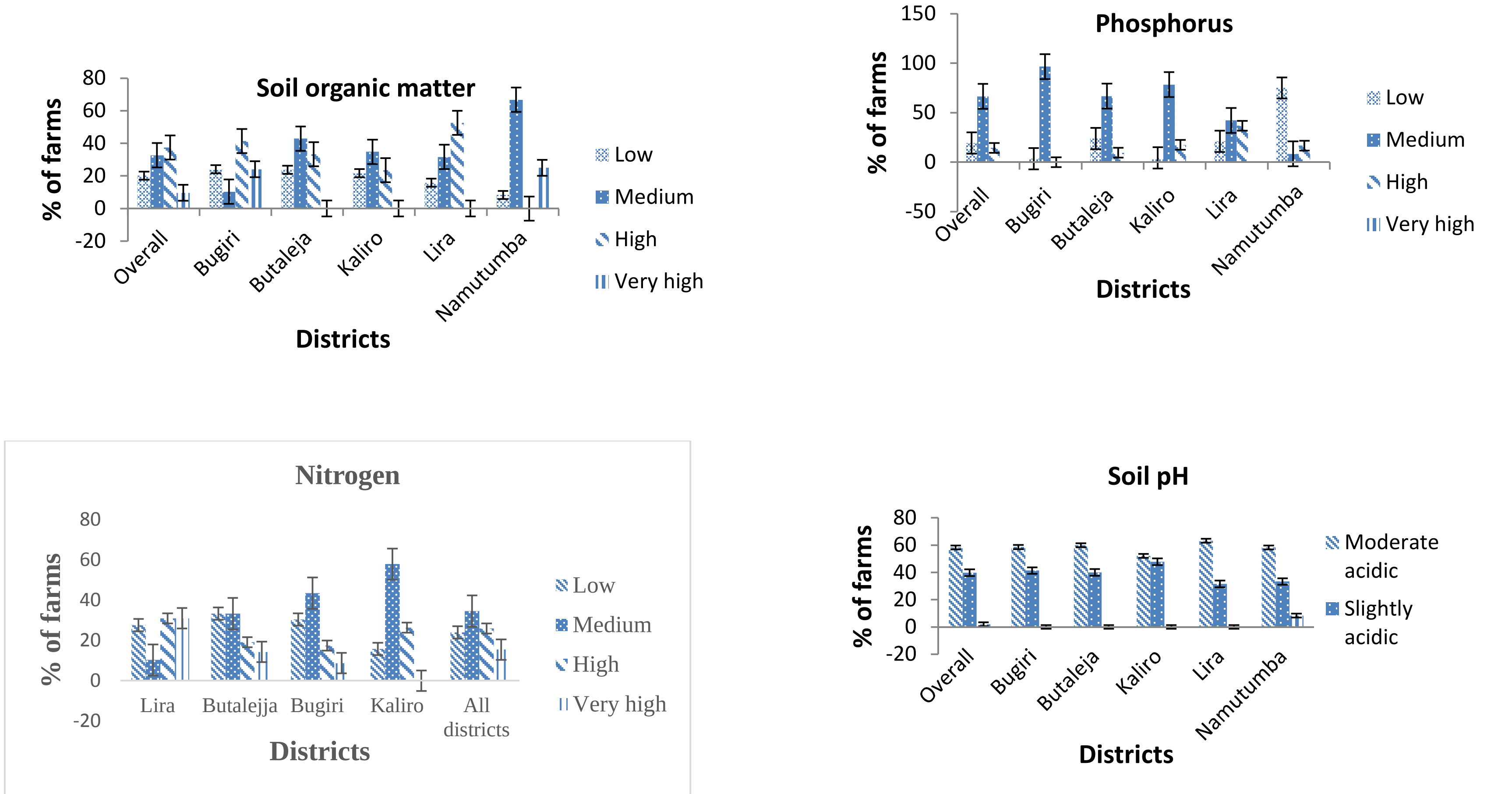
3.3 Soil nutrient status in surveyed farms

The top soil (0-20 cm) sampled from most of the farmers' fields was mostly sandy clay loam. All the sampled fields were moderately acidic with pH levels ranging from 5.1 to 6.5 (Table 3.11). There were significant differences among districts for exchangeable bases Mg and K and available phosphorus. Kaliro and Namutumba districts in eastern Uganda had higher levels of Mg (3.3 and 3.8 cmoles kg^{-1} respectively) and K (1.1 **(**cmoles kg^{-1} each) than the rest of the districts. Similarly, Kaliro district had significantly higher levels of available P (13.3 ppm) than Lira and Namutumba districts. There were no significant differences in the levels of organic matter, total nitrogen, Na and Ca among the five districts. Namutumba and Bugiri districts had about 20% of their farms containing high levels of organic matter. Likewise, about 20% of all surveyed farms in each district had low levels of organic matter. The reverse was true for Olsen P levels in Namutumba district with over 80% of farms having low levels of Olsen P (5-15 mg kg^{-1}).

Table 3.11. Mean averages for organic matter (OM) (%), total N (%), available P (ppm), Na, Mg, K, Ca (Cmoles kg^{-1}) and soil texture across five districts in Uganda

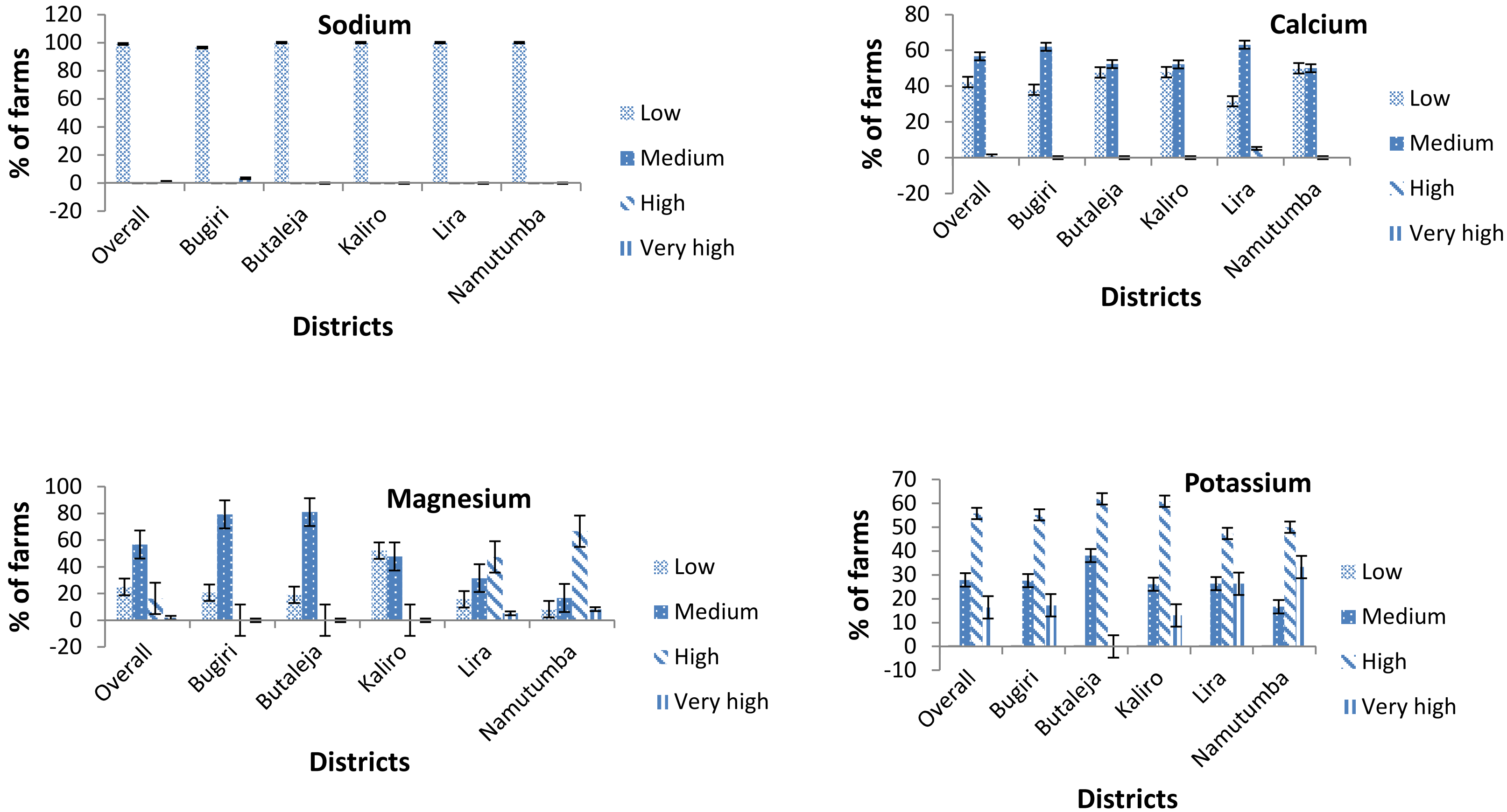
District	OM	Na	Total N	Mg	Exchangeable K	Ca	Available P	% Silt	%Sand	%Clay	pH	Remarks
Bugiri	3.7	0.09	0.18	1.6	0.6	4.9	9.7	15.3	51.7	33.1	6.0	OM, K, P, N- medium, Na- very low
Butalejja	3.4	0.09	0.18	1.8	0.7	5.2	8.3	17.5	50.0	32.5	5.9	OM, N, P- medium, Na- very low, K-high
Kaliro	3.9	0.13	0.18	3.3	1.1	6.1	13.3	16.9	54.7	28.4	5.9	OM, N, P- medium, Na- low, K-high
Lira	4.4	0.22	0.22	1.9	0.8	5.5	7.3	14.3	54.3	31.4	6.0	P- medium, Na-low OM, N, K-high
Namutumba	4.0	0.14	0.23	3.8	1.1	5.9	8.3	23.3	49.2	27.5	5.9	OM, P- medium, Na-low, N, K-high
Average	3.9	0.14	0.20	2.3	0.8	5.4	9.2	16.7	52.3	31.0	5.9	
P-Value	0.31	0.7	0.24	<0.008	0.008	0.32	0.002	0.003	0.6	0.55	0.98	
$LSD_{0.05}$	NS	NS	NS	0.86	0.34	NS	4.2	4.4	NS	NS	NS	

LSD- Least significant difference, NS- Not significant



Bars – standard error

Figure 3.6a: percentage of farms with low-very high levels of soil organic matter, nitrogen, phosphorus and soil pH in five districts of Uganda (see appendix 1 for rating of each nutrient).



Bars – standard error

Figure 3.6b: Percentage of farms with low-very high levels of sodium, calcium, magnesium and potassium in five districts of Ugandan (see appendix 1 for rating of each nutrient).

Lira district had the highest levels of Olsen P (over 40% of farms) (Figure 3.6a). Farms in Bugiri, Butalejja and Kaliro had medium levels of nitrogen while Lira and Namutumba had high levels of nitrogen. Over 50% of surveyed farms had high levels of potassium (K). No farm was found with low levels of K. On the contrary, all surveyed districts had low levels of sodium (Na) (0.1-0.3 cmoles kg^{-1}). Majority of farms had medium levels of magnesium (mg) and calcium (Ca). Farms in Butaleja, Bugiri and Kaliro districts had similar levels of Mg. Despite being located in completely different environments, farms in Lira and Namutumba districts had high levels of Mg. In almost all districts the number of farms with low levels of Ca was almost equal to those with medium levels (Figure 3.6b).

3.3.1 Weed abundance in farmers' fields

The most common weeds encountered were of the family Cyperaceae (*Cyperus difformis* (Plate F), *Kyllinga erecta* Schum. and *Cyperus rotundus* L.) (Figure 3.7). *Cyperus difformis* is an annual weed with triangular stems common in fields with imperfect flooding and is often dominant while *Cyperus rotundus* L. is perennial with erect stems and thrives in areas under intensive cultivation. *Kyllinga erecta* Schum. is a perennial weed common in lowland rice fields. The next important family was Poaceae with the most dominant species being *Cynodon dactylon* (L.) Pers. (Plate B) and *Echinochloa colona* (L.) Link (Plate C). The latter is an annual weed with erect stems, widespread and common in moist upland and poorly flooded lowland rice areas while the former is common in moist but not flooded soils particularly in disturbed areas. Other weeds encountered included *Ludwigia* spp, *Amaranthus* spp, *Panicum repens* L., *Ramphircarpa fistulosa* (Hochst.) Benth (Plate D) and *Commelina diffusa* Burm. F. (Table 3.12).

Table 3.12. Weed species identified from farmers' fields

Name	Family	Life cycle
Ageratum conyzoides L.	Asteraceae	Annual
Cynodon dactylon (L.) Pers.	Poaceae	Perennial
Echinochloa colona (L.) Link	Poaceae	Annual
Rhamphicarpa fistulosa (Hochst.) Benth	Orobanchaceae	Annual
Ludwigia octovalvis (Jacq.) Raven	Onagraceae	Perennial
Panicum repens L.	Poaceae	Perennial
Cyperus difformis L.	Cyperaceae	Annual
Cyperus rotundus L.	Cyperaceae	Perennial
Ludwigia hyssopifolia (G. Don) Exell	Onagraceae	Perennial
Amaranthus viridis Hook. F.	Amaranthaceae	Annual
Amaranthus spinosus L.	Amaranthaceae	Annual
Kyllinga erecta Schum.	Cyperaceae	Perennial
Commelina diffusa Burm. F.	Commelinaceae	Annual

3.4 Determinants of use of agro-inputs by farmers in lowland rice production

Use or no use of fertilizer or agro-chemicals by rice farmers in Uganda was modeled using the probit model (Table 3.13). Overall, occupation, age and fertilizer prices had a significant effect on fertilizer use. Occupation of farmers was a positive significant factor determining fertilizer use among rice farmers. Hence, farmers with other sources of income were more likely to use fertilizers. High price of fertilizers was another significant factor but with a negative coefficient implying that the high price of fertilizers reduced access leading to the lower use. Age was a negative factor implying that old people (>30 years) were less likely to use fertilizers.

A: *Ageratum conyzoides* L.

B: *Cynodon dactylon* (L.) Pers.

C: *Echinochloa colona* (L.) Link

D: *Rhamphicarpa fistulosa* (Hochst.) Benth

E: *Ludwigia octovalvis* (Jacq.) Raven

F: *Cyperus difformis* L.

G: *Cyperus rotundus* L.

H: *Commelina diffusa* Burm. F.

Figure 3.7: Common weeds in farmers' fields in Eastern and northern Uganda.

Household size, gender and training in rice production were found to be significant factors determining the use of agro-chemicals among lowland rice farming households. Household size had a positive coefficient implying that larger households were more likely to use agro-chemicals than small households. Gender was another factor that had a significant positive coefficient implying that more male farmers were likely to use agro-chemicals than their female counterparts. Training on rice production was also significant and positive indicating that farmers who received training on rice production also used agro-chemicals more than those who did not receive training.

Table 3.13: Determinants of use of fertilizers and agro-chemicals in rice production (Probit model)

	Inorganic fertilizers		**Other agro-chemicals**	
Variable	**Coefficient**	**Standard error**	**Coefficient**	**Standard error**
Household size			0.047*	0.026
Gender	-0.11	0.481	1.249**	0.512
Improved variety	-0.05	0.308	-0.257	0.256
Training in Rice production	0.07	0.584	1.444***	0.507
Training in soil fertility	0.191	0.335		
No knowledge on fertilizers	-0.317	0.316		
Education	0.281	0.276	0.219	0.223
Size of Land	-0.019	0.034	0.002	0.025
Occupation	1.135***	0.502	0.099	0.459
Age				
<30 years old	-0.068	0.307	-0.104	0.274
>more than 50 years old	-0.426	0.495	-0.683	0.413
High price of inputs	-0.802**	0.481		
Yield trend (decreasing)	0.433	0.403		
Yield trend (constant)	1.142**	0.481		
Constant	-0.508	0.648	-1.859***	0.562
Pseudo R^2	0.163		0.105	

***, **, * denote 1%, 5% and 10% significance levels, respectively

3.5 Discussion

3.5.1 Rice production in eastern and northern Uganda

In this study, rice was ranked as the second most important cash crop after maize and fourth most important food crop after maize, sweetpotatoes, cassava and beans (Figure 3.2). Rice is therefore a very important income and food security crop for farmers in eastern and northern Uganda. The results of this report corroborate results by Statistics U. B. O. S (2010) that rice is an important food and cash crop among rice farmers in eastern and northern Uganda. Supa and Kaiso varieties were the most popular lowland rice cultivars grown with the former being the most preferred. Farmers in eastern and northern Uganda have clearly indicated that Kaiso is preferred for its high yield while Supa is preferred for its aroma. Haneishi *et al.*, 2013 found Supa and Kaiso to be the dominant varieties and estimated that 50% of all lowland rice plots surveyed were planted with Supa. Noteworthy is the fact that Supa and Kaiso varieties were introduced in the 1970s when farmers started taking up rice production. There is therefore need to introduce modern high yielding rice varieties to farmers in order to raise production. Such modern varieties were central to the acceleration of yield growth during the Asian green revolution and were recently shown to increase yields and income in Tanzania if adopted with inorganic fertilizers and proper crop management practices like bunding and transplanting in rows (Nakano and Kajisa, 2012). This calls for investment in a robust research and extension system that can ably take new technologies to the farmers.

3.5.2 Use of agro-inputs in rice production in eastern and northern Uganda

The survey results found few farmers using agro-inputs in lowland rice production. The most commonly used input was herbicides used to manage weeds while less than 15% of the farmers used inorganic fertilizers. Most farmers said they maintained soil fertility by fallowing while others used crop residues. Interviewed farmers viewed the high prices of fertilizers as the most limiting factor to fertilizer use (Figure 3.5). Other limiting factors mentioned included inadequate knowledge, low availability and profitability. Yamano and Arai, (2011) pointed out that fertilizer use intensity in SSA had only increased from 7 to 8 kg ha^{-1} between 1982 and 2002, compared to an increase from 38 to 101 kg ha^{-1} in south Asia during the same period. The results presented here are supported by FAO, (2010) which indicated that the total fertilizer consumption (in nitrogen fertilizer) in Uganda remained at a low level in 2010: the 5-year average being only 3,842 MT, which was about 5% of the Kenyan fertilizer consumption and 12% of the Ethiopian fertilizer consumption at that time. The low usage of inorganic fertilizers in Uganda could be linked to the lack of agricultural credit services, lack of a large scale government fertilizer program that provides subsidized fertilizer to farmers and the absence of an active private fertilizer sector that supplies fertilizer at competitive prices (Yamano and Arai, 2011). The above factors have not only affected accessibility of fertilizers by farmers, they have also contributed to high prices of fertilizers at local dealers stores when available. These results confirm the hypothesis that low yields at smallholder farms are linked to low use of agro inputs including fertilizers and agro-chemicals.

