PHYSIOLOGICAL AND DEVELOPMENTAL RESPONSE OF SELECTED RICE GENOTYPES TO WATER AND NUTRIENT STRESS IN DIFFERENT SOILS IN WESTERN KENYA

By

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ABSTRACT

Drought is a major challenge for all agricultural crops, but for rice, it is even more serious, because of its semi aquatic phylogenetic origins and the diversity of rice ecosystems and growing conditions. The most important source of climate-related risks for rice production in rainfed areas is drought. Crop physiology has made a significant contribution to understanding the mechanisms underlying crop growth and development, and bridging the "phenotype gap" generated by the recent progress in genomics. Some studies involving plant water status and photosynthesis in upland or lowland have been recorded , but a thorough analysis of below and above ground plant biomass in relation to genetic (G) ,environment (E) and management (M) is still lacking. Large genotypic variations have been found for roots in upland rice; however, quantitative comparisons between the deep root morphology of rice cultivars on upland fields and the effects of soil water conditions and nutrient load upon it are still limited. This study assumes that the genotypic characteristics required for drought resistance would be determined as affected by site-specific, soil properties and fertilizer management, and that the assessment of G x E x M interaction is necessary requirement for enhancing and stabilizing the upland rice productivity under drought-prone environments. The study aimed to determine growth and physiological response of selected upland rice genotypes (IRAT 109, Lemont and NERICA 4) to water deficit, fertilizer application and in different soil types. This study was carried out in the University Botanic Garden, Maseno during September 2011 to January 2012. Plants were subjected to water nutrient stress treatment in the field and in PVC tubes. Two experiments were conducted, field trial (Exp. 1) and PVC-tubes trial (Exp. 2). Experiment 1 had three fertilizer treatments, (N, P, and NP) and a control and only N and NP for experiment 2. Experiment 1 and 2 had, 2 and 3 genotypes respectively with 2-water managements, in a split-plot design. Exp. 2 had two-soils-type in Randomized Completely Blocked Design (RCBD). Water treatment started at 42 das in Exp. 1 and 35 das in Exp. 2., fertilizer treatment, was applied at 60 Kgha-^{1}N, and 60 Kgha^{-1}N + 45 Kgha^{-1}P, at 42 and 56 das; in Exp. 2, 80 Kgha^{-1}N, 60 Kgha^{-1}, P and 80 Kgha^{-1}N + 60 Kgha^{-1}P, was applied in fertilized tubes, at 21 and 42 das. Shoots measurements at 21, 42, 63 and 84th das, roots sampling at the same interval at depths of 0-10 cm, 10-20 cm, and 20-40 Cm. the parameters measured included soil moisture content, growth parameters, plant biomass, N content, stomatal conductance and yields. The parameters measured recorded a similar trend in the field and in the PVC tubes. The soil moisture content had significant effect and decreased with increasing water deficit. The growth parameters like plant height, plant biomass both shoot and root reduced with decreasing water content and nutrient load in the soil. The water stressed plant, Lemont, registered the lowest growth parameters. Lemont, being the most water stressed plant had the lower stomatal conductance and N content. The yield component declined in water stressed conditions, IRAT 109 had the highest yield while Lemont the least. Results indicates that under water-nutrient deficit, IRAT 109 has a superior physiological traits such as high stomatal conductance and high N foliar content hence can be recommended for growing under rainfed conditions in Kenya. This finding will ultimately help in poverty eradication through increased income and improved food security.

CHAPTER ONE

INTRODUCTION

1.1 Rice as a cereal food crop

Rice is among the most important cereals which provide food to more than half of the world's population, particularly in many developing countries in Asia, Africa and Latin America (Khush, 2005). Rice is grown on approximately 155 million hectares worldwide (Pandey *et al.*, 2010). Rice accounts for one-fifth of the global calorie supply and an estimated 900 million of the world's poor depend on rice as producers or as consumers (Pandey *et al.*, 2010).

In Kenya, rice is currently the third most important food crop after maize and wheat. It forms part of the larger diet for the urban population and it is gaining popularity among those living in the rural areas. Indeed, consumption of rice in Kenya has been rising at an annual rate of 12% because of changing food preferences in urban and rural areas, high population growth rates, and rapid urbanization. The domestic consumption in Kenya increased from 286,000 tons in 2006 to 410,000 tons in 2009 (MoA, 2009; MoA, 2010). Consumption is projected to grow to 727,000 tons by 2015, 1.28 million tons by 2020 and 3.98 million tons by 2030 (MoA, 2009). It is projected that rice will become the most important cereal in the country by the year 2050 (MoA, 2009). To meet consumption requirements extra tons of rice is imported into Kenya annually. Imports were valued at KES 7 billion (about US$100 million) in 2008 (Mati *et al.*, 2011).

Rice cultivation was introduced in Kenya in 1907 (MoA, 2009). Mainly small-scale farmers grow Rice. Currently, about 80% of rice grown in Kenya is from public irrigation schemes while 20% is produced under rain-fed conditions (MoA, 2009). The schemes include Mwea (6475 ha), Bunyala (213 ha), Tana (900 ha), Ahero (877 ha), West Kano (900 ha). Mwea Irrigation Scheme in plays a major role in rice production accounting for over 85% of the total rice produced. The crop is also grown in the neighbourhood of national irrigation schemes by farmers referred to as out growers.

In Kenya, 95% of the rice produced is originated from irrigated lowland and the remaining 5% from rainfed-cultivation. The potential area for irrigated lowland in Kenya is estimated to be only 11,000 ha, whereas the rainfed conditions have a potential area of more than 400,000 ha (GoK, 2009). Considering the high cost and limited potential for extending irrigated lowland area, upland rice promotion, which requires far less cost, is inevitable for doubling the rice production in Kenya. However, the upland rice production is at trial stage and there are few studies that have been made.

1.2 Response of rice to water deficit

The consequences of water deficit to the plants are both physiological and morphological. Water deficit results into permanent wilting, dehydration and finally death (Fitter and Hay, 1987). Rice farmers rely heavily on irrigation to meet production goals. However irrigation water is a limited resource and its effective management is critical not only in reducing wasteful usage but also in reducing production costs and sustaining productivity, the area for enhancing irrigation too is limited due to space and water resource, so sustainable rice production can be attained through technology that makes effective and efficient use of the erratic rainfall resource (Ogindo, 2003).

Identification of drought tolerant rice varieties is thus crucial in sustaining production in upland areas where water supply is limited but has greater potential for increasing upland rice production (Fageria, 2007). Pirdashti *et al.* (2004) reported that rice is particularly susceptible to water deficit at the reproductive stage. The booting stages through flowering are the most sensitive stages (McKersie and Ya'acov, 1994; Wade *et al.*, 1999). Although water shortage is one of the most severe constraints to rice yield, limited effort has been devoted to developing or identification of a rice cultivars with improved drought tolerance (Fukai *et al.*, 1999; Pantuwan *et al.*, 2002).

