NITROGEN AND PHOSPHORUS SUFFICIENCY LEVELS ASSESSMENT FOR IRRIGATED LOWLAND RICE GROWTH AND YIELD IN CYUNUZI, EASTERN RWANDA

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DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other academic institution.

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ABSTRACT

The present study was undertaken in Cyunuzi (Eastern Rwanda) paddy field using “upland 26’’ variety with the objective of assessing the sufficiency levels of nitrogen and phosphorus in order to develop tools for fertilizer recommendation for optimal rice growth and yields.

The study was carried out as a three replicate 4x3factorial experiment laid in a Randomized Complete Block Design. The treatments included four nitrogen (urea) levels (0, 40, 80 and 120kg N/ha), three phosphorus (single super phosphate) levels(0, 34 and 70kg P_2O_5/ha) and their combinations. All experimental plots received potassium fertilizer (KCl) at the rate of 34kg K_2O/ha. The soil in experimental plots was analyzed for total N, available P (Bray I), exchangeable K, organic C, CEC, pH and bulk density prior to treatments application and for pH, total N and available P at the harvest. The crop (*Oryza sativa*) leaves were analyzed for total nitrogen and phosphorus at the flowering stage. Plant height, tiller number, leaf area and the above-ground biomass were measured as growth parameters whereas the yield components including the number of panicles per plant, total grain per panicle, filled grain per panicle, empty grain per panicle, weight of 1000 grains, the yield per plant and the total yield per plots were determined at harvest.

The results showed that applied phosphorus had no significant effect on grain yield ($P<0.05$) and did not affect any yield component. Nitrogen application significantly improved the crop growth and yield by increasing plant height, leaf area, tillering and panicle numbers. Observed differences in grain yield among nitrogen rates were significant ($P < 0.01$). Tillering activity was the growth parameter that affected most significantly the grain yield, therefore the tiller number was used in estimating the soil nutrients sufficiency levels along with the yield functions. The levels of soil N in the experimental area were estimated to reach only 96, 99 and 97% of the amount required for maximum vegetative growth of the crop, respectively, under 0, 34 and 70kg P_2O_5/ha. For maximum grain yield, the soil nitrogen sufficiency levels reached 98, 99 and 98% under 0, 34 and 70kgP_2O_5/ha, respectively. It is recommended that nitrogen and phosphorus should be applied at rates of 109kg N/ha and 34kg P_2O_5/ha but this should be periodically reviewed depending on the actual soil P availability.

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ACRONYMS AND ABBREVIATIONS

AGRA	Alliance for Green Revolution in Africa
DAT	Days after transpanting
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization of the United Nations Statistical Databases
IITA	International Institute of Tropical Agriculture
IRRI	International Rice Research Institute
ISAE	Higher Institute of Agriculture and Animal Husbandry
ISRIC	International Soil Reference and Information Centre Association
LARMAT	Department of Land Resources Management and Agriculture Technology
MINAGRI	Rwandan Ministry of Agriculture and Animal Resources
MINECOFIN	Rwandan Ministry of Finance and Economic Planning
NRCS	Natural Resources Conservation Service
PPI	Potash and Phosphate Institute
PPIC	Potash and Phosphate Institute of Canada
SSA	Sub-Saharan Africa
SSRM	Sustainable Soil Resources Management
USDA	United States Department of Agriculture
WARDA	West Africa Rice Development

CHAPTER 1. INTRODUCTION

1.1 Background

Rice is one of the leading food crops in the world (Manzoor *et al*, 2006) and it is reported to feed approximately half of the world's population (Khush *et al*., 2001; Maclean *et al*., 2002; Snyder and Slaton, 2002; FAO, 2004). Globally no food grain is more important than rice from a nutritional, food security or economic perspective (Smith and Dilday, 2003). Rice is grown in all continents except Antarctica (Brady, 1981) and occupies 11% of the world's cultivated area (Khush, 1993). In majority of Asian countries it occupies one third or more of cultivated area (IRRI, 1993). The global annual production of rough rice is about 550-600 million tons (Maclean *et al*., 2002 in Bouman *et al*., 2007), of which 90 percent is produced and consumed in Asia (Maclean *et al*., 2000; Buresh and Haefele, 2010).

In Sub-Saharan Africa (SSA), rice is ranked as the fourth most important crop in terms of production after sorghum, maize and millet (Dibba *et al*, 2012). Rice occupies 10% of the total land under cereal production and produces 15% of the total cereal production (Dibba *et al*., 2012). Between 1961 and 2005, the annual increase in rice consumption was 4.52% in SSA and among the major cereals; rice is the most rapidly growing food source in Africa (Sohl 2005; WARDA, 2007). Despite the apparent importance of rice in SSA, the production level is still far below the consumer demand and as a result rice imports keep rising at an alarming rate (Dibba *et al*., 2012). The share of imports in consumption rose from an average of 43% from 1991 to 2000, to an average 57% by 2002-2004(WARDA, 2005).

Rice is a cereal with growing importance in Rwanda (MINAGRI, 2009). The area under rice cultivation rose from 3549 ha in the year 2000 to currently about 12 000 ha, all of which is irrigated. Subsequently, rice production in Rwanda has increased to about 55000 t in 2007. It is a profitable enterprise as far as the utilization of scarce cultivated marshlands and labor is concerned. Having acknowledged the potential of rice production in marshlands and the trends in consumer demand, the Government of Rwanda declared rice as a priority crop in 2002. The national rice program (2006-2016) has been designed with the purpose of exploiting the full potential of rice cultivation in the country so that the country can achieve self sufficiency in rice food needs as well as for export (MINAGRI, 2005).

1.2. Problem statement

Rice has been identified as one of the potential priority crops which can improve farmers' incomes and livelihoods in Rwanda. It is regarded as a strategic crop for food security and income generation in line with the poverty eradication strategy. Rice can also absorb some of the increasing pressure on hillside land for food production (MINAGRI, 2010). Despite the potential of rice in poverty reduction and enhancement of food security, its production lags behind the consumption needs of national market (MINAGRI, 2011). The average rice production on farmers' plots was about 3.5 t/ha in the 2001-2005 period (MINAGRI, 2009). Rice productivity remains low on farms but the potential to increase the yield exist (Kayiranga, 2006). The country currently imports about 30% of the crop it consumes, from countries such as Tanzania, India, Vietnam and Thailand (MINAGRI, 2010). Thus there is an urgent need to improve the total crop production. Soil infertility is a constant threat to sustainability of rice cultivation in marshlands. The low input intensive mono-cropping pattern in the marshlands is constantly depleting the soil and water reserves. The lack of suitable fertilizer recommendations and high fertilizer costs are two major reasons for the poor nutrient management in rice fields (MINAGRI, 2011).

1.3 Justification

Knowledge of soil ability to supply nutrients, the amount of nutrients required for crop growth, and the influence applied nutrients have on crop growth is all needed to improve fertilizer recommendation (Dahnke and Olson, 1990). Among the factors of rice production, fertilizers play an important role. Higher productivity requires increased nutrients inputs (Linquist *et al.*, 2001). Nitrogen and phosphorus fertilizers are the key input for in increasing rice yield (Alam *et al.*, 2009; Dastan *et al.*, 2012).

In Rwanda's marshlands soil fertility is highly variable (MINAGRI, 2011). Limited soil surveys conducted in marshlands show large variations in the balance of macro- and micro-nutrients. Hence the efficiency of fertilizers used in rice fields is often suboptimal (MINAGRI, 2010). No study on the effect of nitrogen and phosphorus on rice performance has been done in Cyunuzi lowland and the site specific fertilizer requirement is not known. Fertilizer recommendation has been so far based on extrapolation from other area. It is therefore important to evaluate the level of nitrogen and phosphorus in order to improve the sustainability of yields and the profitability of rice.

1.4 Objectives

1.4.1. Overall objective

The present study was undertaken to assess the sufficiency levels of nitrogen and phosphorus for rice growth and yield in Cyunuzi paddy field in Eastern in Eastern Rwanda.

1.4.2. The specific objectives

The specific objectives of the study were

1. To determine the total N and available P levels in Cyunuzi lowland soil.
2. To determine the rice response to application of N and P and their various combinations.
3. To determine the critical levels of N and P for rice growth and yields.

1.5. Hypotheses

1. Nitrogen and phosphorus levels in Cyunuzi paddy fields are sub optimal
2. Rice crop responds positively to increasing rates of nitrogen and phosphorus application.
3. The critical levels of N and P for suitable growth and adequate yield in Cyunuzi rice fields are not known.

CHAPTER 2. LITERATURE REVIEW

2.1. Importance of rice

2.1.1. Global rice production

Rice is the only major crop food that can be grown under a wide range of climatic and geographical conditions on five continents and occupies 11% of the world's cultivated area (Khush, 1993). In majority of Asian countries it occupies one third or more of cultivated area (FAOSTAT, 2006). The global annual production of rough rice is about 550-600 million tons (Maclean *et al*., 2002 quoted by Bouman *et al*., 2007), of which 90 percent is produced and consumed in Asia (Maclean *et al.,* 2002; Buresh and Haefele, 2010). In sub-Saharan Africa (SSA), rice is ranked as the fourth most important crop in terms of production after sorghum, maize and millet (Dibba *et al.*, 2012). With no surprise, rice serves as the staple food throughout much of the world. It is one of the most important crops representing the primary source of food for more than half of the world's population, with Asia and Africa the largest consuming regions (Khush *et al*., 2001; Fairhurst and Dobermann, 2002; Maclean *et al.,* 2002; Snyder and Slaton, 2002; FAO, 2004; Sang and Ge, 2007; Roulin *et al.,* 2010).

Rice is the most rapidly growing food source in Africa (Sohl, 2005; WARDA, 2007). Between 1961 and 2005, the annual increase in rice consumption was 4.52% in SSA. However, despite the apparent importance of rice in SSA, the production levels are still far below the consumer demand (Dibba *et al.*, 2012).

2.1.2. Rice in Rwanda

Rice was introduced into Rwanda in the 1950s and it has since become one of the major food crops grown in inland valley (MINAGRI, 2011). The area under rice cultivation, all irrigated, rose from 3549ha in the year 2000 to currently about 12000ha. However, the average yield on farmers' field was about 3.5 t/ha in the 2001-2005 period (MINAGRI, 2009) and the total production still lags behind the consumption needs (MINAGRI, 2011).

Soil infertility is a constant threat to the sustainability of rice cultivation in Rwanda. The low input intensive mono-cropping pattern in the marshlands is constantly depleting the soil. The lack of suitable fertilizer recommendations and high fertilizer cost are the major reasons for the low production in Rwanda (MINAGRI, 2011).

2.2. Nitrogen in paddy soils and rice crop

Nitrogen is the key element in the production of rice (Yoshida, 1981; Rahman *et al.*, 2007). It is generally needed in most rice soils, particularly in places where modern rice varieties which respond to nitrogen are grown (De Datta, 1981). Nitrogen deficiency is the most commonly detected nutrient deficient symptom in rice (Dobermann and Fairhurst, 2000). Significant yield responses to applied N are obtained in nearly all lowland rice soils where irrigation and other nutrients and pests are not limiting (Dobermann and Fairhurst, 2000).

"Paddy soils" denote soils in irrigated and rainfed lowland rice production systems with a prolonged period of submergence (Buresh and Haefele, 2010). Soil submergence leads to a unique sequence of chemical and microbial transformations related to the changes in soil water content that occur during a cropping cycle (Dobermann and Fairhurst, 2000). A change from soil submergence to greater soil aeration can significantly affect the biogeochemical processes influencing nutrient cycling and supply to crops, and rice productivity (Buresh and Haefele, 2010).

2.2.1. Nitrogen status and behavior in submerged soils

The behavior of nitrogen in submerged lowland soils is depicted in figure 1.

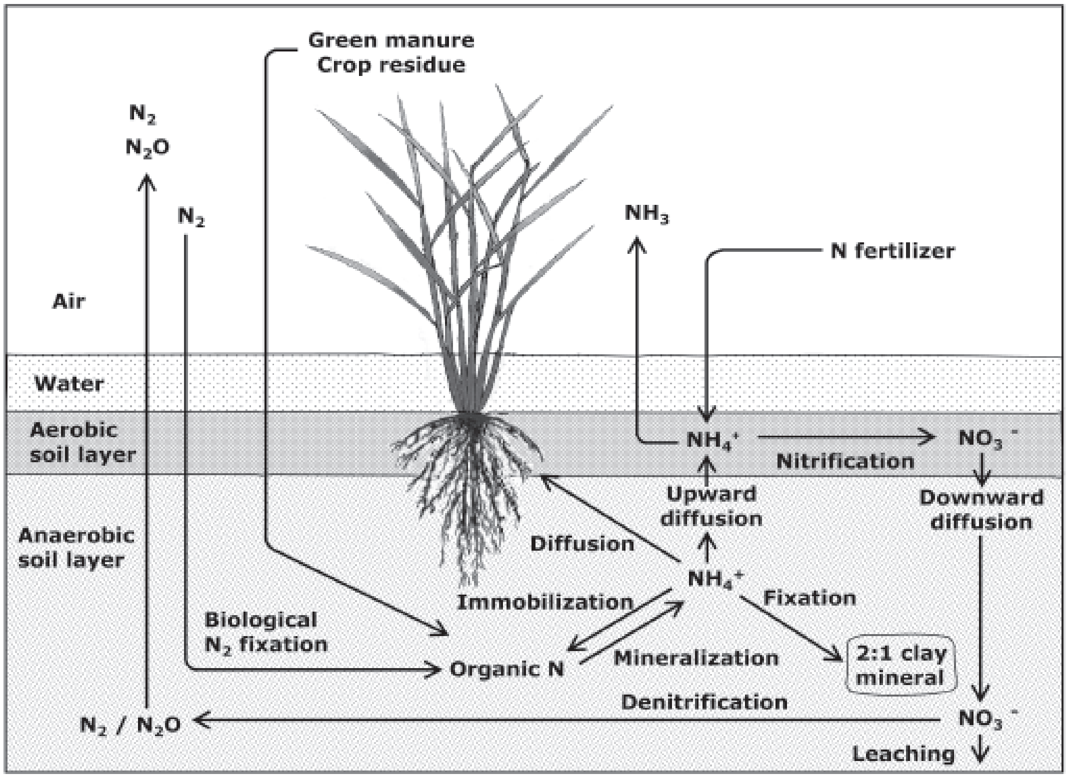

Figure 1: Schematic diagram of N transformation in submerged soil (Buresh *et al*., 2008)

As shown in fig.1, several distinct zones develop in paddy rice soils following submergence. Beneath the aerated floodwater, a thin layer of soil (usually<10 mm) remains oxidized after flooding because of the diffusion of O_2, from oxygenated floodwater above. Below this layer lies the bulk soil in a reduced state, because of the activity of anaerobic soil microorganisms that use nitrate, sulfate(SO_4^{2-}), oxidized iron (Fe $^{3+),}$ and manganese (Mn^{4+}), as terminal electron acceptors in the absence of O_{2}.(Dobermann and Fairhurst, 2000).