3.5.3 Farmer perceptions on soil fertility, yield and ways of gauging soil fertility

Majority of the farmers indicated that their rice yields have been declining over the past five years due to declining soil fertility, pests and diseases, weed problems and insufficient water. This shows that the farmers are aware of the production problems they are facing and are likely to embrace solutions aimed at solving them. Many authors have reported declining soil fertility as a major constraint limiting production (e.g. Amede, 2003; Smaling *et al.*, 1997; Heisey and Mwangi, 1996). In order to reverse this trend, farmers are of the view that training on rice production is intensified and the government should ensure that fertilizers are affordable.

Farmers had indigenous ways of gauging soil fertility. Most farmers gauged poor soil fertility through visual observation of crop stunting, poor harvests, yellowing/ purpling of the crop as well as presence of some weeds (e.g. *Cynodon dactylon* (L.) Pers.). Soil color, crop yield and growth rate were ranked as the most common indicators used by farmers to gauge soil fertility. These factors determine the choice of plots of land to be planted with a specific crop the next season. The findings of this study are consistent with those by Desbiez *et al.*, (2004) who reported that the principal indicators of soil fertility mentioned by farmers in the mid-hills of Nepal were soil color, crop yield, crop height and growth rate. It is clear that farmers use soil fertility indicators to make soil fertility management decisions. That farmers can gauge soil fertility using their own means is good news which can positively influence adoption of technologies targeting soil fertility improvement.

3.5.4 Soil nutrient status in farmers' fields and management

Most of the farms surveyed were moderately acidic with medium levels of organic matter, nitrogen Olsen P, Mg and Ca and high levels of exchangeable K (Figure 3.6). Farms in Namutumba district had exceptionally low levels of Olsen P compared to other farms (>80%) despite having medium to high levels of soil organic matter. Available N levels in Lira and Namutumba districts were high. According to Cassman *et al*. (1996) no correlation was found between total soil organic nitrogen and indigenous nitrogen supply. The surveyed farms had medium levels of OM, available P, total nitrogen and high levels of exchangeable K. The high levels of organic matter, Olsen P and available K recorded can be attributed to the farmers' practice of leaving straws in the garden and fallowing their plots for almost six months before the next season's planting. However, the quality rather than the quantity of soil organic matter leads to improved soil quality, and hence a more sustainable cropping system (Kirk and Olk, 2000). Phosphorus availability is said to increase in flooded soils because of the reduction of ferric phosphate to the more soluble ferrous form and the hydrolysis of phosphate compounds and is more pronounced in acidic soils where P is immobilized by Fe and Al oxides (Fageria *et al*, 2011). The low pH of the sampled soils (5.1- 6.1) thus explains the high levels of phosphorus in this study. The low yields obtained at farmers' fields could be a results of many factors including pests and diseases, drought and low yielding varieties.

3.5.5 Common weed species sampled in farmers' rice fields in eastern and northern Uganda

The most common weeds found in farmers' fields were of the families cyperaceae (*Cyperus difformis, Kyllinga erecta* Schum. and *Cyperus rotundus* L.) and poaceae (*Cynodon dactylon* (L.) Pers. and *Echinochloa colona* (L.) Link.). All weeds were characteristic of areas under intensive cultivation and imperfect flooding (Jonhson, 1997) which highlights the fact that the problem of insufficient water in rainfed lowlands is not only affecting rice yield but it is also favoring the dominance of some weed species. The dominance of these weeds could also be related to their being difficult to manage. The parasitic weed *Ramphircarpa fistulosa* (Hochst.) Benth was also encountered in Butalejja and Bugiri districts. *R. fistulosa* has been reported in Tanzania (Kayeke *et al.,* 2010) and West Africa (Rodenburg *et al.,* 2011) where it has caused yield losses of more than 60%. There is need to map out areas infested by *R. fistulosa* in Uganda so as to identify management solutions for the parasitic weed while training on good weed management techniques would help reduce losses caused by weeds in lowland rice production.

3.5.5 Determinants of the use of fertilizers and agro-chemicals in eastern and northern Uganda

The results of the probit model confirm the factors reported to limit use of fertilizer and agro-chemicals among rice farmers. It also confirms the study's hypothesis that fertilizer prices, household size, training in rice production and gender are important factors determining the usage of fertilizers and agro-chemicals in rice production. Several authors have found similar findings albeit for different crops (e.g. Knepper, 2012; Apkan *et al.*, 2012; Wanyama *et al.*, 2010). Knepper, (2012) found that male headed households growing maize were more likely to use fertilizers than female headed households. Similarly, Apkan *et al.*, (2012) found that male farmers were more likely to increase fertilizer use intensity compared to their female counterparts. That men are more likely to use fertilizers than women could be linked to ease of access to inputs, wealth as head of families and cash from non-agricultural part-time jobs. Indeed, Apkan *et al.* (2012) argues that the gender differences may be linked to cultural barriers which give men more access to resource ownership through inheritance.

The positive coefficient of the household size variable in this study implies that households with more members are more likely to use agro-chemicals. Knepper, (2002); Mussei *et al*., (2001) and Nkonya *et al.*, (1997) reported similar results in Zambia, Tanzania and Uganda respectively. On the contrary, Apkan *et al.*, (2012) and Croppenstedt and Demeke, (1996) found family size to be a negative determinant of fertilizer use and intensity. In their case, increase in household size was associated with decreased fertilizer usage and intensity. In Uganda, large family sizes are associated with availability of cheap labour and is therefore a significant factor determining farm size. As a result, larger households tend to farm bigger plots where they often harvest more food than smaller households irrespective of whether they use fertilizer or not. This explains the positive coefficient of the household variable in the model.

The negative coefficient of the high price variable confirms a prior expectation that increase in fertilizer prices reduces fertilizer usage among lowland rice farmers. This suggests that in Uganda, the prohibitively high farm gate prices of fertilizers are limiting farmers' ability to access them hence only those who have income from other sources can afford it. This has resulted in continuous soil mining and declining rice yields. Similar findings have been found by Apkan *et al*., (2012) in Nigeria and Croppenstedt and Demeke, (1996) in Ethiopia. High fertilizer prices in SSA are said to be the result of infrastructure limitations such as roads and lack of government support programmes.

Training in rice production was found to have a positive impact on the use of fertilizers and agro-chemicals. Farmers who had been trained in rice production were found to use fertilizer more than those who had not received the training. Training is therefore an important determinant in technology adoption (CIMMYT, 1993).

3.6 Conclusion

The results of this research have shown that organic matter and available P were moderate in farmers' fields while total N was deficient. The research also showed that rice production occurs with minimal addition of external inputs with only 12 and 18% of farmers applying fertilizers and herbicides respectively. The most commonly applied fertilizers are DAP and urea applied at a rate of 15-50 kgha^{-1} which is much lower than the expected rate of about 80 kg of N ha^{-1}. Results also showed that farmers are aware that their yields are declining and the main cause is declining soil fertility together with other constraints. In addition, farmers can gauge a poor soil based on the amount of crop harvested, colour of the soil and whether the crop is stunted or not. This helps them to make decisions for next season's planting. The results of the probit analysis showed that occupation and fertilizer prices had a significant effect on fertilizer use while household size, gender and training in rice production were significant factors determining the use of agro-chemicals among lowland rice farming households.

CHAPTER 4: EFFECTS OF NURSERY MANAGEMENT PRACTICES, SEEDLING TRANSPLANTING AGE AND SPLIT N-FERTILIZER APPLICATION ON GROWTH AND YIELD OF RICE

4.1 Abstract

Rice is an important food and cash crop in Uganda. However, rice yields are still low due to poor rice production methods on smallholder farms especially poor nursery and nitrogen fertilizer management practices. This study was set up to investigate the effect of nursery management practices, age of seedlings at transplanting and split application of nitrogen fertilizer on the yield of four rice cultivars (WITA 9, GSR 007, K 85 and K 5) in Uganda. The nursery experiment was established with five treatments: 1) control (no chemical + transplanting 30-day old seedling), 2) di-ammonium phosphate (DAP) + fungicide + transplanting 14 day old seedlings, 3) DAP + transplanting 14 day old seedlings, 4) DAP + transplanting 30 day seedlings and 5) fungicide + transplanting 30 day old seedlings. The effect of split N application on yield, was studied by setting an experiment using a split plot design with four N-fertilizer treatments: 1) control (no fertilizer added), 2) 23 kg N ha^{-1} applied at once, 3) 23 kg N ha^{-1} applied in two splits (tillering and panicle initiation), 4) 46 kg N ha^{-1} applied at once and 5) 46 kg N ha^{-1}applied in two splits (active tillering and panicle initiation). Generally, applying DAP in the nursery and transplanting 14 day old seedlings resulted in a yield increase of 23-30% relative to the control. Transplanting 30 day old seedlings did not result in any yield gain when fertilizer and fungicides were applied in the nursery. Average yield across treatments was 2.4 t ha^{-1}. When 23 kg of N was applied at once to all varieties, GSR 0057 yielded better than WITA 9 but its yield was similar to K 5 and K 85. Application of 46 and 23 kg of N ha^{-1} at once had significantly lower harvest indices (HI= 0.31 and 0.32 respectively) than the control and split application of 23 and 46 kg of N ha^{-1}. The agronomic efficiency of fertilizer N usage was variable registering an average of 22.6 kg kg^{-1}. Gross return

overt fertilizer was increased by 36 and 108 $\$ha^{-1}$ with split application of 23 and 46 kg of Nha^{-1} respectively. Results of this study demonstrate that lowland rice production in Uganda can be increased by a combination of nutrient management in the nursery and transplanting young seedlings. This represents a simple and economical option for farmers to increase rice yields. Improving N- management and nursery management has greater prospects for increasing rice yields on all cultivars in smallholder farms at minimal costs.

4.2 Introduction

Rice (*Oryza sativa* L.) is an important food and cash crop for farmers in Uganda. The major rice growing areas in Uganda include the districts of Pallisa, Butalejja, Iganga, Lira, Bundibujjo and Bugiri (Haneishi, *et al.,* 2013). Rice production has increased in the recent past from 46,000 ha producing 190,736 MT in 2000 to 75,086 ha producing 212,000 MT in 2012 (FAOSTAT, 2015). Despite the increase in rice production, rice yields are still low averaging 1.5 t ha^{-1} in the lowland rice ecosystems. One of the reasons for the low yields is the fact that many farmers cultivate lowland rice without applying appropriate cultivation practices (Balasubramanian *et al.,* 2007). For instance, the majority of the farmers practice continuous rice cropping without fertilizer application leading to continuous soil nutrient mining (Sanchez, 2002). Poor crop establishment methods practiced by farmers also contribute to poor germination and hence low plant population per unit area. The few farmers who practice transplanting transplant old seedlings raised in poorly managed nurseries (Kijima *et al*., 2010). Haneishi *et al.* (2013) found that a few farmers use inorganic fertilizers and other agro chemicals. The fertilizer is often applied as a blanket recommendation rather than according to plant requirements. Split applications of N, a highly mobile nutrient has benefits of increased N- use efficiency, reduced N losses and increased yields

(Linquist and Sengxua, 2003). Fertilizer usage among smallholder farmers is said to be limited by lack of initial capital (Nakano and Kajisa, 2012), inadequate knowledge on their availability and usage and low returns on fertilizer investment (Chapter three of this thesis). Nhamo *et al*. (2014) indicated that the major weakness with the current mineral fertilizers application rates used by smallholder farmers on rice is the fact that they lack scientific basis. One way of helping farmers to maximize benefits from urea is by applying it in splits at active tillering and panicle initiation stages. Another option is to help farmers produce more vigorous seedlings that out-compete weeds and grow faster thereby producing better yields. Properly managed seedbeds with adequate plant nutrition, optimal seedling densities and use of seedlings at appropriate age are important factors leading to vigorous plant stands after transplanting (Lal and Roy, 1996). An additional small investment in raising health and vigorous seedlings in the nursery was projected to increase yields by up to 2 t ha^{-1} (Panda *et al*., 1991). The objective of this study was to investigate the effect of nursery management practices, age of seedlings at transplanting and split application of nitrogen fertilizer on the yield of four rice cultivars (WITA 9, GSR 007, K 85 and K 5) in Uganda.

4.3 Materials and Methods

4.3.1 Site description

The experiments were set up in Bugiri district (034’14.66” N, 33 44’ 56.04”E) eastern Uganda in 2014. The soils are laterite and ferralitic, with deep reddish brown sandy loams mixed with clay loams (Yost and Eswaran, 1990).

In general, there are two distinct rainfall seasons in a year; April to June and August to November. The two are punctuated by a dry season from December to March. Mean temperatures range from 16.7 to 28.1°C with the month of February being the hottest. The average monthly rainfall totals and maximum temperatures for the period 2013 to 2014 are shown in Figure 4.1 and 4.2.

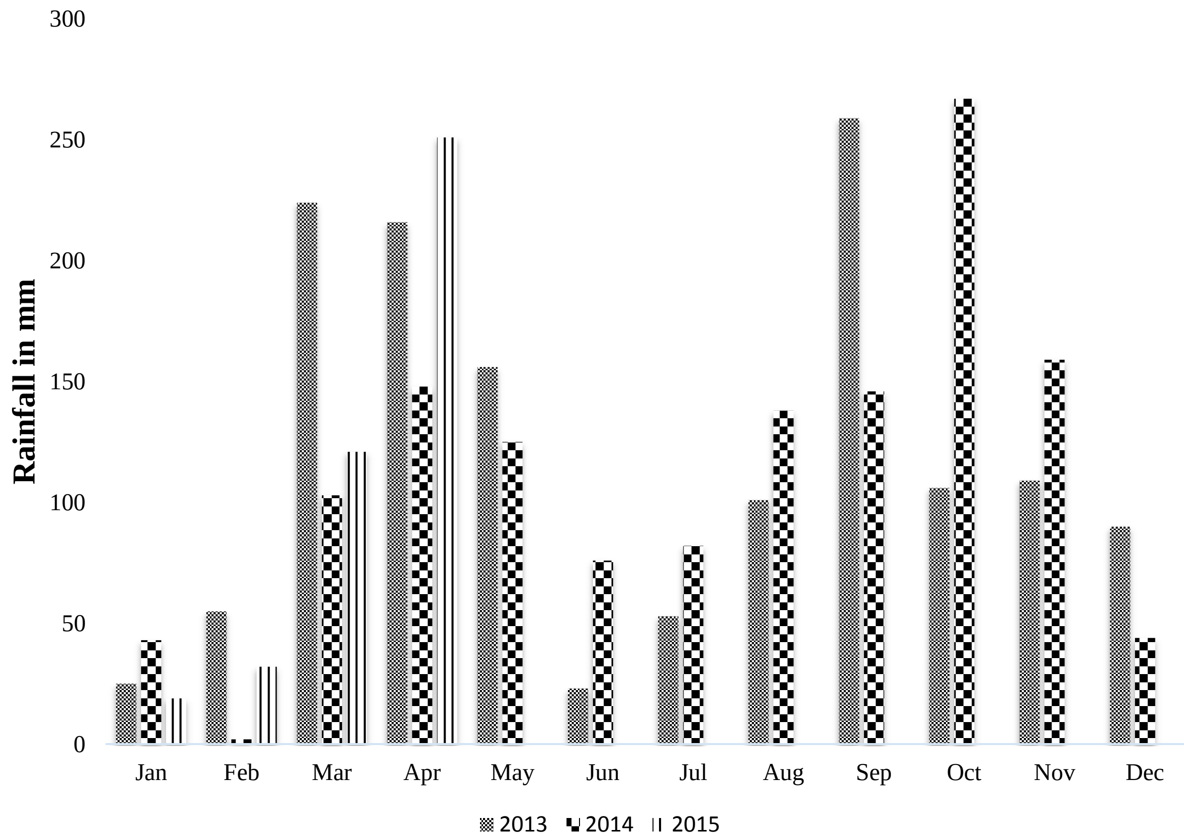


Figure 4.1: Average monthly rainfall (mm) totals for Kibimba and surrounding villages 2013 – 2015. Courtesy: TILDA rice scheme (Kibimba) weather station

4.1.2 Experimental design and treatments

4.1.2.1 Effect of seedling age at transplanting and application of fertilizer and fungicide in the nursery on rice yield

The experiment was initially set up in the nursery using four treatments: 1) control (no chemical), 2) di-ammonium phosphate (DAP) + fungicide, 3) DAP and 4) fungicide. Four varieties namely WITA 9, GSR 007, K 85 and K 5 were used for the experiment. Each treatment was imposed on all four varieties on a plot measuring $4m^2$ ($1m^2$ per variety). Di-ammonium phosphate (DAP) was applied to the nursery at a rate of 50 g m^{-2} and incorporated in the soil before sowing. In the fungicide treatment, seeds were soaked in carbendazim (methyl benzimidazol-2-yl carbamate) over night before being pre-germinated. Carbendazim is indicated for the treatment of fungal pathogens on cereals, fruits, cotton, tobacco, ornamental crops and vegetables.

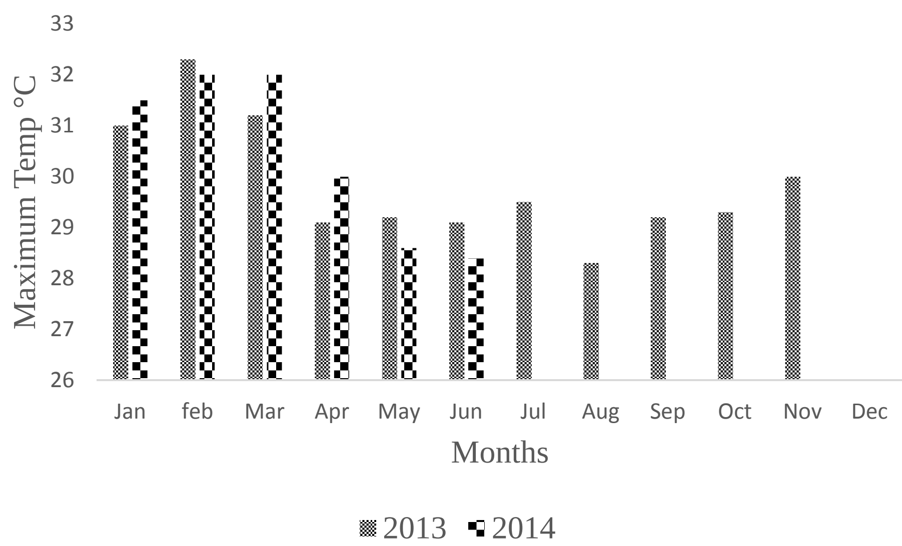


Figure 4.2: Maximum temperatures (°C) for Bugiri district and surrounding areas for 2013 and 2014

The fungicide solution was constituted by mixing 25 ml in 20 liters of water, as per the manufacturer's recommendations. In order to be able to transplant both 14 and 30 day old seedlings at the same time, another nursery with the same treatments was set up 16 days after the first nursery. The nurseries were watered whenever necessary. Seedlings were transplanted to the main experimental field at 14 and 30 days after sowing using the following treatments: 1) control (no chemical + transplanting 30-day old seedling, 2) di-ammonium phosphate (DAP) + fungicide + transplanting 14 day old seedlings, 3) DAP + transplanting 14 day old seedlings, 4) DAP + transplanting 30 day old seedlings and 5) fungicide + transplanting 30 day old seedlings. The treatments were arranged using a split plot design with treatments as main plots and varieties as sub plots and replicated four times. Main plots were measuring 8 x 6 m while subplots were measuring 3 x 4 m. Three rice plants were transplanted per hill at a spacing of 25 cm x 25 cm

4.1.2.2 Effect of splitting N-fertilizer applications on rice yield

In order to investigate the effect of split application of N on yield, an experiment was set up for two seasons in 2013 using four rice varieties: WITA 9, GSR 007, K 85 and K 5. The experiment was set up using a split plot design with four N-fertilizer treatments: 1) control (no fertilizer added), 2) 23 kg N ha^{-1} applied at once, 3) 23 kg N ha^{-1} applied in two splits (tillering and panicle initiation), 4) 46 kg N ha^{-1} applied at once and 5) 46 kg N ha^{-1}applied in two splits (active tillering and panicle initiation). The treatments were replicated four times. Urea (46% N) was used as the source of nitrogen. Main plots were N fertilizer treatments while varieties were sub plots. Main plots were measuring (10 x 6m) while subplots were measuring 3 x 5m. Three rice plants were transplanted per hill at a spacing of 25 cm x 25 cm. The fertilizer N rates adopted for this experiment are either similar to or double those that are used by farmers in the region (Haneishi *et al.*, 2013 and chapter three of this thesis). The rate was doubled in respective treatments (46 kg N ha^{-1}). The four varieties were established in the nursery using a rate of 50 kg/500 m^2. Seedlings were transplanted at 21 days after sowing. Rice plants were transplanted at a spacing of 25 cm x 25 cm with three seedlings per hill. Weeds were managed manually by hand weeding twice each season at 25-30 days after transplanting (DAT) and 40-50 DAT and by spraying with satunil 60EC (40% Theobencarb and 20% propanil at a rate of 200-500 l ha^{-1}). Rice blast was managed by applying Orius (250g l^{-1} tebuconazole) at 750 l ha^{-1} at panicle initiation. All experiments relied on rainfall for water.