Rice has become a model cereal species for investigating the tolerance of grasses to abiotic stresses since genetic and genomic tools have been made available (Genome 2005; Degenkolbe *et al.*, 2009). In particular, comparison of tolerant versus susceptible genotypes is a potent method for research on abiotic stresses by using quantitative genetics (Price and Courtois, 1999), comparative analysis of transcriptome (Degenkolbe *et al.*, 2009), proteome (Perez-Molphe-Balch *et al.*, 1996) or metabolome (Hien *et al.*, 2003; Guo *et al.*, 2006). Indeed cultivated rice has a large ecological and genetic diversity, which may be used for deciphering stress tolerance mechanisms. Rice originated from events of domestication in different ecological areas, *Oryza* *glaberrima* in West Africa and *Oryza sativa* indica or japonica in Asia (Cheng *et al.*, 2003). Genotypes of each species or subspecies have been either lowland in which plants grow in drained soil, thereby relying on the soil water reserve (Lafitte *et al.*, 2006; Bernier *et al.*, 2008).

The overall sensitivity of rice to water deficit is considered as high, and higher in lines adapted to lowland cropping systems than those adapted to upland cropping systems (Lafitte *et al.*, 2006; Venuprasad *et al*, 2007; Bernier *et al.*, 2008). However, physiological bases of this sensitivity are still scarce (Tardieu *et al.*, 2010). There is a consensus that root system is weak, with a high genetic variability (Cairns *et al.*, 2009; Serraj *et al.*, 2009). In contrast, it is not clearly known if the rice stomatal and leaf growth are particularly sensitive to water deficit once the effect of root systems has been taken into account (Lilley and Fukai, 1994; Parent *et al.*, 2010). Some studies involving plant water status and photosynthesis in upland or lowland genotypes (Condon *et al.*, 2004), or root hydraulic conductivity (Mullins *et al.*, 1992) have been recorded, but a thorough analysis of above and below ground plant biomass in relation to genetic (G), environment (E) and management (M) is still lacking

Root plasticity is a key trait for improving drought resistance in rice in upland environments because they contribute to water uptake from the soil, deep rooting ability is believed to be superior quality to shallow and latent root growth, for deeper soil water uptake during drought (Kato *et al.*, 2006). Deep root development is largely affected by soil conditions (Cairns *et al.*, 2004; Kato *et al.*, 2006), and large genotype (G) x environment (E) interactions have been recognised (Kondo *et al.*, 2003). Among environmental effects, the effects of water regime on deep root development of rice grown in pots are well-understood (Asch *et al.*, 2004). However, studies on upland rice are still limited (Kondo *et al.*, 2000; Price *et al.*, 2002).

1.3 Efficacy of major nutrients in rice production.

Nutrients efficacy means increased rice yield upon soil fertilization. Nitrogen, phosphorus, potassium, sulphur and zinc, of which the three major elements are most important both in the terms of the extent of the deficiency in the soils, and in terms of the potential for crop yield increase or losses. Nitrogen is the nutrient element limiting growth in most of the rice soils. (Savant and Datta, 1982). The decline in productivity of rice and wheat with continuous cropping was related to deficiency of phosphorus, potassium, sulphur, zinc and imbalanced nutrition (Kumar and Yadov, 2005).

Rice yield increase depend upon a particular nutrient element fertilization, which in turn depends on the intensity of deficiency level of that particular nutrient prevails in the soil being used for cultivation (Shah *et al.,* 2008). Purposefully a particular nutrient stress was created through none application of nitrogen and phosphorus in specific plots, effect in increasing yield was considered as a measuring stick of nutrient efficacy. The objective therefore, was to measure the extent of each major nutrient exclusion effect in soil to decrease yield and simultaneously their application in the soil to increase rice yield.

1.4 Statement of the problem

Drought is a major challenge for all agricultural crops, but for rice, it is even more serious, because of its semi aquatic phylogenetic origins and the diversity of rice ecosystems and growing conditions (O'Toole, 2004). The most important source of climate-related risks for rice production in rainfed areas is drought (Pandey *et al.*, 2007). Crop physiology has made a significant contribution to understanding the mechanisms underlying crop growth and development, and bridging the "phenotype gap" generated by the recent progress in genomics (Miflin, 2000, Boote and Sinclair, 2006). Sensitive to water deficit is considered as high, and higher in lines adapted to lowland cropping system than those adapted to upland cropping system (Garrity and O'Toole, 1994; Lafitte *et al.,* 2006; Venuprasad *et al.,* 2007; Bernier *et al.,* 2008). There is consensus that root system is weak, with a high genetic variability (Cairns *et al.,* 2009; Serraj *et al.,* 2009). In contrast, it is not clearly known if the rice stomatal control and leaf growth are particularly sensitive to water deficit once the effect of root systems has been taken into account (Lilly and Fukai, 1994; Parent *et al.,* 2010). Some studies involving plant water status and photosynthesis in upland or lowland have been recorded (Nguyen *et al.,* 1997; Parent *et al.,* 2010), but a thorough analysis of below and above ground plant biomass in relation to genetic (G) ,environment (E) and management (M) is still lacking. Root plasticity is a key for improving drought resistance in rice in upland environments because they contribute to water uptake from the soil, deep rooting ability is believed to be superior quality to shallow and latent root growth, for deeper soil water uptake during drought(Kato *et al.*, 2006). Large genotypic variations have been found for roots in upland rice (Kato *et al.*, 2006). However, quantitative comparisons between the deep root morphology of rice cultivars on upland fields and the effects of soil water conditions and nutrient load upon it are still limited. In a pot experiment , Azhiri-Sigari *et al.*, 2000, characterized deep root system development using three root traits: the root to shoot ratio, deep root ratio and specific root lengths, they emphasized that the root to shoot ratio and the deep root ratio were important for deep root development of rainfed lowland rice. Similar approaches are lacking in upland rice yet they may be efficient in characterizing and improving deep root system of rice on upland fields.

1.5 Objectives of the study

1.5.1. General objective

The general objective was to determine growth and physiological response of selected upland rice genotypes to water deficit, nitrogen, and phosphorus fertilizers application under different soil types

1.5.2 Specific objectives

1. To determine the effect of water stress and N and P fertilizer application on growth parameter of selected rice genotypes (Lemont and IRAT 109) under different soil types
2. To determine the effect of water stress and N and P fertilizer application on physiological parameter(foliar chlorophyll content and stomatal conductance) of selected rice genotypes (Lemont and IRAT 109) under different soil types
3. To determine the effect of water stress and N and P fertilizer application on yield (grains) of selected rice genotypes (Lemont and IRAT 109) under different soil types
4. To determine the effect of water stress and N and P fertilizer application on soil compaction under different soil types

1.5.3 Hypotheses

1. Water stress and N and P fertilizer application have significant effect on growth parameters of selected rice genotypes (Lemont, RAT 109 and NERICA 4) under different soil types
2. Water stress and N and P fertilizer application have significant effect on physiological characteristics (foliar chlorophyll content and stomatal conductance) of selected rice genotypes (Lemont, RAT 109 and NERICA 4) under different soil types
3. Water stress and N and P fertilizer application have significant effect on yield (grains) of selected rice genotypes (Lemont, RAT 109 and NERICA 4) under different soil types
4. Water stress and N and P fertilizer application have significant effect soil on compaction under different soil type

1.6 Justification of the study

Kenya has high potential in upland rice production, but this has not been achieved for many years due to lack of information on the various ecological requirements of rice for its maximum production, plant scientists are only looking at the changes in the above ground biomass, but not below ground biomass, which greatly influence the above ground biomass (Onyango, 2010). New challenges are emerging in the world's upland rice farming areas, where already some of the world's poorest farmers try to wrest a living from fragile soils that are fast being degraded. The main solution to the perennial food insecurity should involve determining the best environment and the best interaction combination with higher production efficiency (G x M x E). This study will definitely be of great value to Kenyan Agricultural officers, Academic scholars, and even plant breeders, to inform, educate the farmers on plant choice in relation to their site specificity, improve agricultural production of upland rice, to meet the nation demand and sell the surplus, thus boosting the economy.