The forms of N present in submerged soils are generally similar to those in aerated soils; but the magnitude of the N forms, particularly nitrate and ammonium, and N transformation are markedly affected by the oxidation status of soil as shown in fig.1 as illustrated by Buresh *et al.* (2008). The main N transformation processes in submerged soils as in aerated soils are mineralization, immobilization, nitrification, denitrification, ammonia volatilization, and biological N fixation (De Datta,1981). Soils submergence modifies these processes, and a unique feature of submerged soils is the simultaneous formation and loss of NO_3^- occuring within the adjoining aerobic and anaerobic soil zones (Buresh *et al.*, 2008). Soil nitrogen occurs primarily in organic combination in the soil. The breakdown of organic matter leading to the release of ammonium ions into the soil solution proceeds at a slower rate in a flooded soil than in a non flooded soil (De Datta, 1981). Even though organic matter is mineralized at slower rate in anaerobic soil than in aerobic soil, net mineralized nitrogen is greater because less nitrogen is immobilized (De Datta, 1981).

The transition from aerobic to anaerobic periods strongly influences the addition, accumulation, and loss of soil mineral nitrogen (Buresh and De Datta, 1991). During the period of soil submergence, NH_4^+ is the stable form of inorganic N, which accumulates in the soil (Buresh *et al.*, 2008). During the subsequent period of soil aeration, NO_3^- forms via nitrification of indigenous soil N and fertilizer N applied (fig.1). The accumulated nitrate in aerobic soils during the dry season is lost during the transition to anaerobic conditions by nitrification-denitrification and leaching (Sight *et al.* 1995).

Severe nitrogen losses occur in soils subjected to alternate draining (aerobic) and flooding (anaerobic)(Mutters *et al*., 2006). In lowland rice, large denitrification events occur when the soil is reflooded and then proceeds during flooding in the reduced soil layer (Buresh and De Datta, 1991). Denitrification is probably the major mechanism by which nitrogen is lost from waterlogged soils, although volatilization losses of ammonia can occur under special conditions. Factors contributing to denitrification include pH, temperature, organic matter, wet/dry cycles, and fertilizer management (Stevenson and Cole, 1999; Mutters *et al*., 2006). Ammonia volatilization from urea fertilizer is the major pathway of N loss in tropical flooded rice fields, often causing 50% or more of the applied urea-N (Bouman, 2007). The magnitude of ammonia volatilization largely depends on climatic conditions, field water status, and the method of N fertilizer application (Bouman, 2007). More leaching of nitrate is expected with increased soil aeration than under flooded conditions (Bouman, 2007).

2.2.2. Nitrogen uptake by the rice crop

Nitrogen is taken up by the rice plant from the soil mineral nitrogen (Stevenson and Cole, 1999). The pool of available soil nitrogen consists of nitrogen mineralized by soil microbes or introduced to the system by fertilization. The ability of the soil root system to meet the plant‘s nitrogen demand depends both on the ability of roots to absorbs N from the soil at their surface and on the rate of delivery of the N to the root system (Kirk, 1994).

Considerable evidence indicates that rice grown on flooded soils consistently produces better growth and high yield when fertilized with ammonium rather than nitrate nitrogen. In lowland rice, the dominant form of N taken up is NH_4^+ (Kirk, 1994). Yoshida (1981) reported the rice preference of ammonia over nitrate from a solution that contains both. Ammonium-N fertilizer sources are recommended because the NH_4^+ is stable under flooded soil conditions (Snyder and Slaton, 2002). Nitrate-containing fertilizers have long been recognized as inappropriate for lowland rice because of rapid loss of NO_3^- by denitrification in submerged soils. Urea, because of its high N analysis, is the main N fertilizer source worldwide (Schepers and Raun, 2008). The commonly used ammonium or ammonium-producing sources appear to be about equally effective. Nitrate sources are unsatisfactory for pre-plant application and generally are inferior to ammonium forms when topdressed (Snyder and Slaton, 2002).

2.2.3. Role of nitrogen

Nitrogen is an integral component of many essential plant compounds such as amino acids, which are the building blocks of all proteins including enzymes, nucleic acid and chlorophyll (Brady and Well, 2002, Mutters *et al*., 2006). Being the essential constituent of protein is involved in all the major process of development (FAO, 2002) and good supply of nitrogen to the plant stimulates root growth and development as well as uptake of the other nutrients (Stevenson and Cole, 1999; FAO, 2002). Nitrogen is a regulator that governs to a considerable degree the utilization of K, P and other nutrient constituents in all plants (Brady, 1985).

Nitrogen is the most vital nutrient for rice growth. Rice absorbs large quantities of nitrogen to enhance growth, development, yields and grain quality. It promotes rapid growth (i.e, increased plant height and number of tillers). Yoshida (1981) reported a linear increase in tillering rate with an increasing nitrogen content up to 5%. It promotes increased leaf size, spikelet number per panicle, percentage of filled spikelet in each panicle and grain protein content (Dobermann and Fairhurst, 2000). Thus N affects all parameters contributing to yield (Dobermann and Fairhurst, 2000). Because nitrogen is present in so many essential compounds, it is not surprising that even slight deficiencies can result in reduced growth and productivity (Mutters et al., 2006).

Nitrate and ammonium are the major sources of inorganic nitrogen taken up by the root of higher plants (Marschner, 1993). Depending on the plant species, development stage, and organ, the nitrogen content required for optimal growth varies between 2 and 5% of the plant dry weight (Marschner, 1993). The maximum up-take of nitrogen occurs during the period of most active growth. Rice needs nitrogen almost through the vegetative cycle, but in particular at tillering and panicle initiation stages (Wopereis *et al*., 2009). Nitrogen absorbed by rice during the vegetative growth stages contributes in growth during reproduction and grain-filling through translocation (Norman *et al*., 1992; Bufogle *et al*., 1997). Nitrogen accumulates first in the leaves during vegetative phase, and then migrates to the panicles and grain. At maturity 75% of the nitrogen assimilated is present in the grains (Wopereis *et al*., 2009). When sufficient N is applied to the crop, the demand for other macronutrients such as P and K is increased (Doberman and Fairhurst, 2000).

2.2.4. Nitrogen deficiency in rice

Nitrogen is one of the most commonly deficient plant nutrients (Doberman and Fairhurst, 2000; Stevens *et al*., 2002). Its deficiency is the most commonly detected nutrient disorder observed in rice (Doberman and Fairhurst, 2000; Stevens *et al*., 2002), because large amounts of this element are required to produce amino acid and proteins in the tissues and because nitrogen is easily lost from the soil during wet conditions (Stevens *et al*., 2002). Nitrogen deficiency symptoms are poor tillering, leaves stalks pale, yellowing of lower leaves on young plant, spindly stems and short heads; yellowing starts at leaf tip of older leaves, plant do not form complete canopy over water; poor yield (Stevens *et al*,. 2002). Leaves die under severe N stress (Dobermann and Fairhurst, 2000)

Nitrogen deficiency often occurs at critical growth stages such as tillering and panicle initiation, when the demand for N is large (Dobermann and Fairhurst, 2000; Tiwari, 2002). The visual symptoms of N deficiency can be confused with those of sulfur deficiency, but S deficiency is less common and tends to first affect younger leaves on the plant (Dobermann and Fairhurst, 2000). Slight N deficiency can be confused with Fe deficiency, but the latter affects the emerging leaf first (Dobermann and Fairhurst, 2000). Nitrogen is the main limiting nutrient in the production of lowland rice (Buresh *et al*., 2008), therefore nitrogen fertilization is needed almost everywhere rice is grown.

Table 1: Optimal ranges and critical levels of N in plant tissue

Growth stage	Plant part	Optimum (%)	Critical level for deficiency (%)
Tillering to panicle	Y leaf	2.9-4.2	<2.5
Flowering	Flag leaf	2.2-3.0	<2.0
Maturity	Straw	0.6-0.8	-

Source: Doberman and Fairhurst (2000).

2.3. Phosphorus in paddy soils and rice crop

Application of phosphorus fertilizer is one of the most important for higher crop yields (Bünemann *et al.*, 2011). Phosphorus (P) availability in soil is closely related not only to soil P content but also to soil physico-chemical and biological properties, which are closely associated with P sorption and biochemical transformation (Guo *et al*, 2009). Paddy soils are characterized by a sequence of chemical and microbial transformations related to the changes in soil water content. These changes control the availability of phosphorus which is closely related to the degree of soil reduction (De Datta, 1981).

2.3.1. Phosphorus in submerged soils

The transformation processes of phosphorus in flooded soils are quite different from those in non-flooded soils. De Datta (1981) listed the main reactions involved in the change of P availability due to submergence as follows: (1) Reduction of insoluble ferric ($FePO_4.2H_2O$) to more soluble ferrous phosphate [$Fe_3(PO_4)_2.8H_20$]; (2) Hydrolysis of aluminum and iron phosphate at higher soil pH after submergence; (3) Dissolution of the apatite because of the higher CO_2 pressure in the soil solution and (4) Desorption of phosphorus from clay and oxides of aluminum and iron.

Flooded soils exhibit a greater capacity to supply plant available phosphorus than non-flooded soils (Dobermann and Fairhurst, 2000). Crops grown on flooded soils may not show a response to phosphorus applications, while the same crop grown on the same soil when dry may exhibit deficiencies (De Datta, 1981). Although the increase in availability of P is regarded as a benefit of flooding rice soils, the effect on rice growth may not be appreciable in acid clays high in active Fe (IRRI, 1985). The beneficial effect of flooding on P depends on the intensity of redox condition of submerged soil and Fe content (De Datta, 1981). Phosphorus behavior is not the same in soils that are continuously flooded compared to soil alternately dried and flooded. The duration and depth of flooding affects soil oxygen levels, soil pH, P availability, and levels and forms of some micronutrients. Extractable soil P levels, generally decrease after a flooded field is drained (Snyder, 2002).

2.3.2. Role of phosphorus and effects of P in rice production

Like all cereal grains, rice requires a considerable amount of phosphorus for vigorous growth and high yields (De Datta, 1981). Although in general response to phosphorus in irrigated rice is less marked than response to nitrogen, phosphorus is nontheless a very important nutrient (Dobermann and Fairhurst, 2000). Phosphorus is an essential constituent of adenosine triphosphate (ATP), nucleotides, nucleic acids, and phospholipids. Its major functions are in energy storage and transfer within the plant (Dick, 2011). Phosphorus is a major component in ATP, the molecule that provides "energy" to the plant for such processes as photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration. Phosphorus is also a component of other compounds necessary for protein synthesis and transfer of genetic material (DNA, RNA) (Zhang and Raun, 2006)

Phosphorus is mobile within the plant and promotes tillering by facilitating nitrogen absorption. An increase in tillering rate with P up to 0.2% was reported by Yoshida (1981), above which an increase in phosphorus has no effect on tillering. Phosphorus promotes root development, early flowering, and ripening. It is particularly important in early growth stages (Dobermann and Fairhurst, 2000). The critical level of P for tillering is affected by temperature (Yoshida, 1981).

Phosphorus is particularly important to the rice seedling during the time it is recovering from transplanting shock. Phosphorus greatly stimulates root development in the young plant, thus increasing its ability to absorb other nutrients from the soil (Dobermann and Fairhurst, 2000. During the reproductive phase, the phosphorus intake of rice decreases considerably. When absorbed during the ripening phase, phosphorus increases the protein content of the grains thus improving the food value of the crop. Phosphorus not only enhances the yields but also reduces spikelet sterility (Alam, 2009).

Phosphorus (P) deficiency is one of the major limiting factors of crop productivity in most soils throughout the world (Pierrou, 1976; Li *et al.*, 2006). In addition to area of low absolute soil P content, P deficiency can arise in soils where P is strongly bound to soils particles (Wissuwa *et al.*, 2005). Plants suffering from phosphorus deficiencies exhibit retarded growth (Marschner, 1993, Mutters *et al*., 2006), with greatly reduced tillering (Mutters *et al*., 2006). Leaves are narrow, short, very erect, and dirt dark green. Stems are thin and spindly (Dobermann and Fairhurst, 2000). Other deficiency symptoms are decreased leaf blade length, reduced number of panicles per plant, and reduced number of seeds per panicle. The root architecture of plants can undergo several changes in response to P deficiency. For example Wissuwa *et al.* (2005) showed that P deficiency stimulated root elongation in rice.