4.1.3 Data collection

Data from experimental plots were collected, according to the standard evaluation system of rice (Gomez, 1972) on plant height at 105 days after sowing (DAS), number of tillers at 89 DAT, days to 50% heading, flowering date (50% flowering), days to maturity, number of panicles, grain yield and rice biomass dry weight at harvest. Panicles were counted prior to harvest. Plant height was taken on two hills per plot whereas numbers of tillers and panicles were taken on an area of 0.025 m^2. Plants were harvested from 12 hills in each plot at physiological maturity and used to determine % filled grains, harvest indices and nutrient concentrations in plant tissue. Grain yields were obtained from a central 5 m^2 harvest area in each plot at harvest. Grain yields and total biomass (grain + straw yields) were adjusted to 14% moisture content.

4.1.4 Data analysis

For all the variables, Shapiro-Wilks test ($P<0.05$) (Shapiro and Wilk, 1965) and visual inspection of their respective histograms and box plots showed that they were approximately normally distributed across seasons and treatments with their standard errors in normal range (Crammer, 1998). Data was analyzed with Genstat 12th edition using a generalized model for analysis of variance (ANOVA). Means were separated by Fisher's least significant difference at $P<0.05$.

Agronomic N use efficiency (AE), the increase in yield per unit of applied fertilizer N was used as a measure of N use efficiency (Linquist and Sengxua, 2003) because it is proportional to the cost-benefit ratio from investment in N inputs (Cassman *et al*., 1996). AE was calculated as:

$$AE = \frac{Yield\ (kg)\ in{+}\ N\ plots - Yield\ (kg)\ in{-}N\ plots}{Amount\ of\ fertilizer\ applied\ (kg)}$$

Gross return over fertilizer cost (GRF), the farm gate revenue from produced rice minus cost for fertilizer N applied, was calculated as follows:

GRF = PRYR -TFC_N; Where, TFC_N = total fertilizer cost of N fertilizer ($\$ha^{-1}$), PR =price of rice (\$0.36/kg paddy), and YR = rice yield (kg ha^{-1}). TFC_N = PNFN; where PN = price of N fertilizer (\$1.94/kg N), FN=amount of N applied (kg Nha^{-1}). GRF provides a relative measure for the benefit derived by farmers from the use of fertilizer N.

4.2 Results

4.2.1 Effect of nursery management practices and age of seedlings on yield

There was a significant difference between treatments ($P<0.05$) for yield and the interaction between treatment and season was significant for yield. Applying DAP and transplanting 14 day old seedlings plus applying DAP, fungicide and transplanting 14 day old seedlings resulted in the highest yield (average yield= 3.4 and 3.2 t ha^{-1}respectively) (Table 4.1).

Applying fungicide and transplanting 30 day old seedlings resulted in the lowest yield (average yield= 2.4 t ha^{-1}) but it was not significantly different from the control. Generally, DAP + fungicide and transplanting 14 day old seedlings resulted in a yield increase of 23-30% when compared to the control. There was no significant difference between treatments for mean plant height, number of tillers and panicles, harvest index and percentage of filled grains. However, the interaction between treatment and season was significant for plant height, number of tillers, number of panicles and filled grains. Overall, more tillers and panicles were produced in 2014B than 2014A (Table 4.2). The highest numbers of tillers and panicles were produced when DAP was applied and seedlings transplanted at 14 days after sowing (average number of tillers and panicles = 659 m^{-1} and 532.7 m^{-1} respectively). Likewise, plants that received DAP and were transplanted at 14 days were taller than the rest. On the contrary, plants were taller in 2014A than in 2014B. Similarly, the percentage filled grains were lower when DAP was applied in the nursery and seedlings transplanted at 14 days after sowing than in the rest of the treatments.

Table 4.1: Growth, yield and yield components under different nursery treatments in Bugiri district in 2014

	Yield (t ha^{-1})			Number of tillers			Number of panicles			Plant Height (cm)			% filled grains		
Trt	2014 A	2014 B	Mean	2014 A	2014B	Mean	2014 A	2014B	Mean	2014 A	2014B	Mean	2014 A	2014 B	Mean
Control	1.2	3.1	2.6	434.0	712.5	573.4	282.5	507.5	395.0	88.8	89.0	88.8	84.1	81.1	82.6
F+DAP+14D	3.1	3.3	3.2	602.5	610.5	606.5	507.0	513.0	510.0	87.4	87.9	87.7	81.8	82.8	82.3
DAP+14D	3.2	3.5	3.4	650.0	668.0	659.0	525.0	540.5	532.7	89.1	91.5	90.3	76.1	77.1	76.6
F+30D	1.6	3.1	2.4	511.5	626.5	569.0	384.5	501.0	442.8	91.5	87.3	89.5	87.5	81.0	84.3
DAP+30D	1.9	2.9	2.4	602.0	635.0	618.5	443.0	516.6	485.0	92.9	86.3	89.5	83.9	84.9	84.5
Mean	2.2	3.2		560.0	650.5		428.4	551.7		89.9	88.4		82.0	81.4	
$LSD_{0.05}$ Trt		0.8			145.7			112.5			6.2			8.5	
$LSD_{0.05}$ S		0.2			33.4			24.7			2.2			8.2	
$LSD_{0.05}$ Trt x S		0.9			152.4			117.3			6.7			1.6	
CV (%)		19.1			4.5			15.4			15.6			6.5	

First season 2014, B- Second season 2014, Trt- Treatment, Control (No fertilizer + no chemical + transplanting 30-day seedlings), F- Fungicide, DAP- Di-ammonium phosphate, 14D - transplanting 14-day-old seedlings, 30D- transplanting 30-day old seedlings, S- Season, 2014A- first season 2014, 2014B-second season 2014.

Although mean yields were not significantly different between varieties, the interaction between treatment and variety was significant for plant height. K 85 and K 5 were the tallest varieties but with statically similar heights (Table 4.3). Generally, varieties that received DAP and were transplanted at 14 days after seeding were taller than the rest of the varieties in other treatments. Harvest index was generally below 0.4 for all treatments and varieties with exception of K 85 in the control treatment (harvest index= 0.42)

Table 4.2: Growth, yield and yield components across seasons 2014A and 2014B in Bugiri district

Parameter	Season		CV (%)	$LSD_{0.05}$
	2014A	2014B		
Yield (t ha^{-1})	2.26	3.13	14.1	0.24
Height (cm)	90.44	88.29	2.9	1.71
No. tillers (m^{-2})	563.70	648.9	10.4	33.34
No. panicles (m^{-2})	431.50	516.6	6.2	24.70
HI	0.32	0.35	4.1	1.63
% filled grains	82.89	81.2	4.0	0.02

No. – Number, HI- Harvest index, 2014A- first season 2014, 2014B-second season 2014

Table 4.3: Mean plant height of four varieties under different nursery treatments

Treatment (Trt)	Varieties			
	GSR 007	K 5	K 85	WITA 9
Control	81.3	95.7	97.8	78.9
F+DAP+14D	79.7	101.7	92.3	75.8
DAP+14D	85.3	93.8	100.0	86.9
F+30D	82.8	95.2	97.7	82.2
DAP+30D	84.1	96.4	95.2	82.5
Mean	83.0	96.3	95.2	81.3
$LSD_{0.05}$ Trt	NS			
$LSD_{0.05}$ Variety	2.2			
$LSD_{0.05}$ variety x Trt	7.3			
CV (%)	15.6			

Control (No fertilizer + no chemical + transplanting 30 day seedlings), F- Fungicide, DAP-Di-ammonium phosphate, 14D - transplanting 14-day-old seedlings, 30D- transplanting 30 day old seedlings.

4.2.2 Effect of split application of N fertilizer on yield and yield components

There were no significant differences in number of tillers, number of panicles and plant height across treatments (Table 4.4). Harvest index and percentage of filled grains were significantly different across treatments. However, harvest index was generally low ranging from 0.31 to 0.39. Application of 46 and 23 kg of N ha^{-1} at once had significantly lower harvest indices (HI= 0.31

and 0.32 respectively) than the control and split applications of 23 and 46 kg of N ha^{-1}. There were no significant differences in yield between mean treatments but the interaction between split N applications and variety was significant for yield. Average yield across treatments was 2.4 t ha^{-1}. When 23 kg of N was applied at once to all varieties, GSR 0057 yielded better than WITA 9 but its yield was statistically similar to K 5 and K 85 (Table 4.5). Applying 23 kg of N in splits and applying 46 kg of N in splits or at once did not result in significant differences in the yields of the different varieties. However, in the control treatment, K 85 had a significantly lower yield than the rest of the varieties. No significant differences were detected in the average yields of all the varieties. The lowest yield was registered in K 85 in the control treatment. The agronomic efficiency (AE) of fertilizer N usage was variable registering an average of 22.6 kg kg^{-1}. Split application of 46 kg of N increased AE slightly from 18.1 to 19.6. The gross return over fertilizer increased as the amount of N increased but it was highest (\$855.4 ha^{-1}) when 23 kg of N was applied in splits compared to \$846.8 ha^{-1} when 46 kg of N was applied in splits (Table 4.4). Compared to the control, applying 23 and 46 kg of N in splits had net benefits of \$135 and 126 \$ respectively.

Table 4.4: Effect of splitting N application on agronomic efficiency (AE), gross return over fertilizer N (GRF), growth and yield components

Treatment	**AE (kg kg^{-1})**	**GRF ($/ha)**	**No. Tillers (m^{-2})**	**No. Panicles (m^{-2})**	**Height (cm)**	**HI**	**% filled grains**
Control	22.6	720	480	398.5	84.1	0.38	89.5
23 (2 splits)	25.7	855.4	513	406.7	90.3	0.39	81.8
23 (once)	27.1	819.4	502	408.8	87.4	0.31	81.3
46 (2 splits)	19.6	846.8	555	457.8	89.4	0.34	81.3
46 (once)	18.1	738.8	560	448.5	88.7	0.32	84.4
$LSD_{0.05}$	-	-	NS	NS	NS	0.04	4.6
CV (%)	-	-	9.2	10.0	3.4	8.6	3.6

NS- Not significant at 5% level of significance

Table 4.5: Effect of split N application on yield of four rice varieties

Treatment	Varieties				
	GSR 0057	K5	K85	WITA 9	Mean
Control	2.1	2.5	1.1	2.3	2.0
23 (2 splits)	2.4	2.6	2.3	2.5	2.5
23 (once)	2.9	2.1	2.8	1.9	2.4
46 (2 splits)	2.8	2.7	2.6	2.2	2.6
46 (once)	2.3	2.1	2.7	1.9	2.2
Mean	2.5	2.1	2.3	2.1	2.4
$LSD_{0.05}$ (Trt x variety)	0.9				
CV (%)	19.1				

4.4 Discussion

4.4.1 Effect of improved nursery management practices on yields

The findings of this report have shown that applying di-ammonium phosphate (DAP) in the nursery and transplanting young seedlings can increase yields by up to 23-30%. This corroborates findings by Rajagopahan and Krishnarajan (1987) who found application of di-ammonium phosphate and triple superphosphate in the nursery to increase yield by 21% compared to the control. In addition, Panda *et al*., 1991 stated that using healthy and vigorous seedlings with sufficient nitrogen fertilizers in the nursery results in more productive tillers hence better yields. The findings of this report will help solve the problem of poor nursery management practices which has been cited by Balasubramanian *et al.* (2007) and Kijima *et al*. (2010) as one of the factors contributing to low yields in smallholder farms.

Transplanting young seedlings resulted in better yields than transplanting 30 day old seedlings as is the practice for most smallholder farmers. This finding is in agreement with Thanunathan and Sivasubramanian (2002) who concluded that using seedlings younger than 25 days had a positive impact on yield. The findings of this report however contradict those of Adhikari *et al*. (2013) and Bhagat *et al*. (1991). Adhikari *et al*. (2013) found no significant effect of fertilizer management in the nursery on yield and older seedlings (40 days old) had a highly significant and positive impact on yield. Similarly, Bhagat *et al*. (1991) found that 40 day old seedlings produced higher grain yields than 30, 50 and 60 day old seedlings. Experiments by Adhikari *et al*. (2013) and Bhagat *et al*. (1991) were however done in Bangladesh where there are varying seasons and climates, and different recommendations for age of seedlings.

4.4.2 Effect of split N application on yield and yield components

The interaction between split N applications and variety was significant for yield with GSR 0057 yielding better than WITA 9. Variety K 85 had a significantly lower yield in the control treatment than the rest of the varieties. This implies that variety K 85 requires fertilization to produce sufficient yields. Application of 46 and 23 kg of N ha^{-1} at once had significantly lower harvest indices (HI= 0.31 and 0.32 respectively) than the control and split application of 23 and 46 kg of N ha^{-1}. The low harvest indices could have been caused by increased vegetative growth at the expense of reproductive growth. De Datta *et al*. (1988) attributed the increased yield in split experiments to reduced N losses and more effective crop utilization of N while Mikkelsen (1987) attributed it to N application at the tillering stage when crop N demand is highest. The poor performance in this study could be due to the low N rates used in this study. The Agronomic efficiency of fertilizer N usage was variable registering an average of 22.6 kg kg^{-1}. Splitting 46 kg of N increased AE slightly from 18.1 to 19.6 kg kg^{-1}. Splitting N also increased gross return over fertilizer by 36 and 108 $\$ha^{-1}$ for 23 and 46 $kgha^{-1}$ respectively. Currently, farmers will have to increase amounts of fertilizer they apply to get maximum benefits. Still, as Nhamo *et al*. (2014) has argued, balancing both micro and macro nutrients is necessary for sustainable management of soil fertility.

4.5 Conclusions

The results of this report have shown that application of di-ammonium phosphate and fungicide combined with transplanting young seedlings has the potential to increase yield by over 20%. Given that poor nursery management practices have been cited as one of the factors contributing to low yields in smallholder farms, this is a great opportunity for smallholder farmers to increase yield at minimal costs. Applying 23 kg of N in splits and applying 46 kg of N in splits or at once did not result in significant differences in the yields of the different varieties but increased agronomic efficiency and gross return over fertilizer. Further research is however needed to ascertain the limit at which yield begins to decline with age of seedlings, and what other nutrients need to be added to the nursery for best results. It also not clear whether the available organic fertilizers would achieve the same results as the inorganic fertilizers. This is important considering that organic fertilizers may be more readily available than inorganic fertilizers.

CHAPTER 5: INDIGENOUS NUTRIENT SUPPLY AND FERTILIZER USE EFFICIENCY IN RAINFED LOWLAND RICE IN EASTERN UGANDA

5.1 Abstract

Rice yields in the lowland rice ecologies of Uganda are low because of poor crop and water management, drought, weed problems and poor nutrient management. The few farmers who use fertilizers apply nitrogen based fertilizers at low rates hence they do not realize maximum benefits from fertilizer use. Site specific nutrient management (SSNM) has been shown to increase fertilizer use efficiency and yields in farmers' fields. A study was initiated to determine the indigenous nutrient supply (INS) and the nutrient use efficiency in rainfed lowland rice soils in order to develop a site specific nutrient management option for eastern Uganda. The experiment was set up with five treatments: 1) control (where no fertilizer was applied), 2) full N, P and K (NPK), 3) omission of K with full N and P (NP-K), 4) omission of P with full N and K (NK-P), 5) omission of N with full P and K (PK-N). Full N, P and K rates were 125 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} respectively. A total of 27 omission experiments were set up in 2013 using randomised complete block design. Agronomic efficiency (AE), recovery efficiency (RE), internal use efficiency (IUE), gross return over fertilizer (GRF) and appropriate NPK rates for SSNM were calculated. The average yield was 3.8 t ha^{-1} and ranged from 1.1- 8.7 t ha^{-1}. The full NPK treatment yielded on average 4.83 t ha^{-1}, the yield being 73, 40, 23 and 25% higher than control, PK (-N), NK (-P) and NP (-K) treatments respectively. The average AE was 9.4 kg kg^{-1} and ranged from 6.7 to 18 kg kg^{-1}. The average RE was 31% N, 9.9% P and 59% K with NPK treatment recording an average RE for N of 46.9%. The RE for P was 19% (for NPK), 9.9% (for control and NK), 9.3% for NP and 1.4 for PK. Average IUE was 36.9 kg kg^{-1} for N, 270 kg kg^{-1} for P and 28 kg kg^{-1} for K. The average indigenous nitrogen supply (INS), indigenous phosphorus supply (IPS) and

indigenous potassium supply (IKS) were 52, 9.7 and 87.2 kg N, P and K ha^{-1} respectively. The gross return over fertilizer cost (GRF) for the full NPK treatment was $1,275.3 ha^{-1} with gains of $270 ha^{-1} when compared to the control. The calculated N, P and K doses were 63, 12.6 and 24.5 kg ha^{-1} respectively. This study has shown that fertilizer use in eastern Uganda is profitable and SSNM has demonstrated big savings on fertilizer N, P and K. At the moment, it is not absolutely necessary to apply K in farmers' fields because the indigenous K supply is high. These findings are instrumental in understanding indigenous nutrient supply, fertilizer use efficiency and for fine tuning site specific nutrient requirements for eastern Uganda.