CHAPTER TWO

LITERATURE REVIEW

2.1 Rice plant

2.1.1 The nature of the rice plant

Rice (*Oryza sativa* L.), a semi aquatic cereal, annual grass with cylindrical jointed stem about 50-150 cm tall, but may go up to 5 m in floating rice (Kochlar, 1981; Sikuku, 2007). The internodes are shortest at the base becoming progressively longer. Rice has a shallow root system, its extent being controlled by nature of the soil and water supply (Kochlar, 1981). The roots of early maturing cultivars are less developed as compared to those of late maturing cultivars (Pal *et al.,* 1996). The roots are adventitious and fibrous and consist of a large number of rootlets and hairs growing in the top 10 cm of soil (Charter Jee and Maiti, 1988). The leaves are born alternately on the stem in two ranks one at each node, each consisting of leaf sheath, leaf blade, ligule and auricles. The leaf blade is long, narrow 30-50 cm or more in lengths. The nodes bear a leaf and a bud, which may grow out to a tiller or shoot. Tillers or shoots grow out of the main culms in an alternating order. The number of productive tillers plays a pivotal role in crop production. The rice inflorescence is a loose terminal panicle 7.5 – 38 cm long. The flower is usually self pollinated and is surrounded by a lemna that makes up the husk. The most important panicles are the large and strong ones, since small and weak panicles always yield a lower percentage of ripened grains and cause comparative waste of energy on the part of the plant (Chatter Jee and Maiti, 1988)

The grain consists of the ripened ovary, the lemna, and palea. The embryo is fused with endosperm. There are two phases of growth in rice, the vegetative growth phase, which starts from germination to panicle initiation, the ripening phase, from flowering to full development of the grain (Kochlar, 1981). The reproductive stage begins with panicle initiation, the panicle initiation occurs at the growing tip of the tiller. Flowering typically begins one day after heading and continues down the panicle for approximately 7 days (Linares, 2002) until all florets on the panicle have opened. Anthesis begins with the opening of the florets followed by the stamen elongation (Vaughan, 1994). Rice varieties of the tropics complete their life cycle within a range from 110 to 210 days (Sikuku, 2007). The rapid elongation of internodes occurs after panicles initiation. The stage for harvesting rice is when the panicles have turned down and is yellowish in colour and the lower kernels are in the hard dough stage, premature harvesting tends to lower the yield and also affects the milling quality (Chatter Jee and Maiti, 1988). Once harvested the rice is commonly named paddy rice. It is the name given to the un-milled rice with its protective husks.

2.1.2 Ecology of rice

Rice evolved in humid tropics as a semi-aquatic plant. It has a unique nature to hot, humid environments (Tsunoda and Takahashi, 1984; Jose *et al.,* 2004). There are two general ecological types of rice, the lowland, or irrigated and the upland or none irrigated. The terms upland and lowland do not refer to land elevation or topography but to the use of irrigation water. Rice plant belongs to the group of plants referred to as the C_3 plants of the Calvin cycle because of the presence of photorespiration, high CO_2 compensation point, and luck of the bundle sheath (Chatter Jee and Maiti, 1988). Rice is grown in soils of pH ranges of 4.5 to 8.0. The soils most suited for the cultivation of rice crop are heavy neutral soils like clay, clay loam and loamy soils, such soils are capable of holding water for long and sustain water preventing excessive loss of water due to filtration (Chatter Jee and Maiti, 1988). Upland rice is cultivated mainly in regions, which receive an average annual rainfall of more than 1000 millimetres. If the rainfall is not sufficient, the deficit must be made up by supplementary irrigation.

In direct seeding in dry soil, seed rate varies from 60 to 80 kg per hectare at row spacing of 25 to 30 cm. the ideal depth of seeding is about 3 cm. the addition of nitrogen and phosphate fertilizers improves growth of the plant. Rice is the least drought tolerant of all the cereal crops and soil water availability is the main environmental factor limiting both distribution and yield. Rice cultivars differ according to their morphological and ecological characteristics. Rice is a semi-aquatic species (Tivy, 1990) but it can grow well in saturated soil because of its morphological adaptations of its shoot and root system. The plants respiratory system is adapted to lower oxygen concentration while the roots can affect oxidation in the rhizosphere both of which process help to compensate for the anaerobic conditions associated with soil saturation (Tivy, 1990).

2.1.3 Origin, classification and cultivation of rice

Rice is a member of the Poaceae family formerly the Gramineae; there are 12 genera within the *Oryzeae* tribe (Vaughan, 1994, Pal *et al.,* 1996). The genus *Oryza* contains approximately 22 species of which 20 are wild and two are cultivated, *Oryza sativa* and *Oryza glaberrima* are cultivated (Vaughan, 1994). *Oryza sativa* is the most widely cultivated, it is also known as the Asian rice, it is grown world wide as opposed to *Oryza glaberrima* (African rice), only grown in west African countries. Sativa are replacing glaberrima in many parts of Africa due to its high yielding nature (Linares, 2002). *O. sativa* was first cultivated in south East Asia, India and China between 8000 and 15000 years ago (Normile, 2004). 90% of all rice is grown and consumed in Asia. A large number of *Oryza sativa* cultivars have been developed through centuries of rice domestication. The international rice gene bank at the international Rice Research Institute (IRRI), Los Banos, in the Philippines holds approximately 85,000 different rice cultivars most of which are *Oryza sativa* cultivars. The various cultivars can be distinguished on the basis of many characteristics including the following; adaptation to different water regimes, growth habit and height, shapes, size and colour of the culm and panicle, drought tolerance and many more (Takahashi, 1984)

There are three ecological varieties of rice namely, Japonica, the Japanese rice but from the Indica line, Indica, tropical and subtropical distribution and Javanica, mainly grown in Indonesia. The classification is based on temperature, low temperature limits crop yield. Japonica cultivars are grown predominantly in temperate regions and germinate and grow under low temperatures (15 to 20^0 C) than the tropical and subtropical indica rice cultivars. Temperature below 18^0 C at night during pollen formation results in sterile pollen in all cultivars (Mc Donald, 1994). The New Rice for Africa (NERICA) is the product of interspecific hybridization between the cultivated rice species of African and the Asian type. *Oryza glaberrima* is well adapted to the African environment but prone to lodging and grain shattering. The Asian rice, *Oryza sativa* is of high yielding but poorly adapted to the stresses of African ecologies.

New Rice for Africa (NERICA) is a cross between Asian rice (*Oryza sativa*) and African rice (*Oryza glaberrima*). *Oryza glaberrima* had been cultivated for 3500 years. Thus, its local ancestry and numerous generations of selection *in situ* made *O. glaberrima* well adapted to the African environment (Kato *et al.,* 2008). It had profuse vegetative growth, which served to smother weeds, was resistant to drought, insect pests and diseases like African rice gall midge, rice yellow mottle virus and blast. However, it was relatively low yielding because it was prone to lodging and grain shattering (Hayashi *et al.,* 2006).