Phosphorus is often deficient in sandy soils with low organic matter content, calcareous /saline/alkaline soils, volcanic ash soils or acid upland soils with high P fixation capacity; peat soils and acid sulfate soils high in active iron and aluminum causing decrease in crop yields (Withers *et al*., 1994).

Table 2: Optimal ranges and critical levels of P in rice plant tissue

Growth stage	Plant part	Optimum (%)	Critical level for deficiency (%)
Tillering to panicle initiation	Y leaf	0.20- 0.40	<0.10
Flowering	Flag leaf	0.20-0.30	<0.18
Maturity	Straw	0.10-0.15	<0.06

Source: Dobermann and Fairhurst, 2000

2.3.3. Phosphorus fertilizer application for rice production

Except on extremely acid or alkaline soils, the common P sources are about equally effective. The relative efficiencies are affected to some extent, however, by such factors as soil pH, soil P level and rate, time, and method of application (Sanyal and De Datta 1991). The water soluble P sources, such as superphosphate, are effective in all soil types except those that are extremely acid. In acid soil, soluble P readily reacts with Fe and Al, which apparently reduces its availability (De Datta 1981). The most commonly used P fertilizers for lowland rice are single and triple superphosphates, diammonium phosphate and ammonium phosphate (Sanyal and De Datta, 1991). Phosphate Rocks (PR) are also used as P fertilizers in many countries (De Datta, 1981). The application of PR to lowland rice meets with two difficulties: (1) pH of an acidic soil will rise following submergence and this may adversely affect the solubility of PR in soil; (2) the ability of rice to derive P from PR is relatively low (Sanyal and De Datta, 1991). Several modifications of phosphate rocks have been suggested to increase its effectiveness (De Datta, 1981).

Generally, P fertilizers for rice should be applied at transplanting, but it may also be applied later, before the vigorous tillering stage (De Datta, 1981). Split-application of P has not been effective. Nelson (1980) reported that applying the total dose as basal at transplanting is the best time and method of P fertilization for rice due to the following: more P is required by the rice during the early growth stage; available P from the soil cannot meet the requirement at this early stage; adequate P supply may be conducive to better root development and tillering. In low temperature areas; more P is required during the early growth stage, and application at transplantation is more convenient than topdressing during later growth stage.

CHAPTER 3: STUDY AREA, MATERIALS AND METHODS

3.1. Study area

The present study was conducted from February to July 2012 in Cyunuzi lowland which is located in Eastern Province of Rwanda. Geographically, the coordinates of the study area are $02^{o}16'$ S latitude, $30^{o}33'$E longitude and altitude of 1325meters above sea level (As mesured by GPS). The general view of the experimental site is shown in Fig.2.

Figure 2: A view of the experimental field in Cyunuzi, Eastern Province, Rwanda

Due to its high altitude, Rwanda enjoys a tropical temperate climate. The average annual temperature ranges between 16^{o}C and 20^{o}C without significant variations, with average rainfall of about 1,250 mm per annum (Brian, 2009). The rainfall is generally well distributed throughout the year, with some spatial and temporal variability. Rainfall ranges from about 900 mm in the east and southeast to 1500 mm in the north and northwest volcanic highland areas.

Like everywhere else in Rwanda, the rainfall patterns of the study area are characterized by four seasons, a short rainy season from October to December and a longer season from March to June. Between these seasons are two dry periods, a short one between December and February and a long one from June to August. Temperature, rainfall and relative humidity recorded at the nearest weather station (Kazo weather station) during the experiment period, are presented in presented in Appendix1, whereas the rainfall distribution is shown in Fig.3.

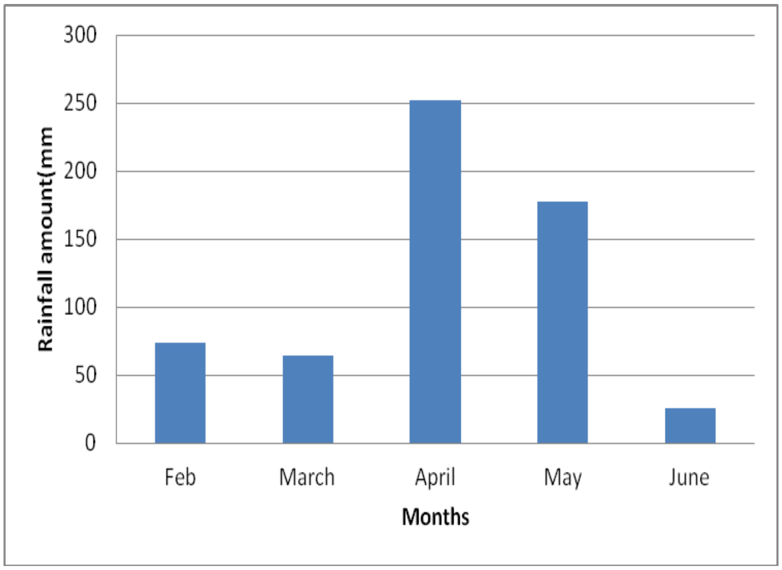

Figure 3: Rainfall distribution during experimental period (adapted) from Rwanda Meteorogical Diretorate.

The physico- chemical properties of the soils of the study area before treatment application are presented in the table 4.

3.2. Materials

Rice (Oryza sativa), ‘‘Upland 26’’ variety was used as a test crop in this study. The vegetative cycle of this variety varies from 120-130 days and its tillering ranges between 10-18 tillers. Soil material consisted of samples collected from rice field in Cyunuzi lowland. Urea(46-0-0), single superphospate (P_2O_5=18%) and KCl were used as fertilizer materials.

3.3. Methods

3.3.1. Experimental design and treatments.

A factorial design in a Randomized Complete Bloc with two factors was used. The two factors consisted of N and P fertilizers whereas the treatments were the combinations of 4 levels of N (0, 40, 80, 120 kg/ha) and 3 levels of P_2O_5 (0, 34, 70 kg/ha). Each treatment in the experiments was laid out in a 6.3m^2 plot and replicated in three blocks. Therefore 36 plots were used. The treatments used are shown in table 3.

Table 3: Treatments used in the study

Treatment code	Treatment
T0	Without Nitrogen and phosphorus
T1	40kg of N/ha without P_2O_5
T2	80kg of N/ha without P_2O_5
T3	120kg of N/ha without P_2O_5
T4	34kg of P_2O_5/ha without N
T5	40kg of N/ha +34kg P_2O_5/ha
T6	80kg of N/ha +34kg P_2O_5/ha
T7	120kg of N/ha +34kg P_2O_5/ha
T8	70kg P_2O_5/ha without N
T9	40kg of N/ha +70kg P_2O_5/ha
T10	80kg of N/ha +70kg P_2O_5/ha
T11	120kg of N/ha +70kg P_2O_5/ha

3.3.2. Planting and cultural practices

The seedbed was prepared by puddling the soil through harrowings. After seedbed preparation, three week-old rice seedlings were transplanted at 20cm×20cm spacing at a rate of 1 seedling per hill at 5cm water depth.

Nitrogen fertilizer was split in three applications i.e. at 3, 6 and 9 weeks after transplanting. Basal 34 and 70 kg P_2O_5/ha were applied 3 weeks after transplanting. K_2O was applied at a rate of 34 kg /ha were applied to all experimental plots 3 weeks after transplanting.

Prior to fertilizer application the field was drained and the plots were re-flooded 4 days after fertilizer application. The field was drained one month before harvesting to allow maximum kernel development. During vegetative growth, hand weeding was done regularly. After harvesting rice grains was dried up to a constant weight.

3.3.3. Data collection and analysis

3. 3.3.1. Soil sampling and analysis

Soil samples were collected twice, before planting and after harvesting. Soil samples were collected at the depth of 0-15cm using a diagonal method. The method consists of taking samples along lines connecting opposite angles of each experimental plot. Soil samples collected prior to planting were mixed to obtain a composite sample per block. Those collected after harvesting were mixed to form composite samples per experimental unit.

Samples so collected were under dried under the shade at laboratory temperature, slightly grounded and stored for chemical analysis. Undisturbed core samples were used to measure the soil bulk density as described by Blake (1965).The following chemical parameter parameters were analyzed: pH; soil organic carbon; total N; available soil P; exchangeable K and cation exchange capacity,CEC.

The pH was measured in water and potassium chloride (1M KCl) suspension in a 1:2.5 soil: liquid ratio using a glass electrode (Van Reeuwijk, 1992). The soil organic carbon was determined using Walkley-Black oxidation method (Allison, 1965). Total N was analyzed using the Kjeldahl as described by Black (1965). Available soil P was analyzed according to the standard procedure of Bray I (Bray and Kurtz, 1945), whereas the cation exchange capacity exchangeable potassium were determined using the ammonium acetate method at pH 7 according to Chapman (1965).

3. 3.3.2. Plant data collection

Five plants were randomly selected and labeled in each experimental unit and used for measuring following parameters:

Plant height

Plant height measurements were taken at different period and started from 36 and continued up to 78 days after transplanting (DAT), measurement was made once in two weeks. This was taken from the five selected plants in the treatment. A tape meter was used for measuring the height from the ground level to the top of the highest leaf. The mean from the five plants per treatment was then determined.

Tiller number

Visual counting of tillers on the five selected plants in each plot was made once in two weeks starting from 36 DAT until the end of vegetative growth. The tillers number was recorded for each plant and the mean values for the treatment were then calculated.

Leaf area

Leaf area data were determined at the end of vegetative growth. The leaf area was determined by the non destructive length x width method using the relation: Leaf area (cm^2) = K× length (cm) x width (cm), where K is a constant (Yoshida, 1981). A constant (K) = 0.8 was used in this study. Leaf width and length were measured using a tailor’s tape. The measurement was taken from the same five plants selected in each plot, and four leaves in each of five plants were measured. After calculation of leaf area for each plant, the average value was calculated for each plot.

Above-ground biomass

At harvest, the above ground biomass of each labeled plants in the plot was collected, sun- dried until a constant weight was obtained and then weighed.

Number of panicles

Panicle numbers ware recorded at harvest by visual counting of panicle number of each of the five plants selected in the plots. The average number of panicles per plant in each plot was then determined.

Number of filled grains per panicle

At harvest, the number of filled grain was determined by visual counting of the filled grain per panicle of the selected five plants in each plot. In each plot the average number was calculated to get the filled number per panicle in each plot.

Number of empty grains per panicle

Empty grain number and % of empty grain were determined. This was done by visual counting as described for filled grain per panicle. After visual counting of the empty grain, the average number was determined. The percentage empty grain per panicle was determined using the following formula:

% empty grain per panicle= (empty grain per panicle/total grain per panicle)*100

1000-grain weight

At harvest, the rice grain from each of the five plants selected for growth and yield parameters were collected separately and labeled. After proper drying, one hundred grains were counted from each sample and weighed using precision balance. The record for 100 grains was multiplied by 10 to get the 1000-grain weight.

Total grain yield

Rice grains were harvested at maturity ie. 125 DAT. The grain weight for each treatment was recorded after proper sun-drying to a constant weight (i.e, 14% moisture content). The yields obtained per plot were converted to the yield per ha.

Plant leaf nutrient content

Plant tissues were sampled at flowering by collecting the third leaf from the flag leaf. The samples collected were dried at room temperature, grounded and analyzed for total nitrogen and P as described by Pauweles *et al.* (1992).

3.3.3.3. Statistical analysis

The ASSISTAT statistical package version Beta 2012 was used to analyze the experimental data. Treatments were compared using the analysis of variance at $P<0.05$ whereas their means were separated using the Turkey's test at the same probability level. Where necessary, correlation and regression analyses were used to investigate relations between soil and plant variables.

3.3.3.4. Nutrients nitrogen and phosphorus sufficiency levels determination

In present study, the sufficiency level was defined as the ratio of the actual nutrient level (content) in the soil to its critical level, the nutrient critical level being defined as the soil nutrient concentration corresponding to the maximum crop growth or grain yield. This concept implies that increasing the nutrient concentration will cause positive crop response in the zone below the critical level but will induce a negative or non-significant reaction to a higher concentration (Rayment and Bruce, 1984). The critical level is therefore the soil nutrient concentration partitioning crop response into two classes: low and high. The soil nutrients concentrations corresponding to the critical levels were estimated from the crop response to fertilizers nitrogen and phosphorus.

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Soil analysis

Soil conditions prior to treatments application and after harvesting are reported in table 4 and 5.

Table 4: Soil conditions at the experimental site prior to treatments application

Sample no	pH (water)	pH$_{(KCl)}$	% C	% N	P avail. (ppm) (Bray I)	K exchang (cmol/kg)	CEC (cmol/kg)	Soil bulk density (g/cm^3)
1	5.26	4.72	4.7	0.44	0.41	0.32	31.2	1.46
2	4.92	4.31	3.5	0.32	0.00	0.29	38.0	1.38
3	4.72	4.29	3.4	0.29	1.05	0.29	25.0	1.36
Mean	**4.97**	**4.44**	**3.87**	**0.35**	**0.49**	**0.30**	**31.4**	**1.40**
STDEV	0.27	0.24	0.72	0.08	0.53	0.02	6.50	0.05

Results in table 4 show that at the initial stage, the soil reaction ranged from very strongly acid to strongly acid according to Hoskins (1997) and Bruce and Rayment (1982) and the field pH standard deviation of 0.27. The observed soil pH range is below the optimal value (5 to 6.5) for rice reported by Hazelton and Murphy (2007) and may impair the crop. Total nitrogen, exchangeable potassium and available phosphorus were also below optimal ranges and their field standard deviations were 0.08, 0.53 and 0.02 respectively. On the other hand the soil cation exchange capacity was found to be high in the study area according to Metson (1961) in Hazelton and Murphy (2007). Poor nutrient status in the soils of the study area soil can be attributed to continuous cropping without adequate fertilization.