5.2 Introduction

Most farmers achieve less than 60 % of the climatic and genetic yield potential of rice varieties in their farms (Matthews, 1995). Farmers in Uganda and sub-saharan Africa (SSA) in general achieve much lower yields ranging on average from 1-2 t ha^{-1}. The low yields can be attributed to climatic constraints, poor seed quality, weeds, pests and diseases, mineral toxicities and inadequate water supply (Dobermann and Fairhurst, 2000). Improved nutrient management can help reduce the yield gap. However, the greatest benefit for improved nutrient management is found on farms with good crop management and few pest problems (Doberman *et al.*, 2002). Unfortunately, farmers in rainfed lowlands in Uganda and other parts of SSA grow a rice crop with minimal use of fertilizers and pesticides. In a recent survey, farmers in eastern Uganda believed that their yields were on a declining trend and attributed it majorly to declining soil fertility and drought. The same survey found only 12% of lowland rice farmers using fertilizers albeit applying low rates of about 50 kg urea per ha (chapter 3 in this thesis). Applying fertilizers is no doubt the most direct way to overcome soil-fertility depletion (Mokwunye and Vlek, 2012). However, a few farmers who apply fertilizers have insufficient knowledge on fertilizer use efficiency and recovery efficiency. This results in underutilization of applied fertilizers by crops hence low yields in farmers' fields. There is therefore need to develop a framework for improved soil fertility management for lowland rice systems in Uganda.

Cassman *et al.* (1998) described nutrient use efficiency using a framework of agronomic indices namely partial factor productivity (PFP, kg crop yield per kg nutrient applied), agronomic efficiency (AE, kg crop yield increase per kg nutrient applied) and apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied), physiological efficiency (PE, kg yield increase per kg nutrient taken up) and internal efficiency of N (IEN) (kg of grain per kg of nutrient taken up). According to Witt *et al*. (1999), with proper nutrient and crop management, partial factor productivity of N should surpass 50 kg grain kg^{-1} N applied; agronomic efficiency of N should be ≥20 kg grain yield increase kg^{-1} N applied; recovery efficiency of N of >0.5 kg kg^{-1} can be achieved; physiological efficiency of N should be close to 50 kg grain kg^{-1} N taken up from fertilizer while under conditions of optimal nutrition and few other constraints to growth, internal use efficiency of N should be close to 68 kg grain kg^{-1}plant N.

Dobermann *et al.* (2002) hypothesized that rice yields, profit, plant nutrient uptake and N- use efficiency can be greatly improved by applying fertilizers on a field specific and cropping season specific basis. Site specific nutrient management (SSNM) was defined by Doberman and White, (1999) as the dynamic, field specific management of nutrients in a particular cropping system to optimize the supply and demand of nutrients according to their differences in cycling through soil-plant systems. The form of SSNM developed for rice attempts to account for regional and seasonal differences in the climatic yield potential and crop nutrient demand. It also attempts to account for field spatial variability in indigenous nutrient supply, field specific within-season dynamics of crop N demand and location specific cropping systems and crop management practices. Further, the SSNM approach developed for rice uses crop based estimates of indigenous nutrient supply instead of relying on soil tests.

SSNM was evaluated in Asia (Wang et al. 2001; Doberman *et al*., 2002) and in West Africa (Haefele *et al*., 2003). The SSNM strategy aims to achieve sustainable, large, and economic yields through proper nutrient and crop management achieved through making efficient use of all available nutrient sources, following plant based N- management strategies, determining indigenous nutrient supply of the soil using omission plots and providing a crop with a balanced supply of nutrients. Doberman (2003) defined indigenous nutrient supply (INS) as the cumulative amount of that nutrient originating from all indigenous sources (non-fertilizer sources) that circulate through the soil solution surrounding the entire roots system during one complete crop cycle. Indigenous nutrient supply can be estimated by plant nutrient accumulation in a nutrient omission plot or estimated from grain yield measurements in small N, P, and K omission plots embedded in farmers' fields if other nutrients are fully supplied and the harvest index is approximately 0.5. The use of SSNM has been shown to be a simple and effective way to increase nitrogen use efficiency. Adoption of SSNM requires an understanding and quantification of the indigenous supply of nutrients.

Considering the growing importance of rice as a cash and food crop, and the growing need to increase productivity, there is a need to understand some aspects of the soil nutrient status including soil indigenous supply and fertilizer use efficiency of the soils which will ultimately lead to fertilizer recommendations for farmers. The objective of this study was to determine the indigenous nutrient supply and nutrient use efficiency of lowland rice soils in eastern Uganda.

5.3 Materials and Methods

5.3.1 Site description

The experiments were set up in Bugiri district (034’14.66” N, 33 44’ 56.04”E) of eastern Uganda in 2013 and 2014. In 2013, the experiment was set up in 10 farmers’ fields in Buwunga Sub County while in 2014 the experiments were set up in 17 farmers’ fields in Buluguyi Sub County. Consequently, a total of 27 omission experiments were set up over the two-year period. The soils covering most of Bugiri district are mainly loamy and sand loams with fine texture and rather loose structure. The soils are laterite and ferralitic, with deep reddish brown sandy loams mixed with clay loams and overlain by clayey subsurface horizons derived from gneiss and granites (Yost and Eswaran, 1990).

Soil characteristics of experimental sites are shown in Table 5.1. Bugiri district has two distinct rainfall seasons per year - April to June and August to November – with a dry season lasting from December to March. The mean annual rainfall is 1,200 mm ranging from 1,000 mm to 1,500 mm in the southern parts of the district. Mean temperatures range from 16.7 to 28.1°C with the month of February being the hottest. The monthly rainfall data for Kibimba and surrounding villages is shown in Figure 4.1. For majority of the farmers, rice is grown as a monocrop either twice or once a year with no known crop rotation regimes. Second season planting of rice is normally dependent on the arrival of the rains, and for some farmers it is not planted if the rains come late.

5.3.2 Experimental design and treatments

A nutrient omission experiment was set up in 27 farmers' fields in a randomised complete block design. Each of the 27 farmers' fields served as a replicate. The experiment was set up with five treatments: full N, P and K (NPK), omission of K with full N and P (NP-K), omission of P with full N and K (NK-P), omission of N with full P and K (PK-N), and a control where no fertilizer was applied. The full N, P and K applications rates used in the experiment were 125 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} respectively. The rates were based on a yield target of 5 t ha^{-1} under SSNM (Fairhurst *et al*., 2007). Nitrogen was applied as urea ($CO(NH_2)_2$), 46% N; phosphorus was applied in the form of triple super phosphate (TSP), 46% P_2O_5 ($Ca(H_2PO_4)2H_2O$) while potassium was applied in the form of muriate of potash (MOP), 50% K_20 (KCL). Nitrogen was applied in three splits: 55, 35 and 35 kg ha^{-1} at basal, active tillering and panicle initiation respectively. Potassium was applied in two equal splits (50% at basal and 50% at panicle initiation). All the phosphorus was applied basally.

The experiment was established with 10, 9 and 8 farmers in first season 2013 (2013A), first season 2014 (2014A) and second season 2014 (2014B) respectively. In 2013B, the experiment was not set up because the drought conditions persisted until November. All plots were 25 square meters (5 m x 5 m) each and were separated by bunds to restrain water movement from one plot to another. All omission experiments were set up with farmer variety Bedinego. Nurseries were sown at a rate of 50 kg seeds /500 m^2 and seedlings were transplanted at 28 days old. Rice plants were transplanted at a spacing of 25 cm x 25 cm with three seedlings per hill. Weeds were managed manually by hand weeding twice each season at 25-30 days after transplanting (DAT) and 40-50 DAT and by spraying with satunil 60EC (40 % Theobencarb and 20% propanil at a rate of 200-

500 l ha^{-1}). Rice blast was managed by applying Orius (250 g l^{-1} tebuconazole) at 750l ha^{-1} at panicle initiation. All experiments relied on rainfall for water.

5.3.3 Data collection

Initial soil samples were taken from a 0-15 cm depth at every site before planting to determine the general properties of the soil. The samples were analyzed at Kawanda Soil Science Laboratory using standard procedures (Okalebo *et al*., 1993) for pH, total carbon, total nitrogen, available P and exchangeable Ca, Mg, and K. Data were collected on plant height at 105 days after sowing (DAS), number of tillers at 89 DAT, days to 50% heading, flowering date (50% flowering), days to maturity, number of panicles, grain yield and rice biomass dry weight at harvest according to the standard evaluation system of rice (Gomezi, 1972). Panicles were counted prior to harvest. Plant height was taken on two hills per plot whereas numbers of tillers and panicles were taken on a 0.025 m^2 area. Plants were harvested from 12 hills in each plot at physiological maturity and used to determine % filled grains, harvest indices and nutrient concentrations in plant tissue. Harvest index was obtained by dividing dry weight of grains by the combined dry weights of grains and straw. Percentage of filled grains was determined by counting number of filled grains out of 100 grains of a sample and multiplying by 100. Nitrogen concentrations in grain and straw were measured by micro-Kjeldahl digestion, distillation and titration (Bremer and Mulvaney, 1982), tissue P by the molybdenum –blue calorimetric method and tissue K by atomic adsorption spectrometer after wet digestion. Grain and straw samples from the 12 hill sample were dried to constant weight at 70 $^{\circ}$C. Grain yields were obtained from a central 5 m^2 harvest area in each plot at harvest. Grain yields and total biomass (grain + straw yields) were adjusted to 14% moisture content.

Optimum N, P and K doses were calculated following Driessen *et al*. (1986):

N = [(YNPK – YPK)/ NU] x 18

P = [(YNPK – YNK)/ PU] x 2.5

Where, *YNPK* =yield in NPK plots, *YPK* = yield in N omission plot, *YNK* =yield in P omission plot, *YNP* = yield in K omission plot, *NU* =N use efficiency (assuming 40%), *PU* =P use efficiency (18%), and *KU* =K use efficiency (assuming 100%).

Gross return over fertilizer cost (GRF), which is the farm gate revenue from produced rice minus cost of fertilizer N applied and provides a relative measure for the benefit derived by farmers from the use of fertilizer, was calculated as follows: *TFC = PNFN + PPFP + PKFK*

GRF = PRYR -TFC (5) Where, *TFC* = total fertilizer cost ($\$ha^{-1}$), *PN* = price of N fertilizer (\$2.1/kg N), *FN*=amount of N applied (kg N ha^{-1}), *PP*=price of P fertilizer (\$2.2/kg P), *FP*=amount of P applied (kg P ha^{-1}), *PK* = price of K fertilizer (\$1.4/ kg K), *FK* =amount of K applied (kg K ha^{-1}), *GRF* = gross return over fertilizer cost (\$/ha), *PR* =price of rice (\$0.36/kg paddy), and *YR* = rice yield (kg ha^{-1}). Economic calculations were made using U.S. dollar as the standard currency.

N-use efficiencies were determined following Cassman *et al*. (1998):

Agronomic efficiency of N (AEN) = (GYN– GY0)/FN; recovery efficiency (RE) = (UN– UN0)/FN; internal use efficiency (IEN) = GYN/UNN where

AEN = agronomic efficiency of applied N (kg grain yield increase per kg N applied), RE = apparent recovery efficiency of applied nutrient (kg nutrient taken up per kg nutrient applied), IEN = internal efficiency of N (kg grain per kg N taken up), GYN is the grain yield in a treatment with N application (kg ha^{-1}), FN is the amount of fertilizer N applied (kg ha^{-1}), GY0 is the grain yield in the 0-N plot without N application, UNN is the total plant nutrient accumulation measured in above ground biomass at physiological maturity (kg ha^{-1}), and UN 0 is the total N accumulation in plots that did not receive nutrients.

Indigenous nitrogen supply (INS), indigenous phosphorus supply (IPS), and indigenous potassium supply (IKS) were estimated from grain yield measurements in N, P, and K omission plots.

5.3.4 Data analysis

Data was checked for normality and homoscedasticity to ensure that it met the assumptions of analysis of variance (ANOVA). Data was then analyzed with Genstat 12th edition using a generalized model for analysis of variance (ANOVA). Means were separated based on Fishers least significant difference at $P<0.05$.

5.4 Results

The nutrient characteristics of the soils in the different experimental sites are shown in table 5.1. Soil pH was acidic (<6) while organic matter was high. Total nitrogen was medium, available P very low and exchangeable bases Ca, Mg and K had high levels.

Table 5.1: Chemical characteristics of soils in the experimental sites

Location (Subcounty)	**pH**	**OM**	**N**	**P**	**Ca**	**Mg**	**K**
		%		**ppm**			
Buwunga	6.0	4.96	0.23	12.10	4893.57	1055.43	61.65
Buluguyi	5.7	4.882	0.252	4.45	1289.13	955.20	93.57
Buluguyi	5.3	4.91	0.22	19.91	4081.28	573.70	40.79

5.4.1 Yield and yield components for 2013 and 2014

Yield was significantly different across treatments. The NPK treatments had significantly higher average grain yield than control and PK (-N) but not NP (-K) and NK (-P). The NK (-P) and NP (-K) treatments significantly out-yielded the control, but their yields were not significantly different from PK which had statistically similar yields with the control (Table 5.2). The average yield in NPK was 73, 40, 23 and 25% higher than in control, PK (-N), NK (-P) and NP (-K) treatments respectively. The NPK, NP (-K) and NK (-P) had significantly higher average tiller number, panicle number and plant height than control and PK. The latter two were not significantly different in the three plant attributes measured. Rice plants in the treatments that received N (NP, NK, and NPK) were generally taller and hence more vigorous than those plants in the control and PK treatments. Percentage filled grains and harvest indices were not significantly different between treatments and ranged from 78.3 to 85% and 0.38 to 0.43 respectively.

Table 5.2: Effect of different nutrient omission treatments on rice yield and yield components across 2013A, 2014A and 2014B at Buwunga and Buluguyi Subcounties, eastern Uganda

Treatment	Yield (t ha^{-1})	Tillers (m^{-2})	Panicles (m^{-2})	Height (cm)	% filled grains	HI
Control	2.79	544	524	83.5	84.7	0.39
PK	3.43	566	544	86.1	82.7	0.39
NK	3.92	674	654	93.3	78.3	0.38
NP	3.85	690	710	93.2	85.0	0.39
NPK	4.83	710	706	91.9	83.9	0.43
Mean	3.76	637	628	89.6	82.9	0.40
P-value	0.004	0.001	<0.001	<0.001	0.12	0.51
$LSD_{0.05}$	1.0	95.8	94.1	5.1	NS	NS
CV (%)	24.5	21.3	21.3	8.1	9.6	18.6

Harvest index (HI) = (grain yield/combined yield of grain and straw), NS= Not significant, 2013A-first season 2013, 2014A- first season 2014, 2014B-second season 2014.

The average yield across all seasons was 3.8 t ha^{-1} (Table 5.2). The full NPK treatment performed better than the rest of the treatments. Number of tillers and panicles followed the same trend and were highest in the full NPK treatment. The performance across seasons was significantly different for all parameters. First season 2013 (2013 A) had higher grain yield, panicle number, plant height and % filled grains than first season 2014 (2014A) and second season 2014 (2014B). The average yield was highest in 2013A (5.2 t ha^{-1}) and lowest in 2014A (2.7 t ha^{-1}). Seasons 2014A and 2014B were not significantly different for yield, %filled grains and plant height (Table 5.3). The harvest index in 2014B was significantly different from that in 2014A and 2013A. The harvest indices in 2014B and 2013A were not different. Overall, most of the harvest indices were below 0.5.

The gross return over fertilizer cost (GRF) for the full NPK treatment was \$1,275.4 ha^{-1} (Table 5.4). Comparing with the average yields in the control, a farmer who does not apply fertilizer loses \$ 206.2 $ha^{-1.}$ (Table 5.4).

Table 5.3: Average yield and yield components for different omission treatments at Buwunga and Buluguyi subcounties, eastern Uganda in 2013A, 2014A and 2014B

Treatment	2013A				2014A				2014B			
	Yield (t ha^{-1})	Tillers (m^{-2})	Panicles (m^{-2})	HI	Yield (t ha^{-1})	Tillers (m^{-2})	Panicles (m^{-2})	HI	Yield t ha^{-1})	Tillers (m^{-2})	Panicles (m^{-2})	HI
Control	3.86	624	520	0.40	2.14	474	430	0.43	2.43	607	536	0.34
PK	5.21	666	502	0.40	2.15	488	430	0.47	3.01	665	548	0.34
NK	5.50	726	630	0.38	2.98	555	486	0.42	3.38	813	729	0.34
NP	5.00	806	733	0.42	3.01	538	478	0.43	3.58	884	721	0.37
NPK	6.50	787	685	0.44	3.33	640	581	0.45	4.68	829	703	0.41
Mean	5.2	722	614	0.391	2.72	539	483	0.44	3.41	760	647	0.36
P-value	0.005	0.41	0.05	0.56	0.01	0.05	0.03	0.7	0.002	0.007	0.005	0.16
$LSD_{0.05}$	1.2	NS	179	NS	0.74	116	99	NS	0.95	158	125	NS
CV (%)	31.9	10.9	7.6	13.7	20.4	16.0	15.3	15.1	23.3	17.3	16	13.8

NS- not significant, HI- Harvest index, 2013A-first season 2013, 2014A- first season 2014, 2014B-second season 2014.

Table 5.4: Gross return over fertilizer cost

Treatment	GRF ($)	Return vs Control ($)
NPK	1275.387	206.1869
PK	1039.009	-30.1912
NK	1057.214	-11.9855
NP	1008.951	-60.2495

5.4.2 Grain and straw yields and nutrient concentrations in grain and straw over two seasons

Grain and straw yields (dry weight) and nutrient concentrations are presented in Table 5.5. Average straw yield was 3.8 t ha^{-1} with a range from 2.6 to 5 t ha^{-1}. Similarly, average grain yield was 2.7 t ha^{-1} and ranged from 1.7- 4.0 t ha^{-1}. There were significant differences between treatments for both straw and grain yields with NPK having the highest straw and grain yields of 5.7 and 4.0 t ha^{-1} respectively. The straw and grain yields for PK (-N) and the control were similar but low compared to other treatments. Mean amounts of nutrients in straw were 33.2 kg N ha^{-1}, 5.3 kg P ha^{-1} and 86.3 kg K ha^{-1} while the concentrations in grain were 38.1 kg N ha^{-1}, 4.5 kg P ha^{-1} and 10.5 kg K ha^{-1} (Table 5.5). There were significant differences between treatments for all nutrients in both grain and straw except for the concentration of P in grain. Generally, NPK treatment had the highest nutrient concentrations; 50.5 kg N ha^{-1}, 8.3 kg P ha^{-1} and 128.0 kg K ha^{-1} in straw and 59.0 kg N ha^{-1}, 6.8 kg P ha^{-1} and 15.0 kg K ha^{-1} in grain. There was a strong relationship between grain yield and total nitrogen (R^2=0.40), total phosphorus (R^2=0.45). The relationship between yield and total potassium was very weak (R^2=0.01) (Figure 5.2).