The N4, IRAT 109 and Lemont rice cultivars exhibit heterosis with the following traits; early vegetative growth giving rapid ground cover thus induce artificial ground cover (artificial mulch-canopy), followed by upright growth at vegetative and reproductive stage which enables the plant to support heavy seed heads through maturity to harvest and high absorption of photosynthetic active radiation (PAR), early maturity. NERICA'S typically mature in 90 – 100 days, which confers drought avoidance trait; high yielding (2.5 – 3.5 tons per hectare), contains more protein some varieties have as much as 10.5% protein compared to the sativa parents 8%, moisture deficit tolerant and disease resistant (Ouk *et al.*, 2007). The progeny has shown high potential to revolutionize rice farming even in Africa's stress afflicted ecologies. However, information on their performance in Kenya has not been documented (Atera *et al.,* 2011).

2.2 Drought phenomenon in rice production

The ability of rice to function well at reduced plant water potentials has not been demonstrated to be useful under field drought regimes (Capell *et al.,* 2004.Osmotic adjustment allows maintenance of growth when water uptake from the root system is insufficient due to reduced availability of soil moisture, but possibly, it also could increase extraction of water by the roots (Serraj and Sinclair, 2002). Genotypic variation in osmotic adjustment has been demonstrated in rice (Lilley *et al.,* 1996; Babu *et al.,* 2001). However, there has been no report demonstrating any positive phenotypic or genetic correlation between grain yield and osmotic adjustment in rice under stress (Selote and Khanna-Chopra, 2004; Liu *et al.*, 2006).

A deep root system with higher root density is likely to be useful under intermittent drought if growing conditions permit root development at depth. Under upland conditions, the association between root length density and the amount of water extracted has been well demonstrated (Lilley and Fukai, 1994), including for genotypic variations (Nemoto *et al.,* 1998; Kato *et al.,* 2007a), and deep and thick root traits contribute to better growth and higher yield under drought stress (Lafitte and Courtois, 2002; Babu *et al.,* 2003). In CT9993/IR62266 doubled haploid (DH) lines, three root traits measured in glasshouse experiments – root thickness, deep root weight, and root penetration index were correlated positively with yield and yield components under severe pre-flowering drought conditions in an upland field experiment (Babu *et al.,* 2003).

On the other hand, deep rooting is often poorly expressed under rainfed lowland conditions (Pantuwan *et al.*, 1997), and there is much less evidence of genotypic variation in root traits with regard to water extraction during drought (Kamoshita *et al.*, 2000, 2004). The extent of deep root development measured by partitioning ratio (deep root ratio) is less under anaerobic flooded conditions (ca. 0.3–1.2%) than under aerobic drought conditions (ca. 3–17%) in pot experiments (Azhiri-Sigari et al., 2000; Kamoshita *et al.*, 2004). Genotypic rankings for deep root traits expressed under anaerobic conditions were generally similar to those expressed under aerobic conditions, but in some cases genotype by environment interactions were detected (Champoux *et al.*, 1995; Azhiri-Sigari et al., 2000). Genotypic differences in the ability to penetrate compacted soil layers have been reported (Babu *et al.*, 2001; Samson *et al.*, 2002); these differences are associated with the amount of water extracted from below the compacted layer (Hoque and Kobata, 2000; Kobata *et al.*, 2000).

2.3 Lemont rice cultivar

Lemont (*Oryza sativa* L.), is an early maturing, semi dwarf, long-grain cultivar developed in United States Of America (USA). It was developed from a 1974 cross of Lebonnet and the first filial (F1) generation of the cross of C19881 and P 133158, the same cross from which Bellomont was developed. C19881 is a selection from the cross Bluebelle and Bellepatna, dawn from which Lebonnet was derived. P133158 is a selection from the back cross of Bluebelle and Taichung, native made at the International Rice Research Institute (IRRI), the Philippines McKenzie *et al.*, (1983).

Lemont posses a semi dwarf plant type and in all morphological characteristics most closely resemble Bellemont among current US cultivars. Grown under the same conditions, Lemont and Bellemont plant height averages 82 and 77 cm, respectively. Research and commercial yield results show that Lemont has excellent yield potential, Lemont highest yield in Texas research plots was 10,250 kg/ha at Genade in 1984. The comparative yields of Lemont tended to be greatest in tests where yields superiority of Lemont were expressed when grown under good management practices and climatic conditions Bollich *et al.*, (1984).

Empirical N rates studies and plant analyses show that Lemont requires 20 to 40 kg/ha, more than tall cultivars for maximum yields McKenzie (1984). Lemont has the ability to produce good ratton yields when seeded reasonably early McKenzie *et al.*, (1983), Lemont in commercial fields in Texas, averaged 1800 kg/ha with the highest reported yield 2300 kg/ha. The spikelet of

Lemont is straw coloured, smooth and awnless. At heading, the tip of the apiculus is purple, but the colour fades and is hardly distinguishable at maturity. The stigma is colourless, grains dimensions of Lemont are similar to those of Lebonnet, but are slightly shorter, wider, and thicker than Lebonnet. Average brown rice length and width measurements of Lemont is 7.60 and 2.28 mm, compared with 6.91 and 2.06 for labelle, 7.70 and 2.17 for Lebonnet, 7.02 and 2.09 for Starbonnet and 7.76 and 2.31 for Leah. Brown rice kernel weights are 21.5, 17.9, 22.4, 17.5 and 24.3 mg/kernel, respectively, for Lemont, Labelle, Lebonnet, starbonnet, and Leah Mckerzie *et al.,* 1983. Lemont is resistant to the same races of the blast fungus (*Pyricularia oryzae)* as are labelle and Lebonnet but is moderately susceptible to races 1B-49 and 1-17, to which Labelle and Lebonnet are susceptible. Lemont differs significantly from Bellemont in reaction to various races of the blast fungus and it is the respect that the two cultivars can be most readily distinguishable, Mckerzie *et al.,* 1983. Lemont is resistant to panicle blight, moderately resistant to brown spot, caused by *Bipolaris oryzae*, moderately susceptible to narrow brown leaf spot caused by *Cercaspora oryzae*, moderately resistant to the physiological straight-head disease, and very susceptible to sheath blight caused by *Rhizoctonia solani* Mckerzie *et al.,* 1983. Information on Lemont performance under water stress condition in a new era in rice production is limited (Bollich *et al.,* 1984).

2.4 Root systems development of rice under fluctuating soil moisture

The rice root system consists of different roots such as the seminal root, nodal roots, and lateral roots of various branching orders. These component roots differ in origin, age, morphological and physiological features, and thus respond developmentally to various soil conditions in different manners. Such varied responses among the component roots often results in altered root system structures, which subsequently regulate its function under a given condition. It is therefore important to understand this nature of the root system when its structures and consequent function are to be evaluated. Yamauchi *et al.,* (1996), pointed that phenotypic plasticity in the root system structures plays a key role in the stress tolerance of crop plants.