The mean values of soil pH, total nitrogen and available phosphorus obtained at the end of the experiment are reported in table 5(a). It appears that the soil reaction had shifted from very strongly and strongly acid to weakly acid in all plots as the pH_{H2O} varied from 5.06 to 5.29. Values of relative pH suggest that the increase in pH were more attributable to the flooding of the soil due to irrigation (Synder, 2002) and less to applied treatment.

Table 5: Effects of phosphorus and nitrogen application on soil pH, N and P

	Soil pH				**Soil N**				**Soil P**			
P N	0 kg P_2O_5 /ha	34 kg P_2O_5 /ha	70 kg P_2O_5 /ha	**Average over P_2O_5 levels**	0 kg P_2O_5 /ha	34 kg P_2O_5 /ha	70 kg P_2O_5 /ha	**Average over P_2O_5 levels**	0 kg P_2O_5 /ha	34 kg P_2O_5 /ha	70 kg P_2O_5 /ha	**Average over P_2O_5 levels**
0 kg N/ha	5.27	5.29	5.08	**5.22 a**	0.40	0.31	0.30	**0.34 a**	1.42	2.29	2.35	**2.02 a**
40 kg N/ha	5.17	5.20	5.19	**5.19 a**	0.37	0.35	0.35	**0.36 a**	0.94	1.70	2.62	**1.75 a**
80 kgN /ha	5.25	5.22	5.06	**5.18 a**	0.33	0.33	0.35	**0.33 a**	1.09	2.03	2.26	**1.79 a**
120 kgN/ha	5.20	5.29	5.23	**5.24 a**	0.37	0.29	0.34	**0.33 a**	0.79	2.15	2.07	**1.67 a**
Average over N levels	**5.22 a**	**5.25 a**	**5.14 a**		**0.36 a**	**0.32 a**	**0.34 a**		**1.06 b**	**2.04 a**	**2.32 a**	

In a row/column, mean followed by the same letter are not significantly different at P<0.05 according to the Tukey's test

Table 5 (a): Relative values of soil pH, N and P

	Soil pH				**Soil N**				**Soil P**			
P N	0 kg P_2O_5/ ha	34 kg P_2O_5/ ha	70 kg P_2O_5/ ha	**Average over P_2O_5 levels**	0 kg P_2O_5/ ha	34 kg P_2O_5/ ha	70 kg P_2O_5 /ha	**Average over P_2O_5 levels**	0 kg P_2O_5/ ha	34 kg P_2O_5 /ha	70 kg P_2O_5 /ha	**Average over P_2O_5 levels**
0 kg N/ha	1.06	1.06	1.02	**1.05**	1.14	0.89	0.86	**0.96**	2.90	4.67	4.80	**4.12**
40 kg N/ha	1.04	1.05	1.04	**1.04**	1.06	1.00	1.00	**1.02**	1.92	3.47	5.35	**3.58**
80 kg /ha	1.06	1.05	1.02	**1.04**	0.94	0.94	1.00	**0.96**	2.22	4.14	4.61	**3.66**
120 kg /ha	1.05	1.06	1.05	**1.05**	1.06	0.83	0.97	**0.95**	1.61	4.39	4.22	**3.41**
Average over N levels	**1.05**	**1.06**	**1.03**		**1.05**	**0.91**	**0.96**		**2.16**	**4.17**	**4.74**	

Total nitrogen content slightly increased or decreased or remained unchanged depending on nitrogen-phosphorus fertilizer combinations applied. The change in soil nitrogen after the experiment is evident, the negative balance observed in some treatments might be mainly attributed to plant uptake and removal. On the other hand, soil phosphorus slightly increased probably due to the increase in soil pH after flooding. Relative values in table 5(b) suggest that the soil phosphorus increase varied with the level of applied P fertilizer. However, the soil P increase averaged over P_2O_5 levels decreased with the level of applied N.

4.2. Crop response to applied treatments

The effects of nitrogen, phosphorus and their combination at various application rates on average values of nutrients uptake, plant growth and yield and yield components are summarized in tables 6 to 8 and figure 4 to 7. The detailed results and related statistical analysis are reported in Appendix 9 to 21.

4.2.1. Nutrients uptake

The amount of nutrients accumulated in rice leaves at the flowering stage is reported in table 6. The results show that the amount of nitrogen accumulated in the crop leaves varied depending on the application rates of both nitrogen and phosphorus fertilizers.

Table 6: Nitrogen and phosphorus contents in rice leaves at the flowering stage

	% N in leaves				**% P in leaves**			
P / **N**	0 kg P_2O_5/ha	34 kg P_2O_5/ha	70 kg P_2O_5/ha	**Average over P_2O_5 levels**	0 kg P_2O_5/ha	34 kg P_2O_5/ha	70 kg P_2O_5/ha	**Average over P_2O_5 levels**
0 kg N/ha	2.39	1.91	2.44	**2.25 a**	0.162	0.158	0.204	**0.175 a**
40 kg N/ha	2.47	2.49	2.30	**2.42 a**	0.192	0.185	0.201	**0.193 a**
80 kg /ha	2.58	2.69	2.35	**2.54 a**	0.203	0.185	0.194	**0.194 a**
120 kg /ha	2.74	2.91	2.31	**2.65 a**	0.190	0.195	0.206	**0.197 a**
Average over N levels	**2.55 a**	**2.50 a**	**2.35 a**		**0.187 a**	**0.181 a**	**0.201 a**	

In a row/column, mean followed by the same letter are not significantly different at $P<0.05$ according to the Tukey's test.

Nitrogen content in the leaves steadily increased with the rate of fertilizer nitrogen application in the absence of phosphorus or at low level of phosphorus input (34kg P_2O_5/ha), the most important accumulation being observed in plots where 120kg N/ha was combined with 34kg P_2O_5/ha. An opposite trend was observed in plots where nitrogen was combined with high inputs of phosphorus fertilizer. For example, nitrogen accumulation in the crop leaves decreased from 2.44% under 0 kg N/ha to 2.31% under 120kg N/ha, corresponding to a loss of 5.33%. Nitrogen content in leaves averaged over phosphorus rates shows steady increase with increase in the amount of fertilizer nitrogen applied. On the other hand, averaging nitrogen content in the leaves, over the rates of nitrogen fertilizer application demonstrates an opposite trend, suggesting a decrease in nitrogen uptake with increased rate of P_2O_5 application.

The amount of phosphorus accumulated in rice leaves steadily increased with the rate of phosphorus fertilizer when combined with 120kg N/ha. However, in the treatment without nitrogen application or when combined with lower amounts of nitrogen, i.e., 40 and 80kg N/ha, improvement in phosphorus status in leaves was obtained only with high rate of phosphorus fertilizer. As an example, results in table 6 show that combining 70kg P_2O_5/ha with 40kg N/ha increased the phosphorus leaves content by 4.68%, whereas applying 34kg P_2O_5/ha in combination with the same amount of nitrogen fertilizer led to a decrease of 3.65% in the phosphorus content as compared to plots not receiving phosphorus. Phosphorus content in the leaves averaged over rates of phosphorus fertilizer steadily increased with increasing nitrogen application rate whereas such a trend is not observed with increase in phosphorus application. it can therefore be said that increasing nitrogen application tended to improve the phosphorus status in rice leaves but the effect of phosphorus remained unpredictable in the experimental conditions.

Differences observed among treatments in both nitrogen and phosphorus contents in the rice leaves were statistically negligible at the 5% probability level (Appendix 9 and 10). However, comparing leaf nutrient contents obtained in the present study (table 6) to those reported by Dobermann and Fairhurst (2000) presented in table 1 and 2, show that the nitrogen status was suboptimal in plots fertilized with 34kg P_2O_5/ha without nitrogen application. In plots receiving N-P combinations the nitrogen content in the leaves was in the optima range, but closer to the lower (2.22%) than to the upper limit (3%) of sufficiency. In those plots, the gap between the actual nitrogen and the upper limit of sufficiency narrowed with increase in nitrogen application, except where N is combined with a high rate of P_2O_5 (70kg /ha). The phosphorus content on the other hand was generally suboptimal to critical, except in plots receiving 70kg P_2O_5/ha where it hardly reached the lower limit of sufficiency. Relatively low nitrogen and low phosphorus accumulations in spite of heavy applications of nitrogen and phosphorus fertilizer application is probably due to losses through drainage. From the above results, one can therefore hypothesize that observed differences in nitrogen and phosphorus contents in rice leaves, though negligible may induce significant differences in plant growth and possibly in grain yields.

4.2.2. Plant growth

Means of data showing effects of phosphorus and nitrogen fertilizers on rice growth are given in figures 4 and 5 and table 7whereas detailed results and related statistical analysis are reported in Appendix 11 to 14.

Figure 4 shows trends in plant height. At different growth stage 36, 50, 64 and 78 DAT, plants were generally taller in fertilized plots than in unfertilized ones. In fertilized plots the plant height varied depending on the amount of fertilizer applied. Nevertheless, the analysis of variance (Appendix 11) showed that statistically significant effects of fertilizers were observed only from 64 days after transplanting (DAT). At 64 and 78 DAT, nitrogen application significantly increased the plant height ($P<0.05$) compared to control, but no evidence of difference among rates of application was observed. The present results differ from those of other workers who reported significant increases in plant height with increase in nitrogen application rate (Rahman *et al.,* 2007; Ghanbari-Malidarreh *et al.,* 2009; Awan *et al.,* 2011). This difference is probably attributable to difference in varieties used and the rate of nitrogen fertilizer increment. Moreover, though the nitrogen effect on the growth rate tended to vary depending on the amount of phosphorus used in combination, no significant PxN interaction was observed in the analysis of variance (Appendix 11).