Table 5.5: Total straw and grain (dry weight) yield (t ha^{-1}) and concentrations of N, P, K (kg ha^{-1}) in grain and straw

Treatments	Parameters							
	Straw				Grain			
	N	P	K	Yield	N	P	K	Yield
NP	36.3	6.2	76.6	4.1	40.4	4.9	10.5	2.9
NK	32.8	5.1	97.1	3.7	38.0	4.6	10.7	2.6
NPK	50.5	8.3	128.0	5.7	59.0	6.8	15.0	4.0
PK	22.5	3.5	73.1	2.7	29.5	3.5	9.1	2.1
Control	23.7	3.5	56.8	2.6	23.8	2.9	7.1	1.7
Mean	33.2	5.3	86.3	3.8	38.1	4.5	10.5	2.7
P-value	0.004	0.013	0.002	0.001	0.001	0.06	0.0026	0.002
$LSD_{0.05}$	19.1	2.9	32.2	1.4	15	2.7	4.6	1.0
CV (%)	26.8	26.9	22.0	18.6	32.6	39.2	36.5	31.7

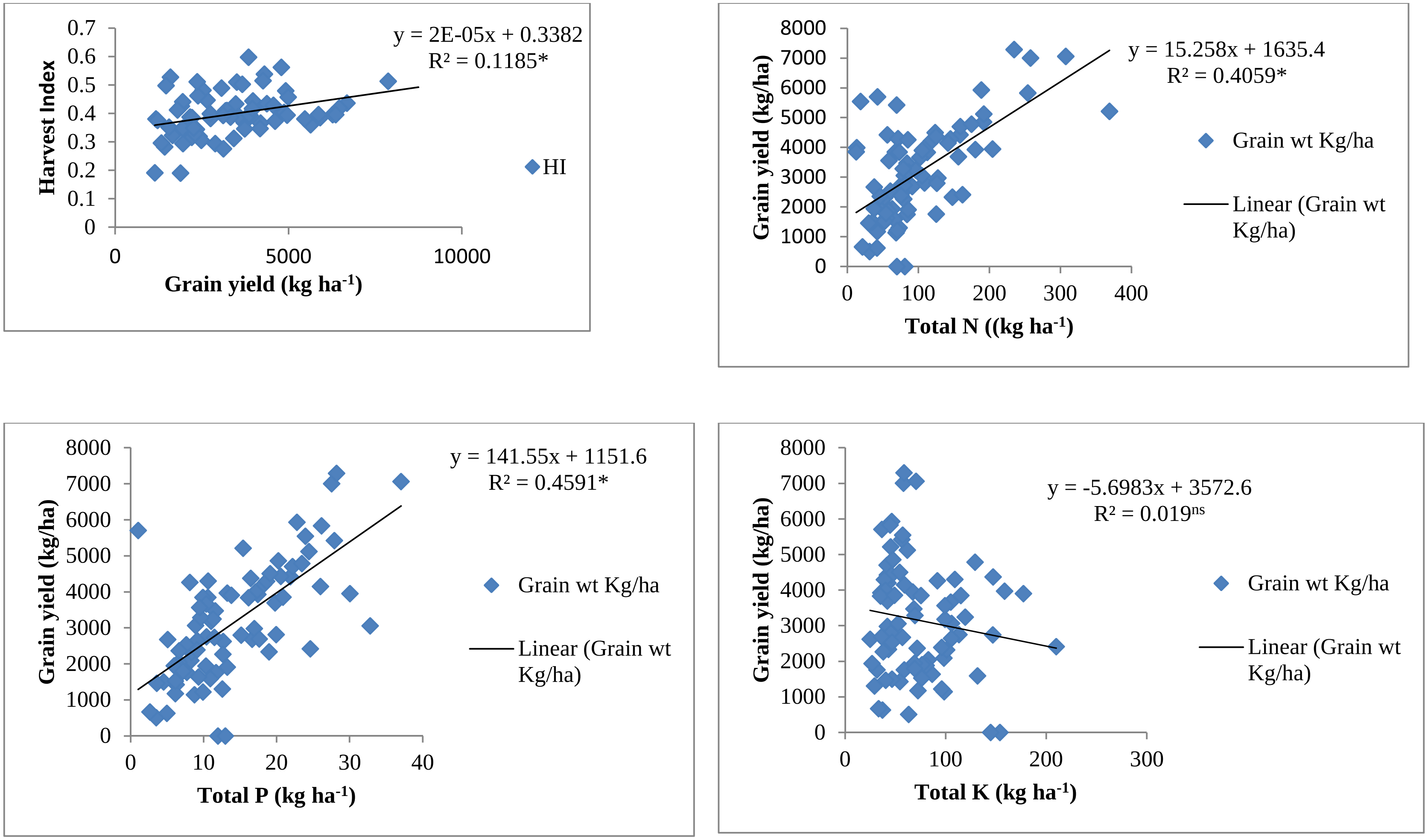


Figure 5.2: Relationship between harvest index and grain yield, grain yield and total N, grain yield and total P and grain yield and total K, *significant at P≤0.05, ns- Not significant

5.4.3 Agronomic efficiency, recovery efficiency and internal use efficiency

Table 5.7 shows the agronomic efficiency (AE), recovery efficiency (RE) and internal use efficiency (IE) under the different treatments. The average AE was 9.4 kg grain kg^{-1} of fertilizer and ranged from 6.7 to 18 kg grain kg^{-1} of fertilizer added for NK (-P) and NPK treatments, respectively. However, no significant differences were observed between treatments for AE. The average RE was 31%N, 9.9% P and 59% K respectively. Though not significantly different among treatments for N, RE ranged from 21.5% (NK-P) to 46.9% (NPK). There was a significant difference between treatments for RE of P ($P<0.05$) with the NPK treatment having the highest RE (19.9%). There was a lot of variability in the RE for P and it ranged from 1.4 to 18%. Average RE for K was 59% with a range of 30% (PK) to 132% (NPK).

Internal use efficiency was not significantly different across treatments for all nutrient elements except for K (Table 5.7). Average IE was 36.9 kg kg^{-1} for N, 270 kg kg^{-1} for P and 28 kg kg^{-1} for K. The IE for N was similar across treatments being highest for NP (-K) (38.3 kg kg^{-1}) and least in the control (35.0 kg kg^{-1}). The IE for P was very similar across treatments. NPK treatment had the highest IE for K (29.0 kg kg^{-1}) followed by the control (27.0 kg kg^{-1}).

Table 5.8 shows the indigenous nutrient supply for N, P and K in farmers' fields. The average INS, IPS and IKS were 52, 9.7 and 87.2 kg N, P and K ha^{-1} respectively. Calculated N, P and K doses required to achieve 5 t ha^{-1} yield were 63, 12.6 and 24.5 kg ha^{-1}, respectively. Compared to the rates used for the experiment, the farmer would save 49, 74 and 59% on NPK treatment (Table 5.8).

Table 5.7: Agronomic efficiency of N (AE) (kg kg^{-1}), Recovery efficiency RE (%) and internal use efficiency (IE) (kg kg^{-1}) of different omission treatments

Treatments	**AE**		**RE**			**IE**	
		N	P	K	N	P	K
NK	6.7	21.5	-	73	35.4	-	24.2
NP	9.4	24.7	9.3	-	38.3	264	-
NPK	18	46.9	18.9	132	37	275	29.0
PK	-	-	1.4	30	-	276	23.9
Control	9.4	31.0	9.9	59	35	266	27.0
Mean	9.4	31.0	9.9	59	36.9	270	28.0
P-value	0.065	0.19	0.022	0.016	0.90	0.99	0.04
$LSD_{0.05}$	NS	NS	11.6	75.6	NS	NS	8.5
CV (%)	27.5	42.4	49.8	48.3	15.3	20.4	25.3

Note: - means that the particular nutrient was not applied in the plot.

Table 5.8: Indigenous nutrient supply of N (INS), P (IPS) and K (IKS) (kg ha^{-1}) in season 2013A, 2014A and 2014B at three locations in Bugiri district

Season	**Location**	**INS**	**IPS**	**IKS**
2013A	Buwunga	55.6	8.9	75.4
2014A	Buluguyi (Bubwoki)	52.0	9.7	87.2
2014B	Buluguyi (Bufunda)	57.7	8.3	61.8
Mean		55.1	8.9	74.8

2013A-first season 2013, 2014A- first season 2014, 2014B-second season 2014.

Table 5.8: Calculated N, P and K doses required to achieve 5 t ha^{-1} rice yield for Bugiri district

Nutrient	**Amount applied (kg ha^{-1})**	**Farmers' practice (kg ha^{-1})**	**Amount to be applied (kg ha^{-1})**	**Amount saved (%)**
N	125	0-60	63.0	49.6
P	50	0	12.6	74.8
K	60	0	24.5	59.2

5.5 Discussion

Yields in NPK, NP and NK treatments were similar but higher than in PK and control treatments. The average yield in NPK was 73, 40, 23 and 25% higher than in control, PK (-N), NK (-P) and NP (-K) treatments. The difference in yields between PK, control and NPK treatments indicate that nitrogen is the most limiting nutrient in lowland rice production. According to Fageria (2009), nitrogen is the most limiting factor in crop production in the tropics and is responsible for increasing yield components and reducing grain sterility. Application of NPK, NP and NK recorded significantly higher tiller and panicle numbers than PK and control. The high yields in NP, NK and NPK treatments can be attributed to the high numbers of tillers and panicles recorded in treatments that received nitrogen. The average grain yields in the different treatments are slightly lower than those recorded by Nath *et al*., 2012 and Doberman *et al*., 2003. The NPK, PK, NK, and NP grain yields recorded by Nath *et al*., 2012 were 5.6, 2.8, 3.7 and 5.1t ha^{-1} while Doberman *et al*. (2003) recorded yields of 3.9, 5.2 and 5.1 t ha^{-1} for PK, NK and NP respectively. It is important to note that the preceding studies were carried out in irrigated environments while the current study was carried out in a rainfed environment. This could explain the differences in grain yields recorded. The average yield in the full NPK plots was 6.5, 3.3 and 4.7 tons/ha in 2013A, 2014A and 2014B respectively. The average yield in 2013A surpassed the set yield target of 5 tons/ ha. The good performance of the NPK treatment implies that in order to achieve good yields, all nutrients have to be applied. The average yields recorded in this study are similar to those recorded in the Sahelian region of West Africa (Haefele *et al*., 2003) and some parts of Asia (Doberman *et al*., 2003; Hossain *et al*., 2005). However, the average harvest indices were lower than those recorded in other studies especially those carried out in irrigated ecologies. The low harvest indices could have been caused by drought and poor performance of the local farmer variety (Benenego) used in the study. The good performance in 2013A and 2014B could have been due to presence of adequate water in the respective seasons. A total of 752 mm and 754 mm of rainfall was received in 2013A and 2014B compared to 665 mm received in the 2013B season (Kibimba weather station). Drought and poor water management are the main constraints of rainfed lowland rice as evidenced by the poor yields in 2014A.

All nutrients in grain and straw were significantly different between treatments except phosphorus concentration in grain. In all cases, the NPK treatment had the highest nutrient concentrations both in grain and straw while PK and control had the lowest concentrations. Mean amounts of nutrients (including unfertilized plots) in straw were 33.3 kg N ha^{-1}, 5.3 kg P ha^{-1} and 86.3 kg K ha^{-1} while concentrations in grain were 38.1 kg N ha^{-1}, 4.5 kg P ha^{-1} and 10.5 kg K ha^{-1}. Phosphorus levels were similar among treatments because phosphorus was adequate in farmers' fields in Bugiri district where this study was conducted (Chapter 3 of this thesis). The nutrient concentrations recorded in straw and grain are similar to those presented by Haefele *et al*. (2003) for the Sahelian region of West Africa and Hossain *et al.* (2005) in Bangladeshi. However, the grain concentrations are lower than those presented by Witt *et al*., 1999. The agronomic efficiency (AE) of nitrogen in the NPK plots (18 kg N kg^{-1} of grain) was almost double the AE in other treatments but similar to those recorded by Hossain *et al*., 2005). According to Witt *et al*. (1999), with proper nutrient and crop management, AE of N should be more than 20 kg of grain per kg of N applied. The AE of N recorded here is therefore slightly below the expected levels. This is not surprising because most of the nutrient efficiency studies have been conducted under irrigation systems in Asia using new improved rice varieties. On the contrary, this study was set up under rainfed conditions where farmers plant a local farmer preferred variety - Bedinego which is a poor yielder. This is evident in the low harvest indices recorded throughout 2013 and 2014. In order to improve agronomic efficiency at farmer level, adoption of fertilizer technologies will have to be accompanied by new improved high yielding rice varieties. The average recovery efficiency (RE) for N and K were significantly different across treatments. The average RE for N was 31% (RE_N in full NPK= 46.9%, NP= 24.7%, NK= 21.5%), RE for P was on average 9.9% (RE for P in full NPK= 18.9%) while RE for K was 59% (RE for K in full NPK = 132%). This means that the crop did not use 78-

53% of N and most of the P applied in the different treatments while in some cases more K was taken up by the crop than what was added. The RE recorded here for N is similar to those recorded in the Sahelian region of West Africa (Haefele *et al.,* 2003) and many parts in Asia but are higher than those recorded by Hossain *et al*., 2005 in Bangladeshi. Where RE values were low, it could have been due to poor timing of N application, poor water management or drought in the case of rainfed rice (Hossain *et al*., 2005). Apart from the RE for P which was very low (average REP= 9.9, REP in full NPK = 18.9), RE for N and K were comparable to those of other studies for example Haefele *et al*., 2003 in the Sahelian region. The RE for K was high across all seasons and (RE for K in full NPK = 132) compared to Haefele *et al*., 2003. This could be because K was not found to be a limiting nutrient in most of the farmers' fields (Chapter 3 of this thesis). High RE recorded for K implies that K may be applied only after soil analysis because results have shown that K is not deficient in lowland rice soils in Buwunga and Buluguyi subcounties.

The internal use efficiency for K differed significantly across treatments while that of P and N were not significantly different across treatments. Treatment NP had the highest IE of K (36.2 kg kg^{-1}) while PK had the lowest IE of K (23.9 kg kg^{-1}). The internal use efficiency for N was very low (average= 36.9 kg kg^{-1}; IE for full NPK = 37 kg kg^{-1}) compared to that recorded in other studies (Haefele *et al*., 2003; Hossain *et al*., 2005) and the expected IE of 68 kg kg^{-1} of N applied under optimal nutrition (Witt *et al*., 1999). The IE for unfertilized plots was also lower than unfertilized plots in the Sahelian region of West Africa. It is still not clear why the IE for unfertilized and fertilized plots were similar but it is clear that yield in rainfed ecologies is limited by other factors apart from nutrient supply. This implies that to achieve maximum benefits from applied fertilizers, good agricultural practices have to be practiced.

The average indigenous nutrient supply of the soils was 55.1, 8.9 and 74.8 kg ha^{-1} for N, P and K respectively. The INS recorded here is similar but slightly higher than that recorded in the Sahel while the IPS and IKS were slightly lower. Haefele *et al*. (2003) recorded INS, IPS and IKS ranging from 33-62 kg N ha^{-1}, 9.8-13.9 kg P ha^{-1} and 67-169 kg K ha^{-1}respectively. The common farmers' practice of leaving straw in the garden and cultivating once a year ensures plenty of K in their soils. Laboratory results of soil samples from farmers' fields recorded high levels of K confirming that K is not a limiting nutrient (chapter three in this thesis).

The gross return over fertilizer cost was $1,275 ha^{-1} and the net return per hectare was $ 206.2. Hence, a farmer who decides to use the full NPK fertilizer rates used in the current study gains $ 206.2 ha^{-1} implying that fertilizer usage is still profitable in rain-fed ecologies. On the other hand, applying either NP, NK or PK alone results in losses of $ 60, 11 and 30 respectively. In addition, following Driesen *et al*. (1986), the calculated NPK rates were 63, 12.6 and 24 kg ha^{-1} implying a saving of 49, 74 and 59% on the current NPK rates used in the experiment. Because of the wide variations in nutrient use efficiency for N and K, an efficiency of 40 for N and 80 for K was adopted for calculations.

5.6 Conclusion

The indigenous nutrient supply of the soils was 55.1, 8.9 and 74.8 kg ha^{-1} for N, P and K respectively. The INS recorded here is similar but slightly higher than that recorded in the Sahel while the IPS and IKS were slightly lower. The agronomic efficiency in NPK plots was 18 kg of grain per kg of N added, and the RE was 46.9%. The internal use efficiencies for N, P and K were equally low. The low nutrient use efficiency is most likely due to the fact that this is a rainfed system where water management is not only inadequate, there are also many other factors affecting nutrient use efficiency like drought, weed problems and poor crop management. The calculated N, P and K doses required to achieve 5 t ha^{-1} rice yield were 63, 12.6 and 24 kg ha^{-1} implying a saving of 49, 74 and 59% on NPK rates used in the experiment. This study has shown that fertilizer use is profitable in lowland rice ecologies of eastern Uganda and SSNM has demonstrated that big savings on fertilizer N and P can be achieved. Based on the low nutrient use efficiency observed, maximum benefits from fertilizer use will only be realized if the farmers can effectively manage water and weeds, and employ good crop management procedures and adopt improved high yielding varieties.

CHAPTER 6: GROWTH AND YIELD RESPONSES OF FOUR RICE CULTIVARS TO VARYING RATES OF INORGANIC FERTILIZERS

6.1 Abstract

Majority (95%) of all the lowland rice is produced on small plots owned by smallholder farmers with minimal use of external inputs. The low use of inorganic fertilizers has contributed to declining soil fertility in many farmers' fields in Uganda. Fertilizer recommendations that are in line with new and old varieties are not available in Uganda. The objective of this study was to assess the growth and yield responses of four rice cultivars to varying rates of inorganic fertilizers. The experiments were set up in Bulesa Sub County, Bugiri district in eastern Uganda in the first season 2013 (2013A) and second season 2013 (2013B) with six fertilizer treatments: 20-20-0, 40-20-0, 60-30-0, 80-20-0, 80-40-0 and 120-40-0 kg ha^{-1} N- P_2O_5- K_2O. Data were collected on plant height, number of tillers, number of panicles, grain yield and rice biomass dry weight at harvest. Profitability analysis of the different fertilizer treatments was also done. There were significant differences ($P<0.05$) between fertilizer treatments for yield, number of panicles, number of tillers and harvest index. Yield generally increased with increase in amounts of fertilizer applied and variety K 85 out yielded all other varieties irrespective of treatment and season. The highest average yield (3.4 t ha^{-1}) was recorded in plots which received 120-40-0 (N, P and K respectively) while the lowest yield was recorded in 20-20-0 NPK (average yield= 1.3 t ha^{-1}). Plots that received 120-40-0 NPK had the highest number of tillers (716 m^{-2}) and panicles (635 m^{-2}) while 40-20-0 NPK had the lowest number of tillers (580 m^{-2}) and panicles (489 m^{-2}) respectively. Generally, 120-40-0 NPK recorded the highest net returns and profits of 30.9% and 28.6% in 2013A and B respectively but the profitability levels were very similar in 2013A for 60-20-0, 80-20-0, 80-40-0 and 120-40-0 NPK. Applying higher rates of inorganic fertilizers resulted in higher yields than

applying lower rates. Applying fertilizers is profitable but maximum benefits can only be achieved if biophysical constraints, especially drought, are managed well.