Approximately a half of the total area planted with rice worldwide is under rainfed conditions where the major production constraint is drought (Fukai *et al.*, 1998). Fukai and Cooper (1995) proposed that genotype variation in the root system is an avenue of improving rice drought tolerance whereby the water collecting ability of the plant could be enhanced. It is widely believed that the rice root system structure greatly differs among cultivars (Sharma *et al.*, 1994).

Several studies have examined the effect of soil water regimes on the gross morphology of the root systems. These studies established the fact that root system morphology is related with water uptake from the soil (Sharma *et al.*, 1994; Pantuwan *et al.*, 1995; Azhiri-Sigari *et al.*, 2000; Kamoshita *et al.*, 2000). However, research work is quite limited especially on the developmental aspects of the root system structure and its possible response to fluctuating soil moisture.

Examination of root characteristics such as root length density and root mass density may reveal how roots absorb water. On the other hand , the developmental analysis on dynamic aspects may provide some clues to the mechanism of how and why root system responds to changing soil water regimes; thereby helping to pinpoint further research groups. Ingram *et al.*, (1994), pointed out that involvement of roots in water uptake and drought tolerance in rice plants is not yet fully understood.

Rice growing areas consist of upland and lowland ecosystems in which the major difference between them lies in hydrology. In upland rice, the soils remain aerobic throughout. In rainfed lowland, ponded water is present for at least part of the season, so plants encounter anaerobic as well as aerobic conditions (Mackill *et al.,* 1996; Kamoshita *et al.,* 1999). This implies that a deep, vigorously branched and highly conductive root system is advantageous under upland conditions. As for the rainfed lowland, Ingram *et al.*, (1994), reported that a quick response to changing soil moisture is one of the important traits that confer drought tolerance. Pantuwan *et al.*, (1995), emphasised the importance of phenotypic plasticity for rice growth under rainfed lowland conditions.

2.5 Effects of drought on physiology and morphology of rice plant

Drought affects nearly all the plant growth processes; however, the stress response depends upon the intensity, rate, and duration of exposure and the developmental stage of the plant. Inhibition of leaf growth by water stress is considered response mechanism, which confers degree of tolerance and adaptive response to water deficit. Reduced leaf growth, limits leaf area and eventually plants rate of transpiration (Sikuku *et al.*, 2010 b). Low or reduced plant rate of transpiration is believed to be a survival mechanism for the plant, to prolong its life by extending the periods of availability of the essential water within the root zones (Payne *et al.*, 1990). The main problem in intensive agriculture is not the prolonging of survival period, but the minimum point of water deficit (non-lethal point).

Reduction in photosynthesis in water stressed leaves may be attributed to stomatal closure (Sharp *et al.*, 1990; Siopongco *et al.*, 2008). Higher stomatal conductance increases CO_2 diffusion into the leaves and favours higher photosynthetic rates, which in turn favours a higher biomass and higher crop yields. Evapotranspiration at the leaf surface lowers leaf temperature thus reduces stomatal conductance creating a cooling effect to the plant (Sikuku *et al.*, 2010).

2.6 Effects of water deficit on plant growth

Water stress has dramatic effects on plant growth and it is likely to be one of the major contributing environmental factors influencing plant productivity and species distribution (Wright, 1992). In many cases, as water deficit increases during drought, the limitations to plant growth is first exerted through a decrease in the growth rate of the assimilating surface (Cornic and Massacci, 1996). Leaf expansion during vegetative stage is very sensitive to water deficit. The level of stress at which leaf extension is affected is variable but in some cases, a fall of soil water potential to -0.7 MPa results in a complete inhibition of leaf elongation (Salisbury and Ross, 1992; Richardson and Mress, 1985; Berlin *et al.,* 1982). The extreme sensitivity seems to be that cell expansion is largely a physical process driven by hydrostatic pressure within the cells, which is the turgor pressure (Jones and Lazenby, 1988). The inhibition of cell expansion is usually followed closely by a reduction in cell wall synthesis (Salisbury and Ross, 1992).

It has also been observed that water deficit reduces the uptake of nutrients since most of the elements are absorbed through the roots by passive diffusion. Water deficit reduces the rate of dark respiration and translocation of assimilates and a times changes the pattern of partitioning of photosynthates at the expense of quality and quantity of economic yields (Boyer, 1985). The most familiar visible manifestation of water deficit is the drooping and sagging of the plant tissues, especially the leaves, referred to as wilting. Wilting is due to a change in elastic properties of all walls when turgor pressure declines below a certain critical value. Leaf rolling is also a well recognised response of water deficit in cereals; leaf rolling is common in rice plants (McKersie and Ya'acov. 1994). In sorghum (*Sorghum bicolor L.)* Leaf rolling occurs when the turgor potentials of leaves approach zero (Wright *et al.,* 1983).research has been carried out on the effects of water deficit on rice. However, information regarding the effect of drought on upland rice is limited (Kato *et al.,* 2009)

2.7 Effects of water deficit on stomatal conductance

Stomata are the major variables resistance controlling gaseous exchange between the cells of the leaf and the air and consequently they are important regulators of water loss from the plant (Jones and Lazenby, 1988). As leaf water potential declines during developments of water deficit stress there is usually a range over which there is no effect on the stomata, then below a threshold value the conductance declines (Jones and Lazenby, 1988).any mechanism that regulates stomatal closure also has a profound effect on the rate of transpiration, gaseous exchange and leaf air temperature difference to diffusion of CO_2 into the leaf, much of the reduction in the rate of CO_2 assimilation per unit leaf area during water deficit is due to stomata impeding the inward passage of CO_2, (Jones *et al.*,1993). During decreasing water potential, the rate of CO_2 assimilation generally decreases in virtually the same proportion as the rate of transpiration ((Jones *et al.*, 1993). Water deficit has been found to decrease stomatal conductance in most crops (Sionit and Kramer, 1983). In cotton, the stomata of adapted plants become less sensitive to low water potentials thereby giving higher stomatal conductance at low water potentials (Ackerson, 1981).

2.8 Root systems under drought

Root system is a direct interface for water movement between soil and plant. While the progress in understanding root dynamics and its functions has lagged behind because it has been coined as, "hidden half", current advances in evaluation, techniques, and genome techniques have shown that crops have the large genotypic variations in root systems.

The ability of plants to change themselves for adapting to the surrounding environments is termed as "phenotypic plasticity" by O'Toole and Bland, (1987), the one of root system as "root plasticity". Kono *et al.*, (1987), classified the various roots into two types, based on their morphological response to soil water conditions; constitutive roots and elastic roots. The latter is a part of root that is responsive to surrounding water regimes, and represents the performance of root plasticity. Previous studies reported that the root plasticity play essential role on functionally optimizing the acquisition of nutrient and water resources and a key adaptive traits for drought environment (Tailor and Yamauchi, 1996; Banoc *et al.*, 2000).

Since breeding drought-resistant upland variety started from 1970's, root depth has been targeted as a primary root characteristic (Kamoshita *et al.*, 2000, 2002). Deep rooting habit helps the plants to absorb the unused water from the deep soil layer and to maintain the plant water status when water is depleted in surface soil (Yoshida and Hasegawa, 1982; Kato *et al.*, 2009). However, the deep rooting performance is reported from a small scale (Kondo *et al.*, 2000). It has been reported that shallow soil depth restricted the full performance of deep root traits (Ram *et al.*, 2002). Soil compaction is also another physical factor to limit the deep rooting habit (Iijima *et al.*, 1991). In addition to environment factors, nutrient management is also important factors for expression of root habits (Haefele *et al.*, 2004). The ideotype of rooting habits, therefore, must be determined not only by phenotyping but also by diagnosis of environments and managements (Morita *et al.*, 1995).