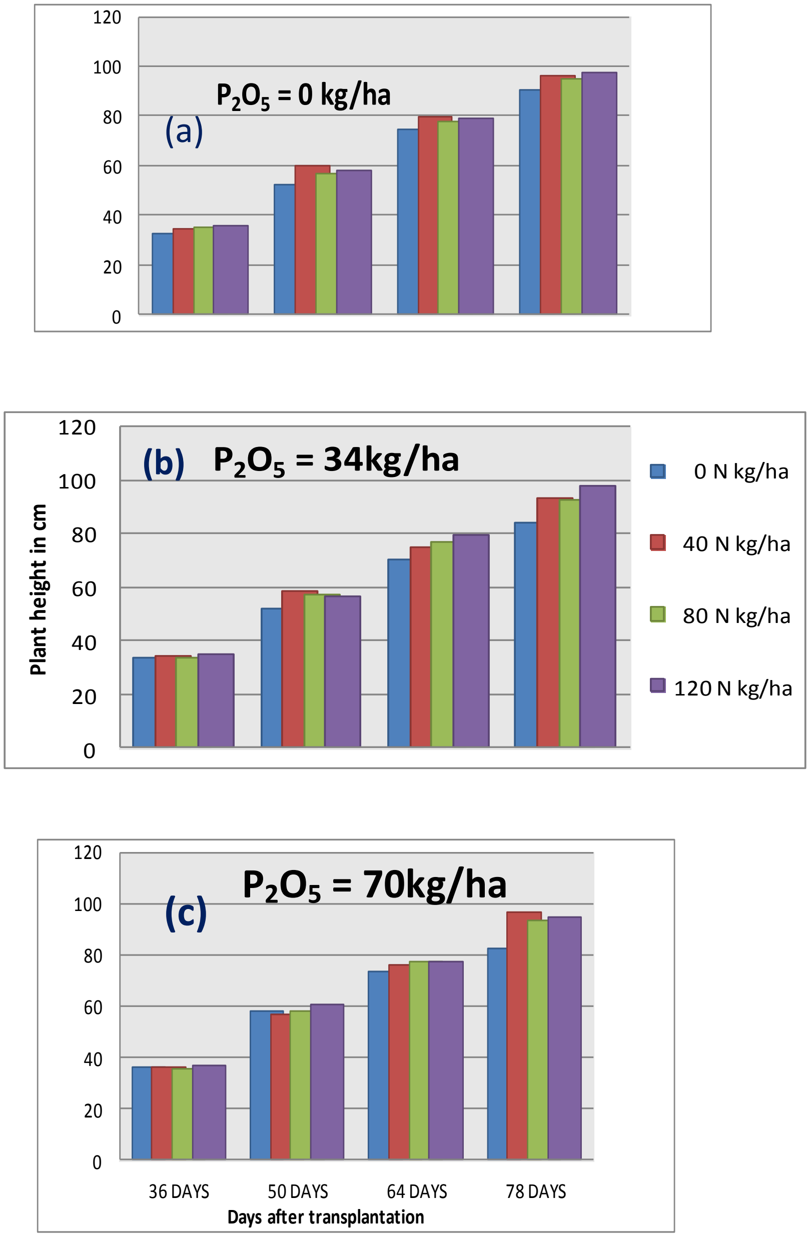

Figure 4: Effects of nitrogen and phosphorus fertilizer on plant height

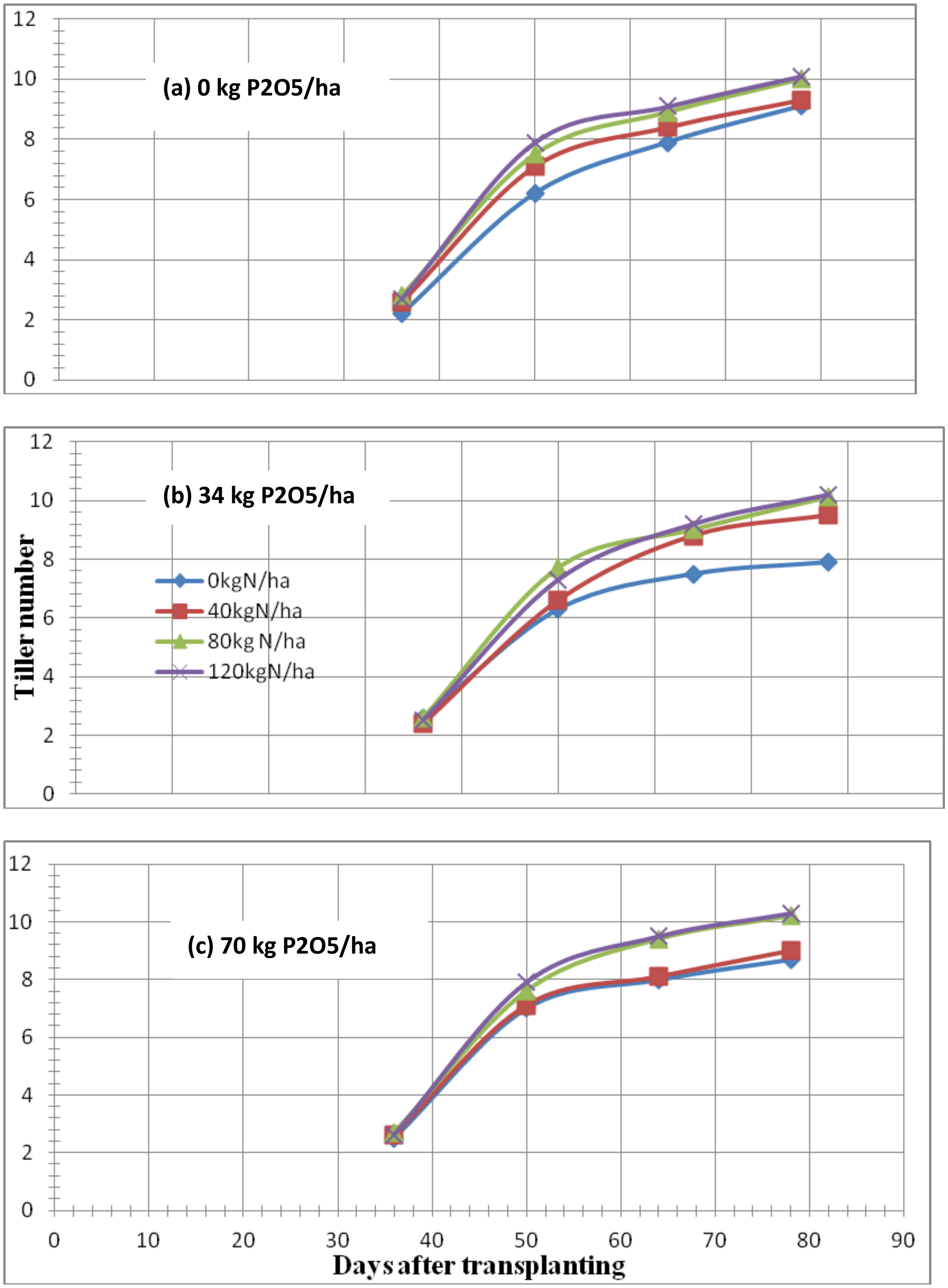

Figure 5: Effect of nitrogen and phosphorus on rice tillering pattern

Trends in tiller numbers before 78 DAT (fig. 5) followed a similar pattern as in plant height though observed differences among treatments were relatively more noticeable (Appendix 12). At initial stages (36 and 50 DAT) tiller numbers were not remarkably influenced by the treatments. Significant differences were observed from 64 DAT. The effect of N on tillers numbers was similar at 64 and 78 DAT. Table 7 shows the final values of growth parameters at 78 DAT.

Table 7: Effect of phosphorus and nitrogen application on different growth parameters at the end of vegetative growth

Fertilizers	**Plant height (cm)**				**Tiller number per plant**			
P **N**	0 kg P_2O_5/ha	34 kg P_2O_5/ha	70 kg P_2O_5/ha	**Average over P_2O_5 levels**	0 kg P_2O_5/ha	34 kg P_2O_5/ha	70 kg P_2O_5/ha	**Average over P_2O_5 levels**
0 kg N/ha	90.27	84.20	82.57	**85.68 b**	9.07	7.93	8.73	**8.58 b**
40 kg N/ha	96.23	93.17	96.77	**95.39 a**	9.30	9.50	9.03	**9.28 ab**
80 kg N/ha	95.00	92.73	93.67	**93.80 a**	9.97	10.13	10.23	**10.11 a**
120 kg N/ha	97.53	97.97	94.37	**96.62 a**	10.13	10.23	10.27	**10.21 a**
Average over N levels	**94.76 a**	**92.02 a**	**91.84 a**		**9.6 a**	**9.5 a**	**9.6 a**	

Table 7 (cont'd)

Fertilizers	**Leaf area (cm^2 per leaf)**				**Above ground biomass (g/plant)**			
P **N**	0 kg P_2O_5/ha	34 kg P_2O_5/ha	70 kg P_2O_5/ha	**Average over P_2O_5 levels**	0 kg P_2O_5/ha	34 kg P_2O_5/ha	70 kg P_2O_5/ha	**Average over P_2O_5 levels**
0 kg N/ha	41.10	38.13	38.20	**39.14 b**	27.50	20.87	24.47	**24.28 b**
40 kg N/ha	46.73	44.20	41.97	**44.30 ab**	45.60	36.63	34.07	**38.77 a**
80 kg /ha	49.23	42.77	46.73	**46.25 a**	39.53	33.80	38.63	**37.32 a**
120 kg N/ha	42.47	50.00	46.70	**46.39 a**	36.13	37.97	36.83	**36.98 a**
Average over N levels	**44.88 a**	**43.78 a**	**43.40 a**		**37.19 a**	**32.32 a**	**33.50 a**	

In a row/column, mean followed by the same letter are not significantly different at $P<0.05$ according to the Tukey's test.

It appears that in general, increasing phosphorus application rate slightly decreased the values of growth indicators averaged over nitrogen levels, except for the tiller number which remained almost constant. The highest reduction was observed with the above-ground biomass which decreased by 13% and 10%, as the application rate increased from 0kg/ha to 34kg /ha and from 0kg/ha to 70kg/ha, respectively. These variations were, however, not significant at $P<0.05$ as indicated by the analysis of variance reported in Appendix 14. These finding are in line with the work of YosefTabar (2012) who reported no significant differences in tiller numbers due to phosphorus application.

On the other hand, the leaf areas and the tiller numbers averaged over phosphorus levels increased consistently with increase in the amount of nitrogen applied. Leaf area varied from an average of 39.2 cm^2 in control plots (0kg N/ha) to 46.4 cm^2 under 120kg N/ha, while tiller numbers ranged from an average of 8.6 in the control to 10.2 under 120kgN/ha. These results are in accordance with those obtained by Awan *et al*. (2011) who reported an increase in tiller numbers associated with high nitrogen application. Enhanced tillering at high nitrogen application levels can be attributed to more nitrogen available to the plants at active tillering. According to Ghanbari-Malidarreh *et al.* (2009), rice plants require nitrogen during the vegetative stage to promote growth and tillering. It has been reported that nitrogen absorbed during the vegetative period promotes the tillering activity. Accordingly, Yoshida (1972) observed that there is an increase in the number of tillers per square meter as the amount of nitrogen absorbed by the crop increase.

The above-ground biomass sharply increased from 24.28g under 0kg N/ha to 38.77g under 40 kg N/ha, showing an improvement of 60% as compared to the unfertilized control, then steadily declined with further increase in nitrogen application level, but remained higher (36.98g) than the control (24.28g). On contrary, although the plant height was positively affected by nitrogen fertilizer, the variation in this growth parameter was inconsistent with the rate of nitrogen application. The analysis of variance reported in Appendix 11(c) and 11(d)show that unlike with phosphorus, the main effect of nitrogen fertilizer on plant growth was significant at $P<0.05$. However, although the extent of improvement in plant growth varied with the rate of nitrogen application depending on phosphorus level, the analysis of variance show no significant difference between 40, 80, and 120kg N/ha at $P<0.05$ neither was NxP interaction significant at the same probability level.

The role played by the growth parameters presented above, on rice grain production, is known. The leaf area can affect the plant yield as it determines the photosynthetic activity. Some research reports have shown that growth response to changes in N supply was reflected in effects on net assimilation rate as well as on leaf area (Radin, 1983 in Shieh and Liao 1985). The relationship between plant growth parameters is shown in figure 6. It appears that plant height, the tiller numbers and the above-ground biomass were all significantly affected by the leaf area which, in turn, varied with the rate of nitrogen application.

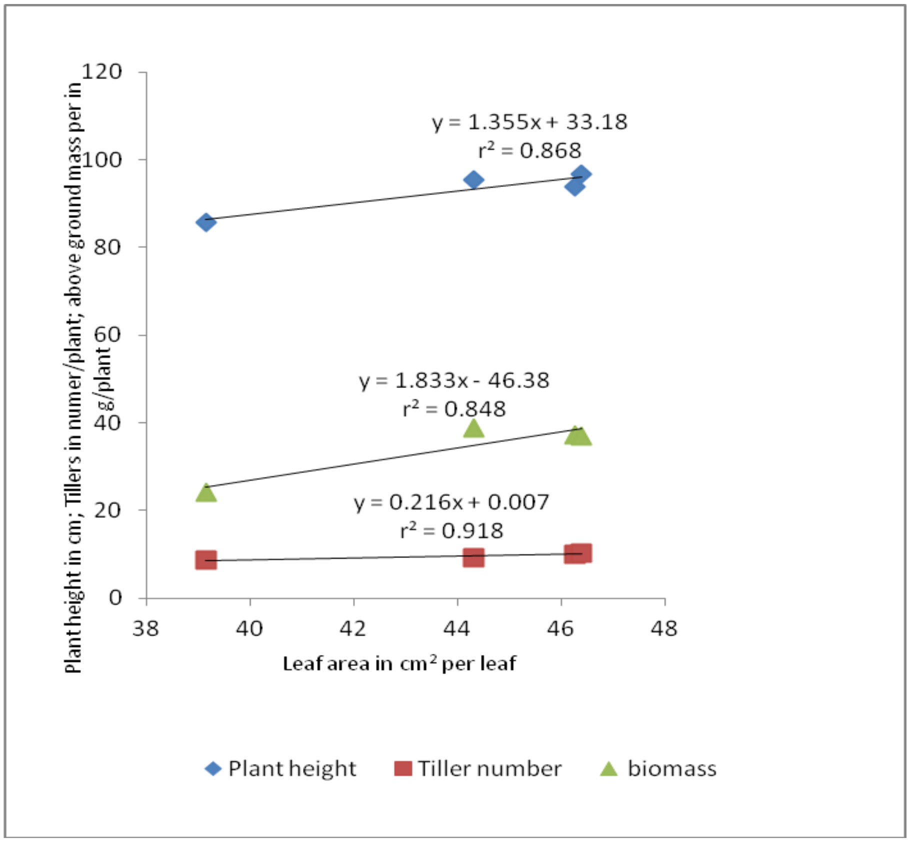

Figure 6: Relationship between vegetative growth parameters

It is therefore expected that nitrogen-induced variability in the leaf area will accordingly impact on the grain yield. Similarly, Watson (1952, 1963) in Shieh and Liao (1985) reported that change in nutrient supply affects the yields of plants by changing the size of photosynthetic system.

4.2.3. Grain yield

Figure 7 shows the effects of phosphorus and nitrogen application and their combinations on the rice grain yield.

It appears that the grain yield varied with both nitrogen and phosphorus application rates. With no phosphorus application, the grain yield steadily increased with increased nitrogen level. With

34kg P_2O_5 application rate, the grain yield increased from 6.2t/ha under 0kg nitrogen to 8.5t/ha under 80kg nitrogen/ha but declined to 8.4t under 120kg N/ha.

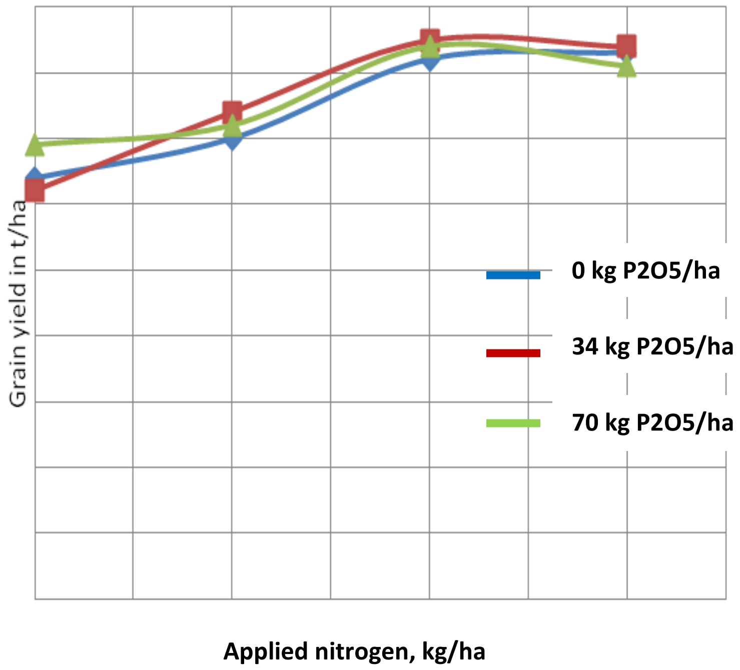

Figure 7: Effect of applied nitrogen and phosphorus on rice grain yield

A similar trend was observed when nitrogen rates were combined with 70kg P_2O_5 /ha. In relation to phosphorus, the highest yield was obtained with 34kg P_2O_5/ha. However, in the absence of nitrogen, the grain yield decreased from 6.4t/ha under 0kg P_2O_5/ha to 6.2t/ha under 34kg P_2O_5/ha but it increased to 6.9t/ha when 70kg P_2O_5 /ha was applied.