6.2 Introduction

Rice (*Oryza sativa* L.) is an important food and cash crop for farmers in Uganda (Fungo *et al*., 2013). The eastern region produces more than 67% of all the rice produced in Uganda. During a recent survey, rice was ranked the second most important cash crop after maize by farmers in Bugiri, Namutumba, Butalejja, Kaliro and Lira districts (Chapter three of this thesis). Most of the rice grown is rainfed (95 %) of which 60 % is lowland (Haneishi *et al.*, 2013) yielding an average of 1 t ha^{-1} compared to the world potential yield in rainfed lowlands of 5-6 t ha^{-1}. Majority (95%) of all the lowland rice is produced on small plots owned by smallholder farmers while the remaining 5% is produced by large scale rice schemes (Haneishi *et al.*, 2013). With the exception of the large scale rice schemes, most of the rice in smallholder farms is produced with minimal use of external inputs. For example, a recent survey found only 12% of smallholder farmers in five districts (four in eastern Uganda) using inorganic fertilizers; majorly urea and di-ammonium phosphate (Chapter three of this thesis). The low use of inorganic fertilizers has contributed to declining soil fertility in many farmers' fields in Uganda (Bekunda *et al.*, 2010). Decline of soil fertility is generally seen as the most important constraint to crop production in Uganda, where most agro-ecosystems remove more nutrients than are provided by external inputs making it a fundamental biophysical root cause for declining food security in the smallholder farms (Nandwa and Bekunda, 1998). The World Bank observed that increasing fertilizer use can increase production by up to 40% as was the case in Asia during the green revolution (World Bank, 2006). Likewise, Larson *et al*. (2010) indicated that input intensive practices are required in rice production to deal with continuous nutrient extraction from soils hence inorganic fertilizers have a huge role to play in this aspect.

Although blanket fertilizer recommendations are thought to be available to most rice farmers in Asia and Africa, recent recommendations that are in line with new and old varieties are not yet available in Uganda. As a result, farmers normally borrow rates from other crops especially maize and apply them to rice. Blanket fertilizer recommendations are slowly being phased out in favor of site specific nutrient management (SSNM) which ensure efficient use of nutrients and increases yield (Doberman *et al*., 2002). However, developing SSNM options for rice farmers around the whole country will take time. As we work towards a SSNM approach for the rainfed lowland systems in all parts of the country, there is need for a temporary nutrient management option that farmers can use to reverse the declining soil fertility and productivity in their farms. This would also serve as a guide towards developing a SSNM option for different locations. The objective of this study was to assess the growth and yield responses of four rice cultivars to varying rates of inorganic fertilizers.

6.3 Materials and Methods

6.3.1 Site description

The experiments were set up in Bulesa subcounty, Bugiri district (034'14.66" N, 33 44' 56.04"E) of eastern Uganda in the first season 2013 (2013A) and second season 2013 (2013B). The soils and climate of Bugiri district have been described in Chapter 4 of this thesis.

6.3.2 Experimental design and treatments

The experiment was laid out in a split plot design with four replications. The fertilizer treatments comprised: 20 kg Nha^{-1}+ 20 kg P_2O_5 ha^{-1}+ 0 kg K_2O ha^{-1} (20-20-0), 40 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} + 0 kg K_2O ha^{-1} (40-20-0), 60 kg N ha^{-1} + 30 kg P_2O_5 ha^{-1} + 0 kg K_2O ha^{-1} (60-30-0), 80 kg N ha-

^{1} + 20 kg P_2O_5 ha^{-1} + 0 kg K_2O ha^{-1} (80-20-0), 80 kg N ha^{-1}+ 40 kg P_2O_5 ha^{-1} + 0 kg K_2O ha^{-1} (80-40-0) and 120 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} + 0 kg K_2O ha^{-1} (120-40-0). Treatment 80-20-20 N-P_2O_5-K_2O is the rate used in the researcher managed plots at the National Crops Resource Research Institute (NaCRRI) because the appropriate fertilizer recommendations for farmers are not in place. Farmers apply rates below 80-20-20 N-P-K ha^{-1} while some apply slightly more than what the researchers use in their plots. Experimental plots measured 3 m by 5 m. Nitrogen was applied as urea ($CO(NH_2)_2$) with 46% N while phosphorus was applied in the form of di-ammonium phosphate (DAP) (18-46-0). Rice varieties WITA 9, K 5, K85 and GSR 0057 were used in the experiment. Varieties K 5, K85 and WITA 9 are high yielding and popular among farmers. In addition, WITA 9 is tolerant to the rice yellow mottle virus. Variety GSR 0057 is pre released but is already grown by farmers. Variety K 5 served as the check of the experiment because it is the most common variety grown by farmers and it is high yielding. Nitrogen was applied in splits; at establishment, tillering and panicle initiation in 40, 30 and 30% proportions respectively while all the phosphorus was incorporated in each plot at transplanting.

6.3.3 Crop management

Nurseries were sown at a rate of 50 kg seeds per 500 m^2 and seedlings were transplanted at 21 days after seeding. Rice plants were transplanted at a spacing of 25 x 25 cm and a rate of three seedlings per hill. Weeds were managed manually by hand weeding at 25-30 and 40-50 days after transplanting (DAT) and by spraying with Satunil 60EC™ (40% theobencarb and 20% propanil at a rate of 200-500 l ha^{-1} once a season) three weeks after transplanting. Rice blast was managed by spraying with Orius (250 g l^{-1} tebuconazole) at 750 l ha^{-1} once a season. The experiment was rainfed. Each plot was bunded to maintain a uniform water depth and also to ensure that fertilizer treatments did not mix. Birds were controlled manually by bird scarers.

6.3.4 Data collection

Initial soil samples were taken from a 0-15 cm depth at every site before planting to determine general properties of the soil. The samples were analyzed at Kawanda Soil Science Laboratory for pH, total carbon, total nitrogen, available P and exchangeable Ca, Mg, and K using standard procedures (Okalebo *et al*., 1993).

Data from experimental plots were collected according to the standard evaluation system of rice (Gomez, 1972), on plant height, number of tillers and panicles at 105 days after sowing (DAS), days to 50% heading, flowering date (50% flowering), days to maturity, grain yield, % filled grains and rice biomass dry weight at harvest. Plant height was taken on four hills per plot while numbers of tillers and panicles were taken on 0.025 m^2 area. A 12 hill plant sample equivalent to 0.75 m^2 was collected per plot at physiological maturity for determination of yield components, harvest index and nutrient concentrations in plant tissue. Grain and straw samples from the 12 hill sample were dried to constant weight at 70°C. Nitrogen concentrations in grain and straw were measured by micro-Kjeldahl digestion, distillation and titration (Bremer and Mulvaney, 1982), tissue P by the molybdenum –blue calorimetric method and tissue K by atomic adsorption spectrometer after wet digestion. At rice maturity 5 m^2 areas were harvested, rice threshed and grain yield and grain moisture content determined. Grain yield was adjusted to 14% moisture content.

6.3.5 Data analysis

For all the variables, Shapiro-Wilks test ($P<0.05$) (Shapiro and Wilk, 1965) and visual inspection of their respective histograms and box plots showed that they were approximately normally distributed across seasons and treatments with their standard errors in normal range (Crammer, 1998). Data was then analyzed with Genstat 12th edition using a generalized model for analysis of variance (ANOVA). Means were separated by Fishers least significance difference at P<0.05.

Profitability analysis was done following Krupnik *et al.* (2012). Data for profitability was generated from expenses during the two seasons of experimentation based on local rates paid by farmers for the same tasks. Fertilizer costs included an 18% value added tax (VAT) levied by Government of Uganda. Labour costs in the study area are charged per task (20 square meter of a plot) and have remained static over the past three years. Labour costs for both seasons were therefore the same. Yield was adjusted to 14% moisture content and rice valued at $0.36 and $0.38 per kg of paddy in 2013A and 2013B respectively. Rice was slightly more expensive in the second season than in the first season because less rice is normally produced in the former than the latter.

6.4 Results

The nutrient characteristics of the soils in the experimental site are shown in Table 6.1. Organic matter, total nitrogen, exchangeable bases K, Mg and Calcium had high levels while available P was very low.

Table 6.1: Chemical characteristics of the experimental sites

Season	pH	OM	N	P	Ca	Mg	K
		%		ppm			
2013A	5.30	10.50	0.47	10.40	5342.57	1750.07	172.68
2013B	5.60	7.50	0.31	7.51	4509.17	1624.76	85.98

6.4.1 Effect of fertilizer regimes on yield

The effect of inorganic fertilizer on yield and yield components is summarized in Table 6.2. There were significant differences (P<0.05) between fertilizer treatments for yield, number of panicles, number of tillers and harvest index. Yield generally increased with increase in amounts of fertilizer applied. The average yield was 2.4 t ha^{-1} and ranged from 0.5-4.9 t ha^{-1} over two seasons. The highest average yield (3.4 t ha^{-1}) was recorded in plots which received 120-40-0 N, P and K and was closely followed by plots which received 80-40-0. The lowest yield was recorded in treatment 20-20-0 (average yield= 1.3 t ha^{-1}). The interaction between treatment and season was only significant for yield and grain filling. Overall, the performance in 1st season 2013 (2013A) was better than that recorded in the second season of the same year (2013B). Average yield in 2013A was 2.7 t ha^{-1}compared to 2.1 t ha^{-1} in 2013B (Table 6.2). The same trend was observed for grain filling over the two seasons. There were significant differences between varieties ($P<0.05$) for harvest index and grain filling (Table 6.2). WITA 9 had higher HI (0.4) than K 85 and K5 but not GSR 007. WITA 9 also had higher percentage of filled grains (70.2%) than GSR 007 and K 85 but not K 5 (Table 6.3).

Table 6.3: Mean plant height (cm), harvest index and % filled grains for four varieties under different fertilizer treatments

Variety	**HI**	**% filled grains**
GSR007	0.39	63.6
K5	0.37	64.8
K85	0.35	61.3
WITA9	0.40	70.2
Mean	0.30	65.0
P-value	0.002	0.04
$LSD_{0.05}$	0.02	6.2
CV (%)	12	16.5

CV- coefficient of variation, Hi- Harvest index

Table 6.2: Effect of season on yield, number of panicles and number of tillers under different fertilizer treatments

	Yield (t ha^{-1})		% filled grains		No. tillers (m^{-2})		No. panicles (m^{-2})		HI		Plant height (cm)	
Treatment	2013A	2013B	2013A	2013B	2013A	2013B	2013A	2013B	2013A	2013B	2013A	2013B
20-20-0	1.5	1.2	74.3	50.1	558	664	482	510	0.3	0.37	91.9	82.3
40-20-0	2.0	1.3	76.2	50.9	533	628	462	516	0.32	0.41	90.3	80.2
60-30-0	2.9	1.8	73.5	52.6	610	661	541	533	33	0.41	94.7	82.1
80-20-0	2.8	2.4	74.6	57.1	696	723	577	566	0.38	0.42	93.6	86.1
80-40-0	3.2	2.7	76.2	61.6	643	721	556	651	0.38	0.43	93	84
120-40-0	3.6	3.3	69.2	63.8	702	729	620	651	0.36	0.44	95.9	88.2
Mean	2.7	2.1	74	56	624	688	539.7	571.2	0.35	0.41	93.2	83.8
$LSD_{0.05}$ (Trt x S)	0.4		8.3		NS		NS		NS		NS	
CV (%)	17.6		17.9		21.8		23.9		12		9.5	

CV- coefficient of variation, No.- Number, HI- Harvest index, NS- Not significant, Trt- Treatment, S-Season, 2013A-first season 2013, 2014A- first season 2014, 2014B-second season 2014.

The interaction between variety and season was only significant for plant height, number of panicles and harvest index (Table 6.5). Plants were significantly taller in 2013A than in 2013B. K 85 was the tallest variety and was significantly taller than WITA 9 and GSR in both seasons (average height = 105 cm in 2013A and 93 cm in 2013B). On the contrary, more panicles were produced in 2013 B than 2013A. GSR 007 produced the highest number of panicles in 2013B (average = 636 m^{-2}) while WITA 9 produced the highest number of panicles in 2013A (average = 558 m^{-2}) (Table 6.4). The interaction between fertilizer regime and variety was only significant for yield ($P<0.05$) (Table 6.4). All varieties recorded high yields in the 120-40-0 treatment; 2.9 t ha^{-1} for WITA 9 and GSR 007, 3.8 t ha^{-1} for K5 and 4.1 t ha^{-1} for K85 (Table 6.5). Average yields for the different varieties were 2.0, 2.6, 3.0 and 2.1 t ha^{-1} for GSR007, K 5, K85, and WITA9 respectively. Treatments 120-40-0 had significantly higher yield than 80-40-0 in GSR007 and K 5 but the two treatments were not significantly different in K85 and WITA9. Similarly, treatment 80-20-0 only significantly outperformed 60-30-0 in variety K 85. There were no differences among varieties for treatments 20-20-0 and 40-20-0. Increasing P rate to 40 kg ha^{-1} while holding the N rate constant resulted in yield gains of 0.2, 0.6, 0.8 and 0.7 t ha^{-1} for GSR007, K 5, K 85 and WITA 9 respectively. Overall K 85 yielded higher than the rest of the varieties tested followed by K 5. Similarly, the numbers of tillers and panicles increased as the amount of fertilizers added increased but unlike yield, 40-20-0 recorded the lowest numbers of tillers and panicles; 580 and 489 m^{-2} respectively (Table 6.6). The harvest indices recorded in the different fertilizer treatments were generally low but significantly different ($P<0.05$). Three treatments (120-40-0, 80-40-0, 80-20-0) had a harvest index of 0.4 each which is higher than for treatment 20-20-0 (0.34).

Table 6.4: Growth and yield components for four varieties across two seasons 2013A and B

Variety	Plant height (cm)		No. tillers (m^{-2})		No. Panicles (m^{-2})		HI	
	2013A	2013B	2013A	2013B	2013A	2013B	2013A	2013B
GSR 007	83.9	76.8	599	751	506.0	636	0.35	0.43
K 5	103.3	88.9	612	651	553.3	527.3	0.32	0.42
K 85	105	93	613	654	541.3	545.3	0.34	0.35
WITA 9	80.7	76.4	671	694	558.0	576.0	0.36	0.43
Mean	93.2	83.8	624	688	539.7	571.2	0.34	0.41
$LSD_{0.05}$ (S)	2.4		41		NS		0.02	
$LSD_{0.05}$ (Var x S)	4.4		NS		71.4		NS	
CV (%)	9.5		11.9		12.4		20.4	

CV- coefficient of variation, Hi- Harvest index, Trt- Treatment, Var- Variety, 2013A-first season 2013, 2014A- first season 2014, 2014B-second season 2014.

TABLE 6. 5: Effect of the interaction between fertilizer treatment and variety on yield (t ha^{-1})

	Varieties				
Treatment	**GSR 007**	**K5**	**K85**	**WITA9**	**Mean**
20-20-0	1.15	1.34	1.58	1.12	1.30
40-20-0	1.45	1.70	1.90	1.60	1.67
60-30-0	2.06	2.47	2.91	2.04	2.37
80-20-0	2.08	2.98	3.48	1.99	2.63
80-40-0	2.32	3.11	3.71	2.71	2.96
120-40-0	2.91	3.80	4.13	2.89	3.43
Mean	2.00	2.57	2.95	2.06	2.39
LSD0.05(Trt)			0.36		
$LSD_{0.05}$ (Var)			0.13		
$LSD_{0.05}$ (Trt x Var)			0.51		
CV (%)			9.8		

CV- coefficient of variation, Trt- Treatment, Var- Variety

Table 6.6: Effect of different fertilizer treatments on yield components of rice

Treatment	No. tillers (m^{-2})	No. panicles (m^{-2})	HI	Plant height (cm)	% filled grains
20-20-0	611.0	496.0	0.34	87.1	62.2
40-20-0	580.1	489.0	0.37	85.2	63.5
60-30-0	635.0	537.0	0.37	88.4	63.1
80-20-0	709.0	571.5	0.40	89.8	65.9
80-40-0	682.0	603.5	0.40	88.5	68.9
120-40-0	716.0	635.5	0.40	92.0	66.5
Mean	656.0	555.4	0.38	88.5	65.0
P-value	0.034	0.012	0.036	0.07	0.27
$LSD_{0.05}$	91.8	84.9	0.04	NS	NS
CV (%)	9.3	10.1	7.7	3.3	6.5

HI- Harvest index, CV- coefficient of variation

6.4.3 Profitability of different fertilizer treatments

Profitability analysis is shown in tables 6.7a and 6.7b. In 2013A, treatment 120-40-0 recorded the highest net returns followed by 80-40-0>60-20-0>80-20-0>40-20-0>20-20-0 in that order. The profitability levels in 2013A were similar for 120-40-0 (29.0%), 80-40-0 (27.8%) and 60-20-0 (26.7%) (Table 6.7a). The prolonged drought in 2013B reduced the profitability margins in that season with 120-40-0 treatment producing the highest margin of 26.8% followed by 80-40-0 and 80-20-0 treatments respectively (Table 6.7b). Majority of the farmers do not apply chemicals so they were not considered in the profitability analysis.