The first green revolution was mainly based on the above ground plant biomass; success was attributed to the development of semi-dwarf rice and wheat plants with improved productivity. It is projected that, the second green revolution would be attributed to below ground plant biomass (Ramalingam *et al.*, 2003). Scientific work has been done on various genotypic characteristics by exploring the roots phenology, morphology and growth by using wax as the growth media, the physiological aspects, the genetic diversity of the root systems, their morphological traits or traits linked to water extraction patterns, activity at depth and root pulling force (O'Toole and Bland, 1987). Differences have also been observed for root plasticity in response to water stress, with some varieties able to adjust their root growth to maintain water supply (O'Toole and Bland, 1987).

This failure may be attributed to the failure to consider the various three components of genotype (G), Environmental factors (E) and the management practices (M) and their various interactions in the field. Thus, the main aim of this study was to explore these variables and their interactive effects on the roots, for it is the main connection point between the above plant biomass and the soil. In this study, the genotypic traits (G), environmental effects (E) and the management practices (M), on selected upland rice varieties was assessed, with known root architecture, to investigate their interactive effects on yield improvement. The progress in crop improvements depends on identification of combinations of genotypes (G) and management practices (M) from among in numerable possible combinations. The main parameters for the investigation are on the roots plasticity, soil compaction effect and fertilizer application as a management practice. Much has been done under controlled environment, but little has been done in the actual fields. Therefore, it is unclear to what extent G×E interaction effects on root morphologies (Kondo *et al.*, 2000).

This study investigated the root growth as affected by drought and performance of selected upland rice varieties grown under different soil characteristics. This approach was intended to add value to the conventional field testing by examining potential combinations of traits and management systems in a range of production environments, which included but ecological zones, soil, soil characteristics, and seasonal variations among others. This research will contributes to the measures of breeding values through genotype, management and environmental factors and their various interactions.

2.9 Phosphorus acquisition by rice plant

Phosphorus (P) deficiency is common in agricultural soils mainly because of its precipitation with Ca and its adsorption on $CaCO_3$ in calcareous soils with high pH (Rahmatullah *et al.*, 1994) and its precipitation and adsorption with Fe and Al oxides in soils with low pH (Vance *et al.*, 2003). More than 80% of soils in Kenya are deficient in available P (contains< 10 $mgKg^{-1}$ Olsen –P (Memon, 2005). The phosphorus balance of Kenyan soils is negative (5-10 $Kgha^{-1}$) (Ahmed & Rashid, 2003). High pH and calcareousness is the major reason for low P availability in Kenyan soils as a major portion of total P exists as calcium phosphates of varying solubility (Rahmatullah *et al.*, 1994).

Application of phosphatic fertilizer is the common strategy to ameliorate its deficiency. This option is not very much feasible because of low use efficiency of applied P, huge rise in its prices, environmental concerns and fear of depletion of non –renewable rock phosphate reserves mined for production of P fertilizers (Vance *et al.,* 2003). Raw phosphate rock contains almost no soluble P and plants generally cannot uptake insoluble P. A number of plants have adopted strategies to solubilise P in rooting medium. Nonetheless, cultivars differ in one or more strategies; hence show differential P acquisition from sparingly soluble or insoluble P sources (Gill *et al.*, 2002; Kosar *et al.*, 2002; Gahoonia & Nielsen, 2004; Aziz *et al.*, 2006; Aziz *et al.*, 2010). Exploitation of these genetic differences in field crops can greatly improve the fertilizer use and sustain agricultural productivity (Aziz *et al.*, 2005).

2.10 Nitrogen availability for plant use and soil pH

One of the key reserve plant nutrients is nitrogen (N). Plants can take up N in the ammonium (NH_4^+) or nitrate ($N0_3^-$) form. At pH's near neutral (pH 7), the microbial conversion of NH_4^+ to nitrate (nitrification) is rapid, and crops generally take up nitrate. In acid soils (pH < 6), nitrification is slow, and plants with the ability to take up NH_4^+ may have an advantage. Soil pH also plays an important role in volatization losses. Ammonium in the soil solution exists in equilibrium with ammonia gas (NH_3). The equilibrium is strongly pH dependent. The difference between NH_3 and $NH_4{}^+$ is an H^+. For example, if $NH_4{}^+$ were applied to a soil at pH 7, the equilibrium condition would be 99% $NH_4{}^+$ and 1% NH_3. At pH 8, approximately 10% would exist as NH_3.

This means that a fertilizer like urea, NPK (46-0-0) is generally subject to higher losses at higher pH. However, it does not mean that losses at pH 7 will be 1% or less. The equilibrium is dynamic. As soon as a molecule of NH_3 escapes the soil, a molecule of $NH_4{}^+$ converts to NH_3 to maintain the equilibrium. Other factors such as soil moisture, temperature, texture, and cation exchange capacity can affect volatilization. The important point to remember is that under conditions of low soil moisture or poor incorporation, volatilization loss can be considerable even at pH values as low as 5.5, the study site is as illustrated in figure 2.1.

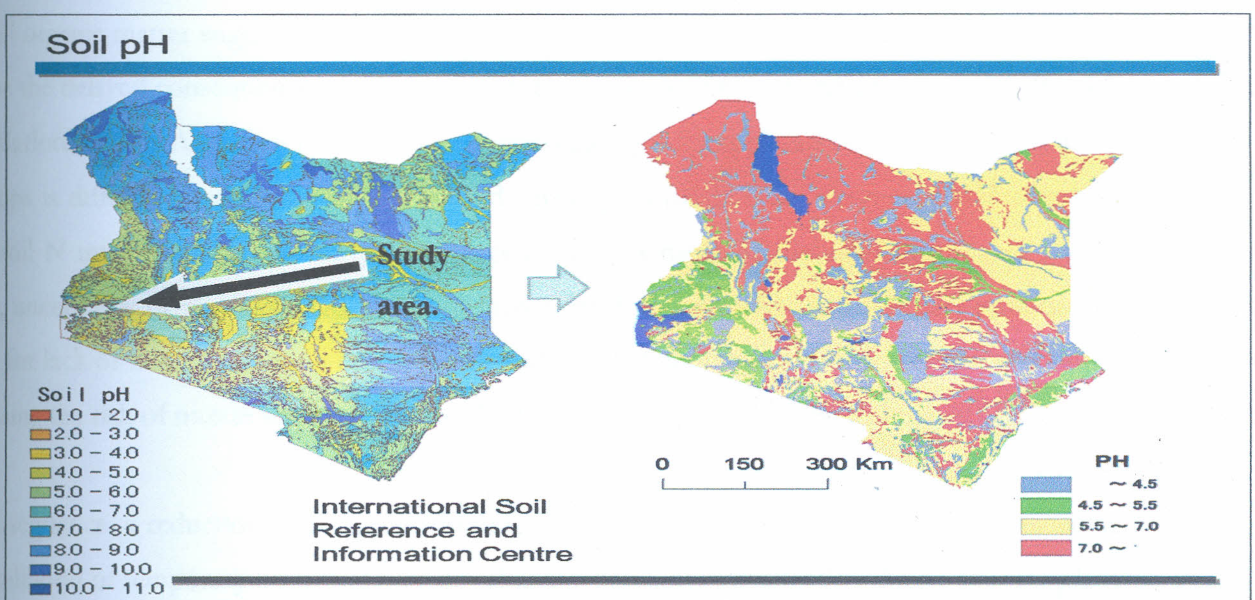


Figure 2.1. Soil pH levels in Kenya.