The analysis of variance presented in Appendix 21 shows that phosphorus had no significant effect on grain yield. This is in accordance with the earlier observation that phosphorus fertilizer did not significantly affect vegetative factors, i.e., leaf area, plant height and tiller numbers that are critical to the grain production. On the other hand, observed differences in grain yield among nitrogen rates were significant ($P < 0.01$). The mean separation using Tukey's test (table 8) showed that the grain yield averaged over phosphorus levels varied with nitrogen application as follows:

6.5t (0kgN/ha) ≤ 7.2t (40kg N/ha) <8.3t (120kg N/ha) ≤ 8.4t (80kg N/ha)

In terms of relative yield the ranking was

1.00(0kgN/ha) ≤ 1.11 (40kg N/ha) < 1.28(120kg N/ha) ≤ 1.29(80kg N/ha)

Indicating yield increases of 11, 29 and 28%, respectively, under 40, 80 and 120kg N/ha. It follows that the most significant yield improvement was obtained by applying 80kgN/ha.

Differences in grain yield among nitrogen fertilized-plots were associated with nitrogen fertilizer effect on the yield components. Kumar and Rao (1992) and Thankur (1993) also reported improvements in grain yields and they attributed this to increments in yield components. Mean values of the yield components obtained with different treatments are reported in table 10. It appears that phosphorus application did not significantly affect any yield components, therefore, as discussed above, phosphorus did not significantly affect the grain production.

Table 8: Effect of phosphorus and nitrogen application on rice yield components

Fertilizers	Panicle number				Total grains per panicle				Filled grains number per panicle			
P N	0 kg P_2O_5/ ha	34 kg P_2O_5/ ha	70 kg P_2O_5/ ha	**Average over P_2O_5 levels**	0 kg P_2O_5/ ha	34 kg P_2O_5/ ha	70 kg P_2O_5 /ha	**Average over P_2O_5 levels**	0 kg P_2O_5/ ha	34 kg P_2O_5 /ha	70 kg P_2O_5 /ha	**Average over P_2O_5 levels**
0 kg N/ha	8	6	8	**8 b**	139	137	119	**132 b**	118	119	104	**114 b**
40 kgN/ha	10	9	9	**9 ab**	166	160	149	**158 a**	139	128	125	**131 a**
80 kg /ha	10	10	10	**10 a**	158	140	158	**152 a**	130	114	131	**125 ab**
120 kg N/ha	10	9	10	**10 a**	148	163	149	**153 a**	121	134	121	**125 ab**
Average over N levels	**9 a**	**8 a**	**9 a**		**153 a**	**150 a**	**144 a**		**127a**	**123a**	**120a**	

Table 8 (cont'd)

Fertilizers	***Empty grains per panicle*** ****=number ,( )=%***				**1000 grains weight (g)**			
P N	0 kg P_2O_5/ha	34 kg P_2O_5/ha	70 kg P_2O_5/ha	**Average over P_2O_5 levels**	0 kg P_2O_5/ha	34 kg P_2O_5/ha	70 kg P_2O_5/ha	**Average over P_2O_5 levels**
0 kg N /ha	21* 15.2)	18*(13.0)	15*(12.6)	**18* b(13.6 b)**	33.6	34.8	34.4	**34.3 a**
40 kg N/ha	29* (17.3)	32*(19.7)	24*(15.7)	**28* a (17.6 a)**	34.4	32.9	33.8	**33.7 a**
80 kg /ha	28* (7.6)	26* 18.2)	27*(17.2)	**27* a (17.7 a)**	33.3	33.5	33.4	**33.4 a**
120 kg N/ha	26* (17.6)	30*(18.1)	29*(18.7)	**28* a (18.1 a)**	33.8	33.8	33.7	**33.8 a**
Average over N levels	**26* a (16.9a)**	**27* a (17.2a)**	**24* a (16.1 a)**		**33.8 a**	**33.8 a**	**33.8 a**	

In a row/column, mean followed by the same letter are not significantly different at P<0.05 according to the Tukey's test.

Unlike with phosphorus, nitrogen application significantly affected all yield components except the grain filling as expressed by the weight of 1000 grains. This is evident, the kernel (grain) weight differs among varieties, it was reported to be the least variable yield component (Hill, 2005). All N-fertilized plots produced more panicles, grains/panicle and filled grains/panicle than control plots irrespective of phosphorus levels. This resulted in significant increases in grain yield. Sarder *et al*. (1988) and Mannan *et al.* (2010) also found no significant difference in 1000 grains weight due to the application of N.

The simple correlation analysis reported in Appendix 23 show that grain production per individual rice plant was significantly correlated to both the number of panicles (r =0.82), and the number of filled grains per panicle (r = 0.59). The combined effects of the panicle number (X_1), and the number of filled grains per panicle (X_2) on grain production (Y) was quantified as follows using the multiple regression analysis (Steel and Torries, 1960):

$Y(X_1,X_2) = -34.3748 + 3.8102X_1 + 0.2996X_2$

with

$R^2 = 0.94$;

and

$r^2_{YX1.X2}=0.91$;

$r^2_{YX2.X1} =0.60$;

n = 36

The partial correlation coefficients in this equation suggest that 91 and 60% of the grain yield variability among applied treatments were accounted for, respectively, by differences in panicle and filled grains number whereas the partial regression coefficients ratio indicates that the number of panicles was 12.72 times as important as the number of filled grains in determining the grain production.

The simple correlation analysis presented in Appendix 23 showed that the number of panicles was highly correlated with the tiller numbers (r = 0.90) and the plant height (r = 0.60). Similarly, the number of filled grains was highly associated with both the plant height (r =0.54) and the leaf area (r = 0.48). The dependence of these growth parameters upon nitrogen application rates is shown in figure 8.

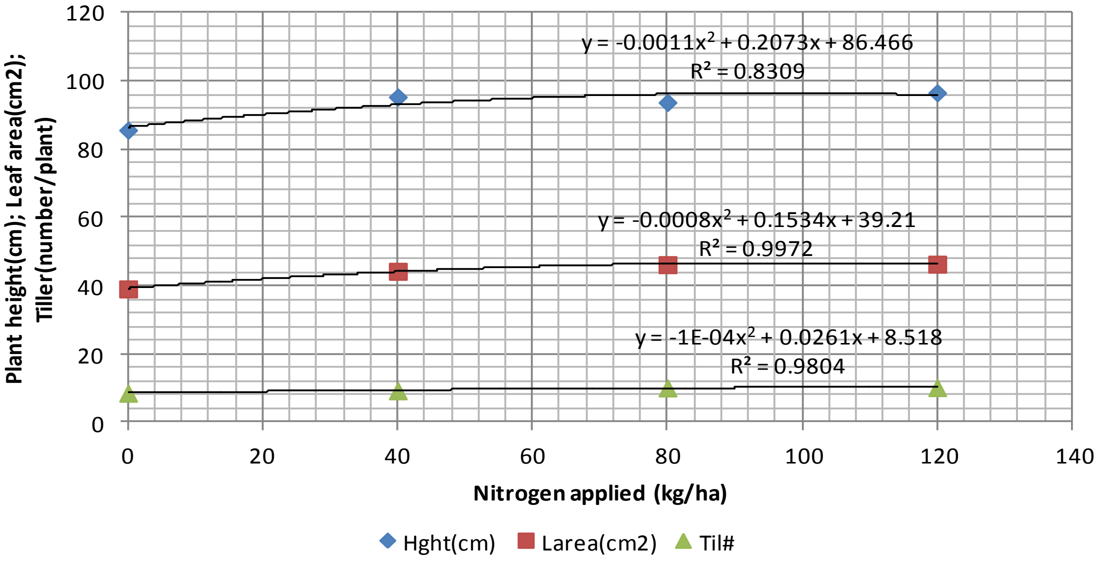

Figure 8: Effect of nitrogen on growth parameters

It is therefore readily seen why nitrogen application significantly improved the grain yield.

Analyzing the grain yield functions Y (N) in figure 6 where N=applied nitrogen and Y=grain yield assuming quadratic model one obtains that

$Y(N)_{P2O5=0} = -8E\text{-}05X^2 + 0.0266X + 6.315$ with R2 = 0.9442; n = 4

$Y(N)_{P2O5=34} = -2E\text{-}04X^2 + 0.0436X + 6.145$ with R2 = 0.9825; n = 4

$Y(N)_{P2O5=70} = -6E\text{-}05X^2 + 0.0210X + 6.790$ with R2 = 0.8609; n = 4

Leading to

$(\partial Y/\partial N)_{P2O5=0} = -16E\text{-}05N + 0.0266$

$(\partial Y/\partial N)_{P2O5=34} = -4E\text{-}04N + 0.0436$

$(\partial Y/\partial N)_{P2O5=70} = -12E\text{-}05N + 0.0210$

Solving these equations for

$(\partial Y/\partial N)_{P2O5=i} = 0$

Shows that the estimated amount of nitrogen required for maximum yield varied with the level of P_2O_5 applied. Without phosphorus application, the highest grain yield (8.53t/ha) would be obtained with 166.25kg N/ha. This amount shifted to 109 and 175kg N/ha to reach maximum yield of 8.52t/ha and 8.63t/ha, respectively when nitrogen was combined with 34 and 70kg P_2O_5/ha. It appears, therefore, that though phosphorus application did not significantly affect the grain yield, it enhanced the fertilizer nitrogen efficiency. The results in figure 6 indicate that in this study and the prevailing field conditions, the nitrogen application was most efficient when combined with 34kg P_2O_5/ha. Relative decrease in grain yield under combination of high rates of both nitrogen and phosphorus is readily understandable. Reeinke *et al*. (1994) reported similar results, showing a decrease in yield with application of high rates of N. It is important to point out at this level that the estimated nitrogen and phosphorus requirements for maximum yields derived from the experimental results differ from those recommended by Rwanda Agriculture Board(RAB) which amount to 80kg/ha and to 34kg/ha for nitrogen and phosphorus, respectively.

4.3. Nutrient sufficiency level for growth and grain yield

The results discussed above have shown that tillering was the growth activity that impacted most the process of grain production. Tiller numbers will be therefore used as the basis for calculating the soil nutrient critical point. No clear crop response to phosphorus application was observed, therefore, only nitrogen critical point and sufficiency level will be discussed.

The combined effects of nitrogen and phosphorus fertilizers on tillering activity are shown in figure 9.

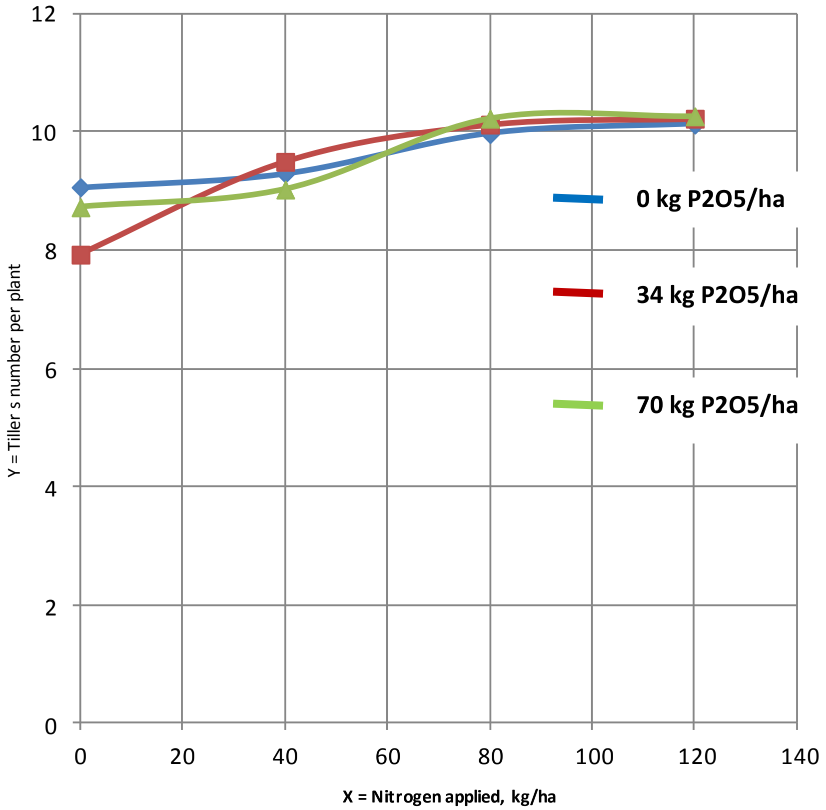

Figure 9: Effect of nitrogen and phosphorus application on tillering activity

It appears that the tillering activity varied with nitrogen application depending on the amount of phosphorus applied.