Table 6.7a: Profitability analysis of fertilizer treatments in 2013A

			Treatments					
ITEM/ACTIVITY	**QTY (ha^{-1})**	**RATE (US $)**	**20-20-0**	**40-20-0**	**60-30-0**	**80-20-0**	**80-40-0**	**120-40-0**
Materials Input Costs								
Land hire fee (ha^{-1})	1.0	114.5	115	115	115	115	115	115
Seeds (ha^{-1})	20.0	0.38	8	8	8	8	8	8
Urea (N-46%) (ha^{-1})	-	2.10	42	84	126	168	168	252
DAP (18-46-0) (ha^{-1})	-	2.30	46	46	69	46	92	92
Insecticide (Rocket) (ha^{-1})	1.2	12.50	15	15	15	15	15	15
Total Input Costs			225	267	332	351	397	481
Activity costs								
Ploughing 1st (ha^{-1})	1.0	57.28	57	57	57	57	57	57
Ploughing 2nd (ha^{-1})	1.0	45.83	46	46	46	46	46	46
Nursery Establishment (100 m^{-2})	1.0	3.79	4	4	4	4	4	4
Bunds repair/formation (ha^{-1})	1.0	3.79	4	4	4	4	4	4
Puddling & leveling (ha^{-1})	1.0	34.37	34	34	34	34	34	34
Transplanting (ha^{-1})	1.0	74.47	74	74	74	74	74	74
Hand weeding (ha^{-1})	1.0	22.91	46	46	46	46	46	46
Fertilizer application labour	3.0	1.89	6	6	6	6	6	6
Insecticide spraying labour	8.0	0.38	3	3	3	3	3	3
Bird scaring (1 Month)	1.0	56.82	57	57	57	57	57	57
Harvesting (ha^{-1})	1.0	68.74	69	69	69	69	69	69
Total labour costs			400	400	400	400	400	400

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Table 6.7a: Profitability analysis of fertilizer treatments in 2013A

			treatments					
ITEM/ACTIVITY	**QTY (ha^{-1})**	**RATE (US $)**	**20-20-0**	**40-20-0**	**60-30-0**	**80-20-0**	**80-40-0**	**120-40-0**
Post-harvest costs								
Threshing (bags)	0.00	0.38	6	8	11	11	12	14
Drying material (Tarpaulins)	3.00	3.79	11	11	11	11	11	11
Packaging material		0.38	6	6	11	11	12	14
Total Post-harvest costs			23	25	33	33	35	39
Total costs			648	692	765	784	832	920
INCOME								
Rice harvested (kg ha^{-1})			1,500	2,000	2,900	2,800	3,200	3,600
Total expected gross income		0.36	540	720	1,044	1,008	1,152	1,296
Total expected net income (profit)			-108	28	279	224	320	376
Profitability (% of income)			-20.0%	4.0%	26.7%	22.3%	27.8%	29.0%

Table 6.7b: Profitability analysis of fertilizer treatments in 2013B

			Treatments					
ITEM/ACTIVITY	**QTY (ha^{-1})**	**RATE (US $)**	**20-20**	**40-20**	**60-30**	**80-20**	**80-40**	**120-40**
Materials Input Costs								
Land hire fee (ha^{-1})	1.0	114.5	115	115	115	115	115	115
Seeds (ha^{-1})	20.0	0.38	8	8	8	8	8	8
Urea (N-46%) (ha^{-1})		2.10	42	84	126	168	168	252
DAP (18-46-0) (ha^{-1})		2.30	46	46	69	46	92	92
Insecticide (Rocket) (ha^{-1})	1.2	12.50	15	15	15	15	15	15
Total Input Costs			225	267	332	351	397	481
Activity costs								
First ploughing (ha^{-1})	1.0	57.28	57	57	57	57	57	57
Second ploughing (ha^{-1})	1.0	45.83	46	46	46	46	46	46
Nursery Establishment (100 m^{-2})	1.0	3.79	4	4	4	4	4	4
Bunds repair/formation (ha^{-1})	1.0	3.79	4	4	4	4	4	4
Puddling & leveling (ha^{-1})	1.0	34.37	34	34	34	34	34	34
Transplanting (ha^{-1})	1.0	74.47	74	74	74	74	74	74
Hand weeding (ha^{-1})	1.0	22.91	46	46	46	46	46	46
Fertilizer application labour	3.0	1.89	6	6	6	6	6	6
Insecticide spraying labour	8.0	0.38	3	3	3	3	3	3
Bird scaring (1 Month)	1.0	56.82	57	57	57	57	57	57
Harvesting (ha^{-1})	1.0	68.74	69	69	69	69	69	69
Total labour costs			400	400	400	400	400	400

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Table 6.7b: Profitability analysis of fertilizer treatments in 2013B

			treatments					
ITEM/ACTIVITY	**QTY (ha^{-1})**	**RATE (US $)**	**20-20-0**	**40-20-0**	**60-30-0**	**80-20-0**	**80-40-0**	**120-40-0**
Post-harvest costs								
Threshing (bags)	0.00	0.38	5	5	7	9	10	13
Drying material (Tarpaulins)	3.00	3.79	11	11	11	11	11	11
Packaging material	0.00	0.38	5	5	7	9	10	13
Total Post-harvest costs			21	21	25	29	31	37
Total costs			646	688	757	780	828	917
INCOME								
Rice harvested (kg ha^{-1})			1,200	1,300	1,800	2,400	2,700	3,300
Total expected gross income		0.38	456	494	684	912	1,026	1,254
Total expected net income (profit)		183	-190	-194	-73	132	198	337
Profitability (% of income)			-41.6%	-39.2%	-10.6%	14.5%	19.3%	26.8%

6.5 Discussion

6.5.1 Use of inorganic fertilizers to increase yield of lowland rice

Applying high rates of inorganic fertilizers resulted in higher rice yields than lower inorganic fertilizer rates. Applying 120-40-0, 80-40-0 and 80-20-0 resulted in yields of 3.4, 3.0 and 2.6 t ha^{-1} respectively. Yield recorded in 120-40-0 was significantly higher than that recorded in 80-40-0 and 80-20-0. The yield in the 60-30-0 plots was not significantly different from 80-20-0. Overall low rates of fertilizers (20-20-0 and 40-20-0) resulted in low yields (1.3-2.3 t ha^{-1}) similar to those obtained by farmers at their farms. The number of tillers produced was highest in the 120-40-0 treatment and least in the 20-20-0 and 40-20-0 treatments. The high yields obtained are attributed to higher numbers of tillers that are normally produced as a result of application of nitrogen based fertilizers. Soil analysis results (chapter three of this thesis) showed that most of the farmers' fields were deficient in nitrogen. The high yields are therefore a response to the application of nitrogen. The yields recorded in this experiment were generally lower than those recorded elsewhere (for example Haefele *et al,* 2000; Krupnik *et al*., 2012, Merteens *et al*., 2003). Meertens *et al.* (2003) recorded average yields of 3.6, 4.1, 4.4 and 4.9 t ha^{-1} for control, 30, 60, and 120 kg of N ha^{-1} respectively while working in the lowland rainfed ecologies of Sukuma land, Tanzania. Krupnik *et al*. (2012) recorded average yields of 7.5 and 5.5 t ha^{-1} in dry and wet seasons respectively in the Senegal River Valley. Likewise, Haefele *et al*. (2000) recorded yields ranging from 4.6-5.6 t ha^{-1} with recommended fertilizer management of 156-20-0 NPK but obtained even higher yields with improved weed management and recommended fertilizer management. The difference in yields could have been due to stress caused by drought especially in the second season of 2013. However, with the exception of Meertens *et al*. (2003), most of the studies on nutrient regimes were conducted in irrigated conditions where water stress and weeds were not major constraints;

therefore, their yields were bound to be higher than in this study. Application of fertilizers has been recommended as the quickest means to increase yields and arrest nutrient mining at farms (World Bank, 2006).

6.5.2 Performance of different varieties under different rates of inorganic fertilizers

The variety K85 outperformed all other varieties irrespective of season and treatments. Variety K 85 recorded the highest yield (4.1 t ha^{-1}) in plots that received 120-40-0 NPK in 2013A. The interaction between fertilizer regime and variety was significant for yield. Plots that received 120-40-0 yielded significantly higher yield than those that received 80-40-0 NPK for GSR and K 5 but not K 85 and WITA 9. Only WITA 9 recorded a significantly higher yield in 80-40-0 than 80-20-0. This implies that high yields can be achieved with K 5 and GSR 007 by applying high rates of fertilizer but applying rates higher than 80-40-0 may not be necessary for K 85 and WITA 9. There were significant differences between varieties for plant height, harvest index and grain filling. K 85 was the tallest variety (average height= 99 cm) while WITA 9 was the shortest (Average height= 78.6 cm). Overall, WiTA 9 and GSR007 also produced the highest number of tillers (682 and 675 m^{-2}). WITA 9 had the highest harvest index and the highest percentage of filled grains (70.2%). Despite its performance, the HI of K 85 was a low. This is related to the fact that K 85 is a tall variety, and therefore has more vegetative cover than WITA 9 which is a short variety. Despite, its low HI, K 85 yielded higher than the rest of the varieties.

6.5.3 Profitability analysis

Applying 120-40-0, 80-40-0 and 60-30-0 NPK gave returns of 29.0, 27.8 and 26.7% respectively in 2013A. The profitability for the same treatments was lower in 2013B due to prolonged drought experienced in that season. As shown by Heafele *et al*., (2000), increasing fertilizer rates and improving application time to coincide with crop demand can increase yields. The profitability rates presented here are similar to Heafele *et al*. (2000) but are much lower than those recorded by Krupnik *et al*. (2012). Heafele *et al*. (2000) observed net benefit of 39% with recommended fertilizer rates of 156-20-0 NPK in the Sahelian West Africa. On the contrary, Krupnik *et al*. (2012) recorded rates of return of up to 146% when they applied 130-20-0 NPK in the Senegal River valley. Krupnik *et al*. (2012) and Heafele *et al*. (2000) however conducted their studies under irrigated conditions where water and weed stresses were not limiting factors. Subjecting their nitrogen trial to partial budgeting and marginal analysis, Meertens *et al*. (2003) only found the 30 kg N ha^{-1} treatment to have a marginal rate of return higher than 100% with the marginal rates of return for 60 and 120 kg of N ha^{-1} being 15 and 8% respectively. Meertens *et al*., 2003 acknowledged that the high yields attained in the Sukuma land were as a result of adequate rains received during the trials. In this study, drought was a major constraint in both seasons hence low yields and low net returns on fertilizer. Whereas use of fertilizers is profitable as shown by Haefele *et al*. (2000) and Krupnik *et al*. (2012), the volatility of the rainfed lowland system because of insufficient rains increases the chances of crop failure, thereby reducing the benefits of fertilizer use.

6.6 Conclusion

This study has shown that applying inorganic fertilizers in rainfed lowland rice increases yields. Applying 120-40-0 NPK gave the highest yields followed by 80-40-0 NPK. Applying 20-20-0 and 40-20-0 NPK resulted in low yields. The variety K85 outperformed all other varieties irrespective of season and treatments. Plots that received 120-40-0 yielded significantly higher yield than those that received 80-40-0 NPK for GSR 007 and K 5 but not K 85 and WITA 9. K 85 is therefore a high yielding variety. However, K 5 and GSR 007 respond to high rates of fertilizer than K 85.

The profitability levels in 2013A were similar for plots that received 120-40-0 (29.0%), 80-40-0 (27.8%) and 60-30-0 (26.7%). In this study, drought was a major constraint in both seasons causing low yields and low net returns on fertilizer more so in the second season of 2013. In order to realize the benefits of fertilizer use, biophysical constraints especially drought and weeds have to be managed adequately by timely planting and use of recommended weed management practices.

CHAPTER 7: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1 Discussion

Only about 12 and 18% of the farmers interviewed used fertilizers and other agro-chemicals respectively. This is attributed majorly to high purchase prices and lack of knowledge on their usage. The results of the probit analysis showed that fertilizer prices and occupation significantly determined fertilizer use implying that high prices of fertilizers limited farmers from purchasing them while farmers who had other sources of income were more likely to use fertilizers. Similarly, gender and training in rice production were significant factors determining the use of agro-chemicals implying that males were more likely to use agro-chemicals than women, and farmers who received training were most likely to use agro-chemicals than those who were not trained. This implies that the use of agro inputs can be increased if the purchase prices are within the reach of the farmers, and the farmers are trained on their importance and usage. Considering the weak public extension system in Uganda, farmer training in rice production and fertility management could help improve adoption of improved technologies hence increasing production. Analysis of soil samples collected from farmers' fields showed that the farms had medium levels of organic matter, total nitrogen and available phosphorus. More external sources of nitrogen and phosphorus are required to improve their levels and increase rice yields. There were significant differences between districts for exchangeable bases Mg and K and available phosphorus with Kaliro and Namutumba districts in eastern Uganda having higher levels of Mg and K than the rest of the districts. Variability of nutrient levels in different locations emphasizes the need for site specific nutrient management rather than blanket recommendations. Results also showed that the most common weeds found in farmers' fields belonged to Cyperaceae and Poaceae families while the parasitic *Ramphircarpa fistulosa* (Hochst.) Benth was identified mainly in Butalejja and Bugiri districts. Weeds in the respective families are difficult to control, and their dominance may be the result of ineffective management methods over the years. Farmers will need to be trained on the effective weed management methods to manage the weeds.

The research findings generally showed that fertilizer use among lowland rice farmers is low, and the rates used are equally low. According to Morris et al. (2007), this negligible fertilizer use partly explains lagging agricultural productivity growth in Sub-Saharan Africa and Uganda in particular. Thus, experts and policy makers agree on the urgent need to increase the use of inorganic fertilizer in the region (Yamano and Arai, 2011). This study has shown that farmers were aware that their yields were declining mainly due to declining soil fertility.

Results showed that applying fertilizer in the nursery and transplanting 14 day old seedlings increased yields by 23-30% relative to the control. This demonstrates that yields at farmer level can be increased at minimal costs by improving nursery management in order to produce vigorous seedlings. This is especially important considering that fertilizer use among smallholder farmers is limited by high prices and limited availability. The interaction between split N applications and variety was significant for yield with GSR 0057 yielding better than WITA 9. Variety K 85 had a significantly lower yield in the control treatment than the rest of the varieties. This implies that variety K 85 requires fertilization to produce sufficient yields. Application of 46 and 23 kg of N ha^{-1} at once had significantly lower harvest indices (HI= 0.31 and 0.32 respectively) than the control and split application of 23 and 46 kg of N ha^{-1}. The low HI resulting from whole applications of nitrogen could be related to accumulation of shoot dry matter at the expense of grains. Split application of nitrogen fertilizer provides the nutrient to the plant at the time when the nutrient is most needed. The marginal increase in yield and agronomic efficiency due to split applications of nitrogen could be related to the low rates of N used, and farmers could record more yield gains if they use high rates. Improving N- management and nursery management has greater prospects for increasing rice yields on all cultivars in smallholder farms at minimal costs.

The study also found that the agronomic efficiency, recovery efficiency and internal use efficiency of fertilizer N were generally low, implying that it would be difficult for farmers to maximize economic benefits from using fertilizers with the current varieties and agronomic practices. This could be a result of many factors including low yielding varieties, poor water management, drought and flood regimes during the same growing season, weed problems and general poor crop management. The low agronomic efficiency (18 kg N kg^{-1}), recovery efficiency (31%) and internal use efficiency (36.9 kg kg^{-1}) are an indication that even though farmers apply fertilizers, they may not realize the benefits unless good agricultural practices are adopted. The low fertilizer efficiency implies that in order for farmers to record maximum benefits from fertilizer use, they need to adopt new improved high yielding varieties and improve water, pest and disease management.

The average indigenous supplies of N, P and K of the soils were 52, 9.7 and 87.2 kg ha^{-1} respectively. The high indigenous K supply levels could be attributed to the fact that farmers predominantly leave rice straw in their gardens and sometimes burn it during land preparation at the beginning of the season. Based on Driesen *et al*. (1986), the calculated rates of N, P and K required to achieve 5 or more t ha^{-1} of paddy are 63,13 and 24 kg ha^{-1} respectively. This translates into a saving of 49, 74 and 59% on N, P and K rates respectively in comparison to the applied full rates. Finally, the evaluation of nutrient options showed that the variety K85 outperformed all other varieties irrespective of season and treatments. Variety K 85 is therefore a high yielding variety. Plots that received 120-40-0 yielded significantly higher yield than those that received 80-40-0 NPK for GSR 007 and K 5 but not K 85 and WITA 9. In addition, the profitability levels were similar for plots that received 120-40-0 (29.0%), 80-40-0 (27.8%) and 60-30-0 (26.7%). This implies that application of more than 63 kg N ha^{-1} is not economical. However, the levels of low agronomic efficiency, recovery efficiency and internal use efficiency of N recorded here implies that it would be difficult for farmers to maximize the benefits of fertilizer use without adopting new high yielding varieties and improving water, weed, pest and disease management at their farms. Considering that there are limited nutrient management recommendations for lowland rice in Uganda, the findings of the current study will be a good start towards development of site specific nutrient management options.

7.2 Conclusions

The findings of this research showed that usage of fertilizers and other agro inputs in lowland rice ecologies of eastern and northern Uganda are low. The results also showed that the main determinants for fertilizer use among rice farmers are farmers' other occupation and fertilizer prices while age, household size, gender and training in agricultural production determine the use of agro-chemicals on rice fields. Most of the interviewed farmers ranked declining soil fertility, pests, diseases, weeds and insufficient rain as the major constraints to rice production. Results also showed that the most common weeds found in farmers' fields belonged to cyperaceae and poaceae families while the parasitic *Ramphircarpa fistulosa* (Hochst.) Benth was identified mainly in Butalejja and Bugiri districts.

Results showed that applying fertilizer in the nursery and transplanting 14 day old seedlings increased yields by 23-30% relative to the control. The effect of split application of nitrogen on rice yield was dependent on varieties. Split application of nitrogen enhanced harvest index.

Results also showed that the full NPK treatment yielded 73, 40, 23 and 25% higher than control, PK (-N), NK (-P) and NP (-K) treatments respectively. The indigenous nutrient supplies for nitrogen and phosphorus were moderate while potassium was high. The agronomic efficiency (18 kg N kg^{-1}), recovery efficiency (31%)and internal use efficiency (36.9 kg kg^{-1}) of N were generally low. The amount of N, P and K required to produce 5 t ha^{-1} of paddy in Bugiri district were 63, 12.6 and 24.5 kg ha^{-1}.

The results also showed that yield generally increased with increase in amounts of fertilizer applied. Rice variety K 85 out yielded all other varieties irrespective of treatment and season. Plots that received 120-40-0 yielded significantly higher yield than those that received 80-40-0 NPK for GSR 007 and K 5. Profitability levels were similar for plots that received 120-40-0 (29.0%), 80-40-0 (27.8%) and 60-30-0 (26.7%) fertilizer regimes.

7.3 Recommendations

1. Based on the omission trials it may be advisable for farmers in Bugiri ditrict to apply fertilizers at the rates of 63, 30 and 20 kg ha^{-1} of N, P and K respectively.
2. Variety K 85 had higher yields than others varieties in fertilized trials but lower yields in unfertilized trials implying it is the best for farmers who use fertilizers. Varieties WITA 9 and GSR 007 had relatively higher yields in unfertilized trials implying that they can be grown by farmers who do not apply fertilizers.
3. Given that this study has been conducted in rainfed lowlands and few sites, it is advisable that the study be conducted in other rainfed lowland rice ecologies as well as in irrigated systems in Uganda.

4. This study used low rates of nitrogen (23 and 46 kg ha^{-1}) resulting in limited yield responses. It is therefore recommended to evaluate the effect of split application on rice yield using higher rates of nitrogen.
5. The study to determine the effect of fertilizer, fungicide and age of seedling transplanting was set up by applying fertilizer and fungicide in the nursery. Although the study showed a 23-30% increase in yield where DAP and fungicide were applied and seedlings transplanted at 14 days, fertilizer was not applied in the main field after transplanting. A similar study that incorporates improved nutrient management in both the nursery and the field needs to be set up.