2.11 Crop responses to nitrogen deficiency and avenues to improve nitrogen use

Over the last 40 years, the worldwide use of mineral N fertilizers increased sevenfold in parallel with the doubling of agricultural food production. The use of N fertilizers in agriculture is therefore one of the key elements for producing sufficient food to meet the demand of increasing human population (Angus, 2001; Eickhout *et al.*, 2006). Nevertheless, production of N fertilizers through the Haber-Bosch process is extremely consuming in fossil energy with large mission of greenhouse gases. Moreover, the use of the large amount of N in intensive gricultural systems has led to important environmental impacts such as the eutrophication of resh water (London, 2005), and marine ecosystems (Beman *et al.*, 2005), and gaseous emission f N oxides and ammonium into the atmosphere (Ramos, 1996; Stulen *et al.*, 1998), through itrogen cascades (Galloway and Cowling, 2002). Problems associated with climate changes, biofuel production, and global food security also question the efficiency of use of N fertilizer in agricultural systems (Cassman, 2007).

For many years, a relatively high grain-to-fertilizer price ratio, particularly in subsidised agricultural systems incited farmers to apply excess N to allow for high yield and profit. This assurance strategy led in a progressive increase in soil N accumulation and an elevated risk of N leaching (Addiscott *et al.*, 1991). This effect, combined with the long residence time of N within the soil organic matter suggests that the pollution of ground water that we observe today could well be the delayed consequence of the intensification of cropping systems one or more decades ago (Marlotti, 1997). Adoption of a more restricted strategy for supply and timing of N fertilizers on crops is difficult because we have a limited capacity to predict the weather that determines both soil N mineralization and crop growth potential. In most of the agricultural area of the world, uncertainty of rainfall is an important factor for decisions related to fertilizer application, either for lack of rainfall reducing crop growth and soil N mineralization or for excess of rainfall increasing the risk of nitrate leaching (Sadras, 2002; Sadra and Roget, 2004; Cabrea *et al.*, 2007).

In consequence, a reduction in N application rates to avoid excess of N in soils would increase the likelihood of temporary crop N deficiency that is when soil N availability does not meet plant N demand. Management (M) techniques and breeding approaches (G) to improve N use efficiency are required under both conditions that favour over-fertilization, for example subsidised economies, intrinsically high fertility, high grain-to-nitrogen price, and systems where shortage of nitrogen is chronic for example semi-arid and arid regions in poorer countries. Therefore, understanding the processes that govern crop N uptake and distribution implants is of major importance for optimizing crop production with the use of minimum N input to reduce environmental hazards (Casman *et al.*, 2002).

For most crops, the plant life cycle can be simplified into two phases; the preanthesis phase, when the plant develops its leaf area and root systems. The young developing leaves and roots behave as sinks. The reproductive phase, after anthesis, the senescing leaves are sources of carbohydrates and reduced N for developing storage organs such as seeds, fruits or tubers. Therefore, we need a better understanding of the control of N uptake and N portioning within the plant during these two distinct phases. It is necessary to evaluate the dynamics of plant and crop N demand in relation to growth potential during the crop cycle, and in a second stage, it is necessary to analyse the physiological and morphological responses of the plant to N deficiency. A better understanding of the regular mechanisms controlling these responses to N deficiency at both plant and crop levels should allow the identification of plant physiological and morphological traits which can be used to improve the deficiency in the use of nitrogen through both breeding and crop management (Good *et al.*, 2004).

Crop N demand at any time of the crop cycle can be identified as the result of maximum crop mass and the critical plant N concentration. The critical plant N concentration is defined as the minimum plant N concentration corresponding to maximum crop mass (Greenwood *et al.*, 1990). Thus, crop N demand corresponds to critical N uptake which is the minimum crop N uptake necessary to achieve maximum crop mass. The concept of critical N can be applied in dynamic terms, such that the daily crop N demand (or critical N uptake rate) is the quantity of N required each day for the crop to maintain its potential growth rate over a given period. This dynamic approach of crop N demand has been used extensively on perennial forage crops such as alfalfa and grasses (Kirk and Bajita, 1995) and further extended to annual crops such as wheat (Justes *et al.*, 1994), maize (Plenet and Lemaire, 1999) and canola (Colnenne *et al.*, 1998). All these studies bring convergent results that have been assembled within consistent theory (Greenwood *et al.*, 1990).

Water stress is common among of most rainfed crop-growing environment, where the potential for crop response to in season tactical management of nitrogen heavily depend on unpredictable rainfall. Under rainfed conditions, matching nitrogen supply and water availability are key to the success of wheat crops. Shortage of nitrogen can impair yield and reduce water use, whereas excess nitrogen, particularly early in the season, can reduce grain through the production of excessive biomass and the haying-off of the crop under terminal drought (Van Oosterom *et al.*, 2001). Therefore, the development of spatial indices that are able to identify areas in the field of potentially positive response to management intervention such as topdressing of nitrogen fertilizer becomes paramount.

2.12 Effects of water deficit on plant yield

Water deficit is an important factor limiting crop yields. It is reported that the world-wide losses in yield from water deficit is significantly higher than the losses attributed to other factors combined. (Berlin *et al.,* 1982; Forbes and Watson, 1994). Yield differences occurs from complex interaction between the environment (E), management (M), genetics (G) and other abiotic stresses that occurs across a field (Bouman and Toung,2001). Rice crop is highly susceptible to water stress that causes large yield losses in many countries (Bouman and Toung, 2001). The demand for moisture at key periods of growth shows rice vulnerability to water stress (Wade *et al.,* 2000). The effect of water stress depends on the stage of the crop growth, deficiency level, and environmental changes during the period of water stress. Mild water stress during specific physiological stages can significantly reduce corn yields by 10 to 25% and four days of visible wilting between the boot stage (only a week prior to tasseling) and the milk stage may reduce yields by 50% or more (Claassen and Shaw, 1970).

Water deficit after rice panicle initiation reduces the potential spikelet number whereas water deficit during anthesis increases unfilled spikelets (Wade *et al.,* 2000).spikelets sterility decreases with decrease in leaf water potential during meiotic stage of pollen development. Water deficit during the period of grain filling affects the translocation of assimilates to the grain which in turn affects the grain weights and increases empty grains (Pantuwan *et al.,* 2002 b). Water deficit at seedling development has no significant effect on the yield, but it hardens the plant making it more droughts tolerant. In maize the critical silking and pollen, shedding stages are greatly affected by water deficit, water deficit during flowering delays silking hence late harvest and reduced yield (Salisbury and Ross, 1992; McKersie and Ya'acov, 1994). Best yields are obtained if soil moisture is adequate when plants transits from vegetative to reproductive stages (Wade *et al.,* 2000).