The analysis of the Y(X) functions where X=amount of nitrogen applied and Y=number of tillers per plant (fig 8) using numerical differentiation showed that

$(\partial Y/\partial X)_{P2O5=0} = - 0.00002X + 0.0109$

$(\partial Y/\partial X)_{P2O5=34} = - 0.00040X + 0.0464$

$(\partial Y/\partial X)_{P2O5=70} = - 0.00008X + 0.0194$

The solutions of these equations i.e. X for (∂Y/∂X)=0 suggest that the amount of nitrogen fertilizer required for maximum vegetative growth varied with the rate of phosphorus application. Without phosphorus application, the maximum growth was to be obtained with 545kg N/ha. This amount decreased to 116 and 242kg N/ha, when nitrogen was combined with 34 and 70kg P_2O_5/ha respectively. Considering the field apparent specific weight of 1400kg/m^3 (table 4) and the rice rooting depth of 20cm, one can convert these amounts into total soil nitrogen content as follows:

545kg N/ha ≡ 0.019 %

116kg N/ha ≡ 0.004 %

242kg N/ha ≡ 0.009 %

Adding these values to initial soil nitrogen content, one can obtain the critical soil nitrogen point for maximum growth as follows depending on applied P_2O_5:

Table 9: Critical soil nitrogen levels for maximum growth

Applied P_2O_5	**Soil N critical point for vegetative growth**
O kg/ha	0.369 %
34 kg/ha	0.354 %
70 kg/ha	0.359 %

Applying the same procedure to the grain yield one obtains the following results in table 10.

Table 10: Critical soil nitrogen levels for maximum growth

Applied P_2O_5	**Soil N critical point for grain yield**
O kg/ha	0.356 %
34 kg/ha	0.354 %
70 kg/ha	0.356 %

Nitrogen sufficiency level can be estimated from nitrogen critical point using the relation

$N_{SL} = N_{ACT}/N_{CP}$

Where N_{SL} stands for nitrogen sufficiency level, N_{ACT} for actual soil nitrogen content and N_{CP} for soil nitrogen critical point. In percentage, the relation reads as follows:

$N_{SL} = 100N_{ACT}/N_{CP}$

Nitrogen sufficiency levels obtained with the above formula are given in the following table:

Table 11: Soil nitrogen sufficiency levels for maximum growth and grain yield

Applied P_2O_5	Sufficiency level in %	
	Vegetative growth	Grain yield
0 kg/ha	95	98
34 kg/ha	99	99
70 kg/ha	97	98

The result in table 11 confirm the earlier observation in the present work that phosphorus application enhanced nitrogen fertilizer efficiency as they show that nitrogen sufficiency level was more pronounced in phosphorus treated plots and highest when fertilizer nitrogen was applied in combination with 34 kg P_2O_5/ha. The results also suggest that in the experimental conditions, vegetative growth was more demanding in nitrogen than the grain production.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The present study monitored rice (*Oryza sativa* var. upland 26) response to fertilizers nitrogen and phosphorus application with an objective to assess the sufficiency levels of these nutrients for growth and yields in Cyunuzi paddy field in Eastern Rwanda.

The results show that after flooding with irrigation water, the soil reaction slightly improved, but remained within a range unfavorable to mineral nutrition of rice as the pH shifted from very strongly acidic to strongly acid. On the other hand, due to nitrogen application, the soil nitrogen content varied depending on the accompanying rate of phosphorus, the highest increase (6%) being obtained with 120kgN/ha combined with 34 P_2O_5kg/ha. Similarly, application of fertilizer phosphorus induced an increase in soil phosphorus content ranging from 317% (under 34kgP_2O_5/ha) to 374% (under 70 kgP_2O_5/ha). The values of soil nitrogen content following N application were medium as compared to the norms defined by Kay (1998) whereas those of phosphorus appeared to be low.

Both nitrogen and phosphorus uptake by the crop increased with the fertilizer application. However, combining nitrogen with high rates of phosphorus fertilizer generally reduced nitrogen uptake probably due to increased immobilization (i.e. reorganization). These trends affected the crop growth. Nitrogen application significantly improved the crop growth and yield by increasing plant height, the leaf area, tillering and panicle numbers. The effect of nitrogen on the crop production varied with the amount of phosphorus applied: it was highest when nitrogen fertilizer was combined with 34kg of P_2O_5 per hectare. On the other hand, no clear effect of phosphorus fertilizer applied alone was observed

Clear positive crop response to nitrogen application suggests that the initial soil nitrogen status in Cyunuzi paddy field was suboptimal. Applying the quadratic model to the yield-fertilizer nitrogen functional relationship, it appeared that without phosphorus application, a maximum grain yield of 8.53t/ha would be obtained with 166.25kgN/ha. This amount shifted to 109 and 175kgN/ha to reach maximum yields of 8.52 and 8.63t/ha when nitrogen was combined with 34 and 70kgP_2O_5/ha, respectively. Adding the amount of fertilizer nitrogen required for maximum crop growth and yield to the initial soil nitrogen content, the sufficiency levels of this nutrient for maximum vegetative growth was estimated to be 96, 99 and 97% under 0, 34 and 70kgP_2O_5/ha, respectively. For maximum grain yield, nitrogen sufficiency levels were 98, 99 and 98% under 0, 34 and 70kg P_2O_5/ha respectively.

Based on the results of this study and also on environmental concern it is recommended that combination of 109 kg of N and 34 kg of P_2O_5 should be used in Cyunuzi paddy fields for maximum yield of rice “upland 26” variety.

It can be recommended that the same study can be conducted with other variety grown in Cyunuzi lowland.

Due to time and financial constraints, the study was conducted in one season. Therefore one may recommend that the same research can be repeated at the same for two seasons using more level of P to assess its sufficiency levels.

I is also recommended that the similar research can be conducted in different paddy fields in Rwanda to confirm the results of the present study and find out the effect of the site.

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APPENDICES

Appendix 1.Relative humidity data at kibungo (kazo) meteorological station (2012)

MOIS	2	3	4	5	6	7
DATE	Relative humidity	Relative humidity	Relative humidity	Relative humidity	Relative humidity	Relative humidity
1	73.5	82.5	90	76	67	57
2	58.1	78.1	80	90	65	61
3	59.1	79.8	70	93	67	63
4	59.3	89.3	65	88	64	50
5	47.5	77.6	86	88	65	55
6	47.3	78.6	92	85	63	49
7	45.5	75.8	85	89	73	50
8	73.7	76.6	83	91	72	48
9	65.4	67.3	82	85	89	55
10	49.4	67.4	75	89	73	55
11	57.4	71.7	67	90	75	56
12	73	71.3	71	83	64	49
13	80.1	62.4	84	83	69	46
14	67.3	55.9	77	80	63	48
15	77.5	60.5	93	90	59	52
16	64.6	78.7	88	91	59	48
17	74.2	69.8	86	81	58	47
18	81.5	73.9	82	83	58	51
19	84.6	76.2	80	82	60	66
20	81.9	80.0	80	86	58	59
21	79.7	70.2	84	83	57	57
22	77	61.5	83	72	53	58
23	81.6	59.6	78	76	62	54
24	89	67.8	95	72	84	74
25	86.6	87.3	87	68	74	56
26	81.2	71.4	81	70	87	53
27	79.5	86.5	81	75	78	53
28	75.1	76.7	81	91	64	54
29	81.5	63.9	84	71	58	52
30		60.7	89	65	49	50
31		90.8		64		51

Source: Rwanda Meteorological Authority

Appendix 2. Relative ratings of degree of acidity and alkalinity

Soil Reaction	pH Range	Normal Crop Response
Extremely acid	Below 4.5	Very Poor*
Very strongly acid	4.5-5.0	Poor*
Strongly acid	5.1-5.5	Moderately good
Medium acid	5.6-6.0	Good
Slightly acid	6.1-6.5	Very good
Neutral	6.6-7.3	Very good
Mildly alkaline	7.4-7.8	Moderately good**
Moderately alkaline	7.9-8.4	Poor**
Strongly alkaline	8.5-9.0	Very good**
alkaline	Above 9.0	Few grow

Bruce R. Hoskins 1997

*Blueberry, Cranberry, Azalea, Rhododendron, and other acid-loving plants are exceptions.

**Micronutrients become the major limiting factor.

Appendix 3: Rating for cation exchange capacity

Rating	CEC [cmol(+)/kg]
Very low	<6
Low	6-12
Moderate	12-25
High	25-40
Very high	>40

Source :Metson(1961) in Hazelton and Murphy (2007

Appendix 4: Level of exchangeable cations (cmol (+)/kg)

Cation	Very low	Low	Moderate	High	Very high
Na	0-0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2.0
K	0-0.2	0.2-0.3	0.3-0.7	0.7-2.0	>2.0
Ca	0-2	2-5	5-10	10-20	>20
Mg	0-0.3	0.3-1.0	1-3	3-8	>8

Source: Abbott (1989) in Hazelton and Murphy (2007)

Appendix 5: Level of total soil nitrogen

Level	Total Nitrogen %
Very low	<0.1
Low	0.1-0.2
Medium	0.2-0.5
High	0.5-1.0
Very high	>1.0

Source :(Kay 1998)

Appendix 6: Variance table for soil pH

```
-----------------------------------------------------------------
VS             DF          SS               MS            F
-----------------------------------------------------------------
Factor1-F1      2          0.08217          0.04109       2.1892 ns
Factor2-F2      3          0.02228          0.00743       0.3956 ns
Int. F1xF2      6          0.07992          0.01332       0.7097 ns
-----------------------------------------------------------------
Treatments     11          0.18436          0.01676       0.8930 ns
Blocks          2          0.76204          0.38102      20.3016 **
Error          22          0.41289          0.01877
-----------------------------------------------------------------
Total          35          1.35930
-----------------------------------------------------------------
** Significative at p < .01  * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 7: Variance table for soil P

```
-------------------------------------------------------------------

VS             DF          SS              MS             F
-------------------------------------------------------------------
Factor1-F1      2         10.56542         5.28271        9.6173 **
Factor2-F2      3          0.60418         0.20139        0.3666 ns
Int. F1xF2      6          1.11009         0.18501        0.3368 ns
-------------------------------------------------------------------
Treatments     11         12.27969         1.11634        2.0323 ns
Blocks          2         13.45121         6.72560       12.2441 **
Error          22         12.08446         0.54929
-------------------------------------------------------------------
Total          35         37.81536
-------------------------------------------------------------------
```

Appendix 8: Variance table for soil N

```
-------------------------------------------------------------------

VS             DF          SS              MS             F
-------------------------------------------------------------------
Factor1-F1      2          0.01211         0.00605        1.4704 ns
Factor2-F2      3          0.00321         0.00107        0.2598 ns
Int. F1xF2      6          0.01925         0.00321        0.7794 ns
-------------------------------------------------------------------
Treatments     11          0.03456         0.00314        0.7633 ns
Blocks          2          0.00637         0.00319        0.7740 ns
Error          22          0.09056         0.00412
-------------------------------------------------------------------
Total          35          0.13150
-------------------------------------------------------------------
```

Appendix 9: Variance table for N in plant leaf

```
-------------------------------------------------------------------
VS             DF          SS              MS             F
-------------------------------------------------------------------
Factor1-F1      2          0.25274         0.12637        0.5542 ns
Factor2-F2      3          0.81274         0.27091        1.1882 ns
Int. F1xF2      6          1.10742         0.18457        0.8095 ns
-------------------------------------------------------------------
Treatments     11          2.17290         0.19754        0.8664 ns
Blocks          2          3.16961         1.58480        6.9506 **
Error          22          5.01619         0.22801
-------------------------------------------------------------------
Total          35         10.35870
-------------------------------------------------------------------
** Significative at p < .01     * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 10:Variance table for P in plant leaf

```
-------------------------------------------------------------------
VS              DF          SS               MS             F
-------------------------------------------------------------------
Factor1-F1       2         14.27722          7.13861       0.4600 ns
Factor2-F2       3        309.68306        103.22769       6.6518 **
Int. F1xF2       6        186.42944         31.07157       2.0022 ns
-------------------------------------------------------------------
Treatments      11        510.38972         46.39907       2.9899 *
Blocks           2         82.33556         41.16778       2.6528 ns
Error           22        341.41111         15.51869
-------------------------------------------------------------------
Total           35        934.13639
-------------------------------------------------------------------
```

Appendix 11. a: Variance table for plant height 36 days after transplanting

```
----------------------------------------------------------------

VS              DF          SS               MS             F
-------------------------------------------------------------------
Factor1-F1       2         27.22389         13.61194       1.4573 ns
Factor2-F2       3         20.71417          6.90472       0.7392 ns
Int. F1xF2       6          7.62500          1.27083       0.1361 *
-------------------------------------------------------------------
Treatments      11         55.56306          5.05119       0.5408 ns
Blocks           2          9.82389          4.91194       0.5259 ns
Error           22        205.48944          9.34043
-------------------------------------------------------------------
Total           35        270.87639
-------------------------------------------------------------------
```

Appendix 11.b. Variance table for plant height 50 days after transplating

```
-------------------------------------------------------------------
VS              DF          SS               MS             F
-------------------------------------------------------------------
Factor1-F1       2         27.74389         13.87194       0.8649 ns
Factor2-F2       3        120.82778         40.27593       2.5113 ns
Int. F1xF2       6         75.81389         12.63565       0.7879 ns
-------------------------------------------------------------------
Treatments      11        224.38556         20.39869       1.2719 ns
Blocks           2         24.41056         12.20528       0.7610 ns
Error           22        352.83611         16.03801
-------------------------------------------------------------------
Total           35        601.63222
-------------------------------------------------------------------

** Significative at p < .01     * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 11.c. Variance table for plant height 64 days after transplating

```
-------------------------------------------------------------------
VS              DF          SS               MS             F
-------------------------------------------------------------------
Factor1-F1       2          36.32389         18.16194       2.1776 ns
Factor2-F2       3         184.99222         61.66407       7.3935 **
Int. F1xF2       6          37.16278          6.19380       0.7426 ns
-------------------------------------------------------------------
Treatments      11         258.47889         23.49808       2.8174 *
Blocks           2         151.18722         75.59361       9.0637 **
Error           22         183.48611          8.34028
-------------------------------------------------------------------
Total           35         593.15222
-------------------------------------------------------------------
```

Appendix 11.d. Variance table for plant height 78 days after transplating