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APPENDICES

Appendix 1: Critical values of nutrients and soil properties

Properties	Critical levels				
	Very low	Low	Medium	High	Very high
OM %	<1	1-2	2-4.2	4.2-6	>6
Total N%	<0.05	0.05-0.125	0.125-0.225	0.225-0.30	>0.3
C/N	<10=good, 10-14=medium and >14=poor				
Ca cmoles/Kg	<2	2-5	5-10	10-20	>20
Mg cmoles/Kg	<0.5	0.5-1.5	1.5-3	3-8	>8
K cmoles/Kg	<0.1	0.1-0.3	0.3-0.6	0.6-1.2	>1.2
Na cmoles/Kg	<0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2.0
Olsen P mg/Kg		<5	5-15	>15	
pH	5.3-6.0 moderately acid; 6.0-7.0=slightly acidic; 7.0-8.5=moderately alkaline				
ESP%		<2	2-8	8-15	15-27
CEC_7 cmoles/Kg	0-20	21-40	41-60	61-80	81-100

Beernaert and Bitondo, 1992.

Appendix 2: Mean squares and significance of F-ratios for grain yield and yield components across different omission treatments and different seasons in 2013 and 2014

Source of variation	**DF**	**Yield (t/ha)**	**Height (cm)**	**Tillers (m^{-2})**	**Panicle (m^{-2})**	**%filled grains**
Season	2	42.02**	192.46*	212128**	525971**	1431.55**
Treatment	4	8.92**	329.83**	92709**	125657**	119.27
Error	73	2.09	52.71	18479	17825	63.00
Total	79					
CV%		38.5	8.1	21.3	21.3	9.6

** Significant at p<0.01, * significant at p<0.05

Appendix 3: Mean squares for yield and yield components in 1st and 2nd season 2013 (Nutrient option experiment)

Source of variation	**DF**	**Yield (t/ha)**	**Height (cm)**	**No. tillers (m^{-2})**	**No. Panicles (m^{-2})**	**% filled grains**	**HI**
Block	3	0.32	86.6	37316	48279	405.9	0.0045
Treatment	5	20.4**	172.2	97429*	110494*	201.8	0.0219*
Error (whole plots)	15	0.46	66.5	29691	25378	142.1	0.00679
Variety	3	9.7**	5342.9**	34318	12008	682.3*	0.0229**
Treatment x variety	15	0.46**	69.5	15878	12080	238.9	0.0028
Error (sub plot)	54	0.11	46.2	15045	13503	230.6	0.00414
Season	1	13.8**	4254.5**	196608*	47628	15525.5**	0.2163**
Treatment x season	5	0.6**	28.72	9325	12668	436.5*	0.0033
Variety x Season	3	0.34	253.8*	42674	55788*	343.0	0.0163
Variety x Season x treatment	15	0.31	33.9	21202	15303	321.9*	0.0019
Error	72	0.17	70.8	20343	17691	135.5	0.0060
Total	191						

Appendix 4: Mean squares of yields and yield parameters for 2013A and 2014B (Split application experiment)

Source of variation	d.f	Yield (tons/ha)	Tiller nos.(m^{-2})	Panicle nos. (m^{-2})	Height (cm)	HI	% filled grains
Block	3	4.27	60785	115268	29.8	0.012	71.77
Treatment	4	1.72	41853	24027	193.75	0.034**	408.99**
Error (whole plot)	12	1.47	17961	14047	60.06	0.007	64.77
Variety	3	0.66	48514	34551	3943.40**	0.049**	367.27**
Trt x Variety	12	1.46**	17764	10198	48.65	0.005	36.58
Error (Sub plot)	45	0.57	23580	19359	64.27	0.003	74.80
Season	1	0.53	118780**	3378	1326.84**	0.051**	1292.71**
Trt x season	4	0.33	7761	2606	86.81*	0.004	99.68
Variety x season	3	1.37*	8369	1075	221.02**	0.005	228.19*
Trt x season x variety	12	0.47	18672	5266	47.53	0.003	97.28
Error	49	0.52	15886	15247	32.03	0.002	55.65
Total	148						

Appendix 5: Mean squares for the effect of fertilizer, fungicide and age of seedlings on yield and its components

Source of variation	d.f	Yield (tons/ha)	Height (cm)	No. tillers (m^{-2})	No. Panicles (m^{-2})	HI	% filled grains
Block	3	5.80	266.97	160242	34917	0.007	420.90
Treatment	4	10.36**	70.39	51555	102798	0.014	284.15
Error	12	2.11	130.96	71580	42668	0.011	226.95
Variety	3	1.29	2796.18**	24797	11990	0.035**	23.30
Trt x variety	12	2.23	82.96**	9946	6421	0.011	84.89
Error	45	1.53	24.83	22903	13554	0.006	117.76
Season	1	30.18**	184.26*	290654**	289680**	0.039**	115.83
Trt x season	4	6.08**	78.35*	110771**	70086**	0.010	74.95*
Variety x season	3	0.35	4.03	26767	3372	0.004	55.29
Trt x variety x season	12	0.82	9.5	12011	7529	0.004	21.44
Error	58	0.58	29.3	11107	6097	0.005	26.80
Total	157						

** Significant at $p<0.01$, * significant at $p<0.05$

Appendix 6: Questionnaire

Objectives of the survey

General objective: To study the status and management of soil fertility in lowland rice growing areas in eastern and northern Uganda.

Specific objectives

1 To understand how farmers maintain soil fertility at their rice farm

2 To document organic and inorganic fertilizers used by farmers in their rice farms

3 To ascertain which cultural measures the farmers use to maintain soil fertility at their farms

4 To understand from the farmers perspective the yield and soil fertility trends at their farms

5 To ascertain the status of nutrients at farmers' rice fields

6 Document how farmers assess and monitor soil fertility

Districts to be visited include Bugiri, Namutumba, Butalejja, Lira and Kaliro. Five sub counties will be selected per district and six farmers' fields will be sampled in each sub-country

Survey Questionnaire

STATUS OF NUTRIENTS AND NUTRIENT MANAGEMENT IN LOWLAND RICE ECOLOGIES IN EASTERN AND NORTHERN UGANDA

Name of the respondent ……………………………………………………..

District of respondent: ……………………………………………………………

County …………………………………………

Sub-county ……………………………………..

Parish……………………………………………

Village/ LC 1 …………………………………………….

Phone Number: ……………………………………………………………

Date of Interview…………………………………………………………

Interviewer's details

Interviewer's name……………………………………………………..

Phone number………………………………………………………………

SECTION A:

Q1. Occupation

1	Peasant (subsistence) farmer	
2	Commercial farmer	
3	Businessman	
4	Civil servant	
5	Student	
88	Others (Specify): ______________________	

Q2. Sex

1	Male	
2	Female	

Q3. Age of respondent

1	15 to 20 Years	☐
2	21 to 30 Years	☐
3	31 to 40 Years	☐
4	41 to 50 Years	☐
5	51 to 60 years	☐
6	More than 60 years	☐

Q4. Marital status

1	Single	☐
2	Married	☐
3	Divorced	☐
5	Widowed	☐

Q5. Highest formal educational level

1	None	☐
2	Primary/Junior	☐
3	Secondary 1-4	☐
4	Secondary 5-6	☐
5	Tertiary Institution	☐
6	University	☐
88	Others (Specify): ______________________________	☐

Q6. What is your family size?

1 Males

2 Females

Section B

Q7a. What is the size of your landholding in acres? ______________________________

Q7b. How much of that is devoted to rice production?

1 Lowland rice

2 Upland rice

Q8. State the five main food crops you have grown for the last three seasons and average acreage per crop

	SEASON 2 (2011)			SEASON 1 (2012)			SEASON 2 (2012)		
Rank	Food Crop code	Acreage	Production (Kg)	Food Crop code	Acreage	Production (Kg)	Food Crop code	Acreage	Production (Kg)
1									
2									
3									
4									

Food crops and their corresponding codes

1. Maize	6. Cassava	11. Sunflower
2. Beans	7. Millet	12. Simsim
3. Groundnuts	8. Sorghum	13. Soybeans
4. Sweetpotatoes	9. Bananas	14. Pigeon Peas
5. Rice	10. Cowpeas	88. Others (specify)

Q9. State the five main cash crops you have grown for the last three seasons and average acreage.

	SEASON 2 (2011)			SEASON 1 (2012)			SEASON 2 (2012)		
Rank	Food Crop code	Acreage	Production (Kg)	Food Crop code	Acreage	Production (Kg)	Food Crop code	Acreage	Production (Kg)
1									
2									
3									
4									

Cash crops and their corresponding codes

1. Maize	8. Groundnuts	15. Bananas
2. Coffee	9. Sweetpotatoes	16. Tobacco
3. Cotton	10. Millet	88. Others (Specify)

4. Sugarcane	11. Cowpeas	
5. Rice	12. Sunflower	
6. Cassava	13. Sorghum	
7. Beans	14. Simsim	

Q10. For how long have you grown rice at your farm?

1	1-2 seasons	
2	3-5 seasons	
3	>5 seasons	

Q11. Which varieties of lowland rice do you grow in preference and why?

Rank	Rice variety	Reason for preference
1.		
2.		
3.		
4.		
5.		
6.		
7.		

Varieties and corresponding codes

1. Supa	7. GSR 0057
2. Kaiso	8. NERICA 1
3. K 98	9. NERICA 3
4. K 85	10. NERICA 4
5. WITA 9	11. NERICA 10
6. K 5	88. Others (Specify)

Reasons for preference

1	High market demand
2	Nice scent/smell
3	Easy to cook
4	Good milling recovery
5	Early maturity
6	Resistance to pest and diseases
7	High yielding
8	High grain quality
9	Easy to grow/manage
10	Not easily attacked by birds
88.	Others (specify)

Q12. Please give the list of crops you have grown at this particular plot for the last four seasons?

	SEASON 1 (2011)			SEASON 2 (2011)			SEASON 1 (2012)			SEASON 2 (2012)		
Rank	Crop code	Acre	yield (kg)	Crop code	Acre	Yield (kg)	Crop code	Acre	Yield (kg)	Crop code	Acre	Yield (Kgs)
1												
2												
3												
4												
5												

Food and Cash crops and their corresponding codes

1. Maize	6. Cassava	11. Sunflower	16. Cotton
2. Beans	7. Millet	12. Simsim	17. Sugarcane
3. Groundnuts	8. Sorghum	13. Soybeans	18. Tobacco
4. Sweetpotatoes	9. Bananas	14. Pigeon Peas	88. Others (Specify)
5. Rice	10. Cowpeas	15. Coffee	

Q13. At what time of the year, do you sow your rice crop?

1	Early March	
2	Mid-March	
3	Late March	
4	Early April	

5	Mid April	
6	Late April	
7	Early September	
8	Mid-September	
9	Late September	
10	Early October	
11	Mid-October	
12	Late October	

Q14. What method of planting do you use at your rice farm?

1	Transplanting	
2	Direct seeding	

Q15. If your answer is transplanting, what is usually the age of your seedlings?

1	2 weeks	
2	3 weeks	
3	1 month	
4	1.5 months	
5	2 months	
6	>2 months	

Q16. What is the source of water for your rice field?

1	Rain water	
2	Irrigation water	

Q17. If your answer in question 16 above is irrigation, how do you ensure nutrients are maintained at your rice field?

1	Application of inorganic fertilizers	
2	Application of organic fertilizers	
3	Rotations with other crops	
88	Others (specify) ___________________	

Q18. Do you have problems of soil erosion/ run off?

0	No	
1	Yes	

Q19. If yes, how do you deal with it?

1	Constructing drainage channels	
2	Planting cover crops	
3	Planting trees	
4	Constructing bunds	
5	Crop rotation	
6	Mulching	
88	Others (Specify) __________________	

Q20**.** What agricultural inputs do you use in rice production and what are their uses?

No.	Agricultural input	Usage
1.		
2.		
3.		
4.		
5.		
6.		
7.		

Codes for agricultural inputs and usage

Inputs	**Usage**
1. Fertilizers	1. Soil fertility enrichment
2. Herbicides	2. Weed management
3. Seed	3. For planting
4. Fungicides	4. Disease and pest control
88. Others (specify)	88. Others (specify)

Q21**.** Do you use fertilizers in rice production at your farm?

0 No ☐

1 Yes ☐

Q22. If yes, which types of inorganic fertilizers do you use and what is the time of application and rates?

No.	Type of inorganic fertilizer	Rate of application per acre	Time of application
1.			
2.			
3.			
4.			

Codes for inorganic fertilizers, rate and time of application

Type of inorganic fertilizer	**Rate of application**	**Time of application**
1. DAP	1. 10 Kg/acre	2. At planting
3. Urea	4. 15 Kg/acre	2. 3 weeks after planting
5. TSP	3. 20 Kg/acre	4. At panicle initiation
6. MOP	5. 40 Kg/acre	5. Before planting
88. Others (specify)	4. 50 Kg/acre	5. After 2nd weeding
	7. 60 Kg/acre	6. At knee height of the crop
	88. Others (specify)	88. Others (specify)

Q23. What types of manures do you use and what is the time of application?

No.	Type of manure	Time of application	Rate of application
1.			
2.			
3.			

Codes for types of manures and time of application

Type of Manure	**Time of application**	**Rate of Application**
1. Compost	1. At planting	1. 2 tons/ ha
2. Cow manure	2. 3 weeks after planting	2. 3 tons/ha
3. Chicken manure	3. At panicle initiation	3. 4 tons/ha
4. Goat manure	4. Before planting	4. 5 tons/ ha
5. Organic sprays	5. After 2nd weeding	5. 6 tons /ha

6. Green manures	6. At knee height of the crop	6. 7-10 tons/ ha
7. Farm yard manure	88. Others (specify)	8. > 10 tons/ ha
88. Others (specify)		88. Others (specify)

Q24. What is the source of your fertilizers?

	Inorganic fertilizers	**Manure**
1		
2		
3		
4		
5		

Source of fertilizers and manure

1	Input dealers
2	Fellow farmers
3	Homemade (own material)
4	Purchased from commercial farmers
88	Others (specify)

Q25. What is the cost of purchase per bag or ton (UGX)?

1	Urea	
2	DAP	
3	TSP	
4	MOP	
5	Manure	

Q26. How do you apply fertilizers at your farm?

1	Broadcasting	
2	In irrigation water	
3	Covering in soil	
88	Others (specify) ________________	

Q27. How often do you use fertilizers?

1	Every season	
2	Skip one season	
3	Do not use at all	

Q28. If you use manure, how do you store it?

1	In open space	
2	In a store	
3	In compost pit	
4	Covered by earth and grass	
88	Others (specify) ________________	

Q29. Have you ever carried out a soil test at your farm?

0	No	
1	Yes	

Q30. If your answer in question 30 above is yes, how often do you do it in a year?

1	Once every season	
2	Twice every year	

3 Two times a year ☐

Q31. State other ways by which you maintain soil fertility at your rice farm.

No.	Soil fertility measure
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

Soil fertility measure

1.	Crop rotation
2.	Planting legumes
3.	Fallowing
4.	Crop residues
88.	Others (specify)

Q32. How do you gauge the fertility of your land?

No.	How you gauge soil fertility
1.	
2.	
3.	
4.	
5.	

How you gauge soil fertility

Code	Method

1.	Appearance of the soil (colour of soil)
2.	Type of vegetation on the land
3.	Yield output from the land
4.	Water holding capacity of soil
5.	Colour of the crop
6.	Stoniness of the land
7.	Difficulty of ploughing
8.	Crop height and growth rate
9.	Soil hardness
10.	Response to fertilizer/ manure
11.	Water holding capacity
12.	Quantity of manure/ fertilizer applied
88.	Others (specify)

Q33. What are the indicators of good and poor soil fertility at your farm?

Good soil fertility	Poor soil fertility
1.	1.
2.	2.
3.	3.
4.	4.
5.	5.
6.	6.

Indicators of good soil fertility and poor soil fertility

Indicators of good soil fertility		**Indicators of poor soil fertility**	
1.	Vigorous crop	1.	Stunted crop

2.	Presence of particular weed species (specify)	2.	Yellowing/ purpling of the crop
3.	Dark green crop	3.	Low yield
4.	High crop yield	4.	Presence of some weeds (specify)
5.	High growth rate of the crop	5.	Poor response to fertilizers/ manures
88.	Others (specify)	88.	Others (specify)

Q34. Over the last five years, what has been the yield trend at your rice farm?

1	Increasing	
2	Decreasing	
3	Constant	

Q35. If your answer in 34 above is 1, what factors do you attribute to the trend?

No.	Factors you attribute to the increasing trend above
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

Q36. If your answer in 34 above is 2, what factors do you attribute to the trend?

No.	What factors do you attribute to the decreasing trend

1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

Q37. What are the major production problems you face at your farm in order of importance?

No.	Major production problems
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	

Problem	**Code**	**Problem**	**Code**
Lack of improved seeds	1	Inadequate knowledge in rice production	7

Low yielding varieties	2	Drought	8
High prices of inputs	3	Lack of credit facilities	9
Pests and diseases	4	Lack of market	10
Poor soil fertility	5	Labour	11
Inaccessibility of inputs	6	Others (specify)	88.

Q38. How do you think these production problems can be solved?

No.	How production problems can be solved
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	

Code	Solution
1	Avail high yielding varieties
2	Increased government incentives to reduce prices of inputs
3	Trainings on rice production
4	Improved accessibility to inputs

5	Construction of irrigation facilities
88.	Others (specify)

Q39. Which factors restrict the use of fertilizers at your farm?

No.	Factors that restrict the use of fertilizers
1.	
2.	
3.	
4.	
5.	
6.	

Code	Factor
1	Not readily available
2	High prices
3	Lack of knowledge on their availability and use
4	The soils are still fertile
5	Use of fertilizer is not cost effective
88.	Others (specify)

Q40. How do you ensure that the fertility status at your farm is maintained every season?

1	Through crop rotation with legumes (please mention examples)	
2	Through fallowing	
3	Application of inorganic fertilizers	
4	Application of organic fertilizers	
88	Others (specify)________________________________	

Q41. How do you manage rice straw after harvest?

No.	How you manage rice straw after harvest
1.	
2.	
3.	
4.	

Code	Practice
1	Burning
2	Do nothing
3	Feed to animals
4	Leave it in the field &incorporate at land preparation
5	Remove from field and dump
88.	Others (specify)

Q42. Have you received any training in rice production?

0	No	
1	Yes	

Q43. If yes, from which organizations?

No.	Organization
1.	
2.	
3.	
4.	

Q44. Have you ever received any training on soil fertility management?

0	No	
1	Yes	

Q45. If your answer in 44 above is yes, which organization provided the training and when?

No.	Organization	When
1		
2		
3		

Codes for when the organization provided the training

1	Last year (2012)
2	1 year ago
3	2 years ago
4	More than two years ago

Q46. What do you see as the most urgent need if soil fertility at your rice farm is to be improved?

No.	Urgent need
1.	
2.	
3.	
4.	
6.	

Urgent needs codes

Code	Needs
1	Training on soil fertility management
2	Incorporating mineral fertilizers and manures in production system
3	Government puts in place a policy on soil fertility management
4	Government & other organizations support farmers with fertilizer subsidies
5	Increasing research on soil fertility
88.	Others (specify)

Thank you for your valuable information and time.

Please allow us to take a soil and three random one sq metre quadrats of weeds samples from your rice field for analysis.