```
-------------------------------------------------------------------
VS              DF          SS               MS             F
-------------------------------------------------------------------
Factor1-F1       2          64.21722         32.10861       1.7499 ns
Factor2-F2       3         657.15222        219.05074      11.9382 **
Int. F1xF2       6          88.15611         14.69269       0.8007 ns
-------------------------------------------------------------------
Treatments      11         809.52556         73.59323       4.0108 **
Blocks           2         411.25389        205.62694      11.2066 **
Error           22         403.67278         18.34876
-------------------------------------------------------------------
Total           35        1624.45222
-------------------------------------------------------------------
```

Appendix 12(a): Variance table for Tiller 36 days after transplating

```
----------------------------------------------------------------
VS              DF          SS              MS            F
----------------------------------------------------------------
Factor1-F1       2          0.06222         0.03111       0.2777 ns
Factor2-F2       3          0.39444         0.13148       1.1737 ns
Int. F1xF2       6          0.46222         0.07704       0.6877 ns
----------------------------------------------------------------
Treatments      11          0.91889         0.08354       0.7457 ns
Blocks           2          2.10889         1.05444       9.4130 **
Error           22          2.46444         0.11202
----------------------------------------------------------------
Total           35          5.49222
----------------------------------------------------------------**
Significative at p < .01     * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)

Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 12.b. Variance for Tiller 50 days after transplating

```
-----------------------------------------------------------------
VS              DF           SS                MS            F
-----------------------------------------------------------------
Factor1-F1       2            1.00389           0.50194       0.4931 ns
Factor2-F2       3            8.46000           2.82000       2.7701 ns
Int. F1xF2       6            1.50500           0.25083       0.2464 ns
-----------------------------------------------------------------
Treatments      11           10.96889           0.99717       0.9795 ns
Blocks           2           13.49056           6.74528       6.6260 **
Error           22           22.39611           1.01801
-----------------------------------------------------------------
Total           35           46.85556
-----------------------------------------------------------------
```

Appendix 12.c. Variance table for Tiller 64 days after transplating

```
-----------------------------------------------------------------
VS              DF           SS                MS            F
-----------------------------------------------------------------
Factor1-F1       2            0.22889           0.11444       0.1188 ns
Factor2-F2       3           11.34306           3.78102       3.9238 *
Int. F1xF2       6            1.72444           0.28741       0.2983 ns
-----------------------------------------------------------------
Treatments      11           13.29639           1.20876       1.2544 ns
Blocks           2           20.79389          10.39694      10.7896 **
Error           22           21.19944           0.96361
-----------------------------------------------------------------
Total           35           55.28972
-----------------------------------------------------------------
```

Appendix 12.d. Variance table for Tiller 78 days after transplating

```
-----------------------------------------------------------------
VS              DF           SS                MS            F
-----------------------------------------------------------------
Factor1-F1       2            0.17556           0.08778       0.0933 ns
Factor2-F2       3           15.94000           5.31333       5.6499 **
Int. F1xF2       6            2.32667           0.38778       0.4123 ns
-----------------------------------------------------------------
Treatments      11           18.44222           1.67657       1.7828 ns
Blocks           2           20.75722          10.37861      11.0360 **
Error           22           20.68944           0.94043
-----------------------------------------------------------------
Total           35           59.88889
-----------------------------------------------------------------
```

```
** Significative at p < .01     * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 13: Variance table for leaf area

```
------------------------------------------------------------------
VS              DF           SS               MS             F
------------------------------------------------------------------
Factor1-F1       2         14.27722          7.13861        0.4600 ns
Factor2-F2       3        309.68306        103.22769        6.6518 **
Int. F1xF2       6        186.42944         31.07157        2.0022 ns
------------------------------------------------------------------
Treatments      11        510.38972         46.39907        2.9899 *
Blocks           2         82.33556         41.16778        2.6528 ns
Error           22        341.41111         15.51869
------------------------------------------------------------------
Total           35        934.13639
------------------------------------------------------------------
```

Appendix 14: Variance table for aboveground biomass

```
------------------------------------------------------------------
VS              DF           SS               MS             F
------------------------------------------------------------------
Factor1-F1       2        155.17722         77.58861        2.3135 ns
Factor2-F2       3       1230.25639        410.08546       12.2278 **
Int. F1xF2       6        193.16944         32.19491        0.9600 ns
------------------------------------------------------------------
Treatments      11       1578.60306        143.50937        4.2791 **
Blocks           2        672.04222        336.02111       10.0194 **
Error           22        737.81778         33.53717
------------------------------------------------------------------
Total           35       2988.46306
------------------------------------------------------------------
```

Appendix 15: Variance table for empty grain per panicle

```
------------------------------------------------------------------
VS              DF           SS               MS             F
------------------------------------------------------------------
Factor1-F1       2         62.00000         31.00000        1.2872 ns
Factor2-F2       3        681.00000        227.00000        9.4256 **
Int. F1xF2       6        136.00000         22.66667        0.9412 ns
------------------------------------------------------------------
Treatments      11        879.00000         79.90909        3.3180 **
Blocks           2        246.16667        123.08333        5.1107 *
Error           22        529.83333         24.08333
------------------------------------------------------------------
Total           35       1655.00000
------------------------------------------------------------------
```

** Significative at p < .01   * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen

Appendix 16: Variance table for %empty grain per panicle

```
------------------------------------------------------------------
VS             DF           SS               MS            F
------------------------------------------------------------------
Factor1-F1      2          8.90722          4.45361       0.7680 ns
Factor2-F2      3        119.68556         39.89519       6.8801 **
Int. F1xF2      6         30.09944          5.01657       0.8651 ns
------------------------------------------------------------------
Treatments     11        158.69222         14.42657       2.4879 *
Blocks          2         52.92389         26.46194       4.5635 *
Error          22        127.56944          5.79861
------------------------------------------------------------------
Total          35        339.18556
------------------------------------------------------------------
```

Appendix 17: Variance table for 1000 grains weight

```
--------------------------------------------------------------------
VS              DF           SS               MS            F
--------------------------------------------------------------------
Factor1-F1       2           0.05389          0.02694       0.0528 ns
Factor2-F2       3           3.25778          1.08593       2.1297 ns
Int. F1xF2       6           5.57056          0.92843       1.8208 ns
--------------------------------------------------------------------
Treatments      11           8.88222          0.80747       1.5836 ns
Blocks           2           9.39556          4.69778       9.2132 **
Error           22          11.21778          0.50990
--------------------------------------------------------------------
Total           35          29.49556
--------------------------------------------------------------------
```

Appendix 18: Variance table for panicle number

```
--------------------------------------------------------------------
VS              DF           SS               MS            F
--------------------------------------------------------------------
Factor1-F1       2           6.11167          3.05583       1.6101 ns
Factor2-F2       3          27.29194          9.09731       4.7932 *
Int. F1xF2       6           4.45722          0.74287       0.3914 ns
--------------------------------------------------------------------
Treatments      11          37.86083          3.44189       1.8135 ns
Blocks           2          16.57167          8.28583       4.3657 *
Error           22          41.75500          1.89795
--------------------------------------------------------------------
Total           35          96.18750
--------------------------------------------------------------------
** Significative at p < .01  * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 19: Variance table for total grain panicle-1

```
------------------------------------------------------------------
VS             DF          SS              MS            F
------------------------------------------------------------------
Factor1-F1      2        475.38889       237.69444       1.0281 ns
Factor2-F2      3       3752.44444      1250.81481       5.4101 **
Int. F1xF2      6       1756.38889       292.73148       1.2661 ns
------------------------------------------------------------------
Treatments     11       5984.22222       544.02020       2.3530 *
Blocks          2        666.88889       333.44444       1.4422 ns
Error          22       5086.44444       231.20202
------------------------------------------------------------------
Total          35      11737.55556
------------------------------------------------------------------
** Significative at p < .01  * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 20: Variance table for filled grain number panicle-1

```
-------------------------------------------------------------------
VS             DF           SS              MS            F
-------------------------------------------------------------------
Factor1-F1      2         287.38889       143.69444       0.9368 ns
Factor2-F2      3        1362.08333       454.02778       2.9601 ns
Int. F1xF2      6        1337.50000       222.91667       1.4533 ns
-------------------------------------------------------------------
Treatments     11        2986.97222       271.54293       1.7703 ns
Blocks          2         124.22222        62.11111       0.4049 ns
Error          22        3374.44444       153.38384
-------------------------------------------------------------------
Total          35        6485.63889
-------------------------------------------------------------------
** Significative at p < .01  * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 21: Variance table for total grain yield ha-1

```
-------------------------------------------------------------------
VS              DF          SS               MS              F
-------------------------------------------------------------------
Factor1-F1       2     236546.04389    118273.02194        0.1985 ns
Factor2-F2       3   21769102.13861   7256367.37954       12.1782 **
Int. F1xF2       6     817168.02056    136194.67009        0.2286 ns
-------------------------------------------------------------------
Treatments      11   22822816.20305   2074801.47300        3.4821 **
Blocks           2    6981128.57556   3490564.28778        5.8581 **
Error           22   13108673.68444    595848.80384
-------------------------------------------------------------------
Total           35   42912618.46305
-------------------------------------------------------------------
** Significative at p < .01  * Significative at(.01 =< p < .05)
ns Non-significative (p >= .05)
Factor 1 = phosphorus, Factor 2 = nitrogen
```

Appendix 22: Rainfall and temperature data of the study area (year 2012)

Month	Temperature(^{o}C)		Rainfall (mm)
	Max	Min	Total
Feb	30.5	14	73.38
March	29.8	14.5	63.9
April	27.6	14.5	252
May	26.7	14.7	177.8
June	27	13.9	26
July	29.2	12.8	-
Total			593.08

Source: Rwanda meteorological Directorate

Appendix 23: Correlation analysis

	pH	*N(soil)*	*P(soil)(ppm*	*%N in plant*	*%P in plant*	*leaf area*	*plant height*	*Tiller #*	*biomass*	*1000GW*	*Pan#*	*total /pan*	*filled/pan*	*empty/pan*	*% empty/pan*	*yield / plant*
pH	1															
N(soil)	0.1041845	1														
P(soil)(ppm	-0.092417	-0.2519162	1													
%N in plant	-0.35705	-0.21296	-0.1191407	1												
%P in plant	0.0446489	0.1750878	-0.0317971	0.1346752	1											
leaf area	0.1135633	0.1286813	-0.3238351	0.0958769	0.4521058	1										
plant height	-0.179106	0.2516327	-0.4328505	0.3598472	0.203516	0.4983872	1									
Tiller #	-0.561099	0.0354364	-0.2246921	0.4653889	0.1038276	0.237813	0.530459	1								
biomass	-0.372134	0.244878	-0.375706	0.414716	0.2666933	0.5245005	0.8110791	0.6833912	1							
1000GW	0.180638	-0.3299809	0.4470526	-0.3743257	-0.269369	-0.361788	-0.581571	-0.591762	-0.572051	1						
Pan#	-0.47468	0.088371	-0.3573848	0.340941	0.1911324	0.2751941	0.6018455	0.9004527	0.7901626	-0.5307207	1					
total /panicle	0.0306712	0.1592194	-0.2271046	0.1746432	0.0504952	0.5931813	0.6612816	0.1228351	0.6544697	-0.2570414	0.1732778	1				
filled/pan	0.055047	0.1174652	-0.1305987	0.0457054	-0.056447	0.4816235	0.5363062	-0.02598	0.532519	-0.0359038	0.055829	0.955191	1			
empty/pan	-0.022243	0.1921745	-0.3564114	0.3835146	0.2494683	0.6568784	0.7218592	0.3805263	0.7063367	-0.6286966	0.3503389	0.804645	0.593273	1		
% empty/pan	0.1413939	0.1444136	-0.4158445	0.2997722	0.2663149	0.5219964	0.5546042	0.3327096	0.4928553	-0.5779418	0.3334691	0.462895	0.22714	0.7996228	1	
yield / plant	-0.406556	0.1270467	-0.3391923	0.2940415	0.0834451	0.4382904	0.689155	0.6854322	0.8998409	-0.3192299	0.8213208	0.596079	0.558196	0.4940988	0.301666	1

N(soil)= total nitrogen in soil

P(soil) available phosphorus in soil

%N in plant= percentage nitrogen in plant

Tiller #= Tiller number

1000GW= 1000 grains weight;

total /pan= total grain per panicle;

filled/pan= filled grain per panicle

empty/pan= empty grain per panicle

% empty/pan=percentage empty grain per panicle

yield / plant= grain yield per plant

Appendix 24: Table of Multiple regression analysis

Regression Statistics	
Multiple R	0.968443865
R Square	0.93788352
Adjusted R Square	0.934118885
Standard Error	2.041635491
Observations	36

Appendix 24 cont'd

ANOVA					
	Df	*SS*	*MS*	*F*	*Significance F*
Regression	2	2076.884856	1038.442428	249.13	1.22437E-20
Residual	33	137.5530908	4.168275479		
Total	35	2214.437947			

Appendix 24 cont'd

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-34.3748467	3.574156108	-9.617611994	4.26E-11	-41.6465	-27.1032	-41.6465	-27.10317141
Pan#	3.8103274	0.208889832	18.2408468	8.36E-19	3.385338	4.235317	3.385338	4.235316976
filled/pan	0.29960026	0.025330884	11.82746977	2.06E-13	0.248064	0.351136	0.248064	0.351136335