2.13 Water deficit and plant response.

Water deficit evoke responses in plants, which are based on the development of physiological drought making soil water unavailable to the plant (Shalhevet and Hsiao, 1986). Plants vary widely in their response to water deficit. Such plant responses are manifested with respect to their wide variability for example for being either tolerant or sensitive (Joene *et al.,* 1993). The consequences of water deficit to the plants are both morphological and physiological. Water deficit if unrelieved may develop into permanent wilting, dehydration and death (Fitter and Hay, 1987). Drought tolerant varieties have been identified within several agronomic crops such as wheat, barley, and cotton. A common factor to drought tolerant genotypes within those species appears to be the ability to maintain leaf turgor at low water potential (Richard *et al.,* 1987). Any mechanism enhancing survival in drought conditions tend to decrease the potential dry matter productivity for example photosynthesis would be decreased by stomatal closure (Tenhunen *et al.,* 1985).

According to Kramer (1980), plants are understood to survive in water deficit areas through the following mechanisms; drought escape, which involves early maturity and development of elasticity; drought tolerance with high tissue potential, reduction of water loss through epidermal resistance, reduction in absorbed radiation and reduction in evaporative surface;. Drought tolerance is also enhanced through uptake of water due to increased rooting and low resistance to water flow. The last mechanism is through drought tolerance with low tissue water potential.

Water deficit can be damaging when it coincides with critical stages of crop development, for example, an extensive wheat crop may be sown and germinated to seedling stage by early rains, however, lack of subsequent rains soon enough after germination may cause severe wilting of the seedling and if persistent induces death (Mckersie and Ya'acov, 1984). Water deficit also affects the reproductive development with a period of water deficit being required to stimulate floral initiation in some species. In other cases, severe water deficit can cause emergence of ready differentiated floral buds (Tenhunen *et al.,* 1985) and drought during developmental stages prior to kernel filling cause has wizened undeveloped seeds. Likewise, premature drop of orchard fruit may be caused by untimely drought (Mckersie and Ya'acov, 1994). In wheat for example, mild water stress can advance flowering by up to a week though with corresponding decrease in the number of spikelets and in pollen fertility and grain set (Levitt, 1980). Periods of drought stress in maize even when irrigated are part of virtually every plants existence, the critical silking, and pollen shedding (anthesis) stages being especially vulnerable. Silk delay is the interval between days to pollen shed and days to silk; ideally, maize should silk simultaneously. A delay in silking is deleterious and indicates poor adaptation to drought stress (Mckersie and Ya'acov, 1994).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The study was carried out at the University Botanic Garden in the field and in the special plastic tubes. Various physiological, shoot and root morphological and yield parameters were determined to establish if there was a difference in growth and physiological response of selected upland rice genotypes to water deficit, nitrogen and phosphorus fertilizers application and soil types

3.2 Field experiment

3.2.1 Study site characteristics.

The study was done at Maseno University, within the University Botanical garden, Maseno, Kisumu County, western part of Kenya. The area receives a mean annual precipitation of 1750 mm with a bimodal distribution. The mean temperature at Maseno is 28.7 °C and it is approximately 1500 m above the sea level. Maseno lies at latitude 0°1'N-0'12'S and longitude 34 ° 25'E-47'E. The soils at Maseno are acrisol being well-drained, deep reddish brown clay with pH range of 4.6 – 5.4 (Mwai, 2001).

3.2.2 Treatment and design

The experiment was carried out during the short drought season of September 2010 to January 2011. The seeds of IRAT 109 and Lemont were planted in 2 m x 2 m plots. The experimental design was split-split plot design as shown in plate 1, with four different fertilizer application and two water watering regimes. The treatments were;

(a) Fertilizer application levels

- Nitrogen fertilized plot – N, at a rate of 60 Kg/ha of Urea
- Phosphorus fertilized plot – P at a rate of 45 Kg/ha of TSP
- Nitrogen-phosphorus fertilized plot – NP at a rate of 60 Kg/ha of urea and 45 Kg/ha TSP

- No fertilizer application – Control

(b) Water application regimes

- Watered plots – W
- Non watered plots – D

The experiment was based on rainfall precipitation and irrigation among the wet plots (W), while the non-watered plots were completely sheltered from rainfall as shown in plate 1. 20 litres of water were used for irrigating each plot among the wet plots and twice the amount, 40 litres was used to irrigate the dry plots when their leaf roll score was above three. The seeds were soaked a day prior to planting and the spacing was 20 cm x 20 cm. Four seeds were sown per hill with the two selected upland cultivars, IRAT 109 and Lemont. The plots were hand tilled before planting with two seeds of upland rice cultivars, a path of 0.5 m was left between the two plots with similar treatment to prevent contamination due to overflow or underground seapage.1 m path was left between the wet plots, the dry plots, and the replicates. The plots were kept weed free by hand, pulling the weeds, this was to maintain the soil structure for compaction was a measurement to be determined. Soil moisture measurements were determined by the use of soil profile probe, were fixed in the plots as shown in the experimental layout figure 3.1 and in plate 3.1

DRAINAGE.								
REP 1	LEM P fert. Wet.	IRAT 109 N.fert. Wet.	LEM Cont. Wet.	IRAT 109 NP.fert Wet.	LEM N.fert Dry.	IRAT 109 P.fert Dry.	LEM NP.fert Dry.	IRAT 109 Cont Dry.
	IRAT 109 P.fert. Wet.	LEM N.fert. Wet.	IRAT 109 Cont. Wet.	LEM NP.fert Wet.	IRAT 109 N.fert Dry.	LEM P.fert Dry.	IRAT 109 NP.fert Dry.	LEM Cont. Dry.
DRAINAGE.								
REP 2	LEM N.fert Dry.	IRAT 109 NP.fer t Dry.	LEM Cont. D	IRAT 109 P.fert Dry.	LEM NP.fert Wet.	IRAT 109 P.fert Wet.	LEM Cont. Wet.	IRAT 109 N.fert Wet.
	IRAT 109 N.fert Dry.	LEM NP.fer t Dry.	IRAT 109 Cont. Dry.	LEM P.fert Dry.	IRAT 109 NP.fert Wet.	LEM P.fert Wet.	IRAT 109 Cont. Wet.	LEM N.fert Wet.
DRAINAGE.								
REP 3	LEM NP.fert Wet.	IRAT 109 Cont Wet.	LEM P.fert Wet.	IRAT 109 N.fert Wet.	LEM N.fert Dry.	IRAT 109 P.fert Dry.	LEM NP.fert Dry.	IRAT 109 Cont. Dry.
	IRAT 109 NP.fert Wet.	LEM Co Wet.	IRAT 109 P.fert Wet.	LEM N.fert Wet.	IRAT 109 N.fert Dry.	LEM P.fert Dry.	IRAT 109 NP.fert Dry.	LEM Cont. Dry.
DRAINAGE.								

Figure 3. 1 Field plot layout

<u>VARIETIES</u>

IRAT 109
LEM- Lemont

-pF tubes

-SM profile probe

<u>**TREATMENTS.**</u>

Fertilizer (4 levels); P- phosphate applied plots; N-Nitrates applied plots; NP- both phosphate & nitrates applied plots; Cont. - not fertilized plots.
Water (2 levels); Wet- well watered plots; Dry- not watered plots

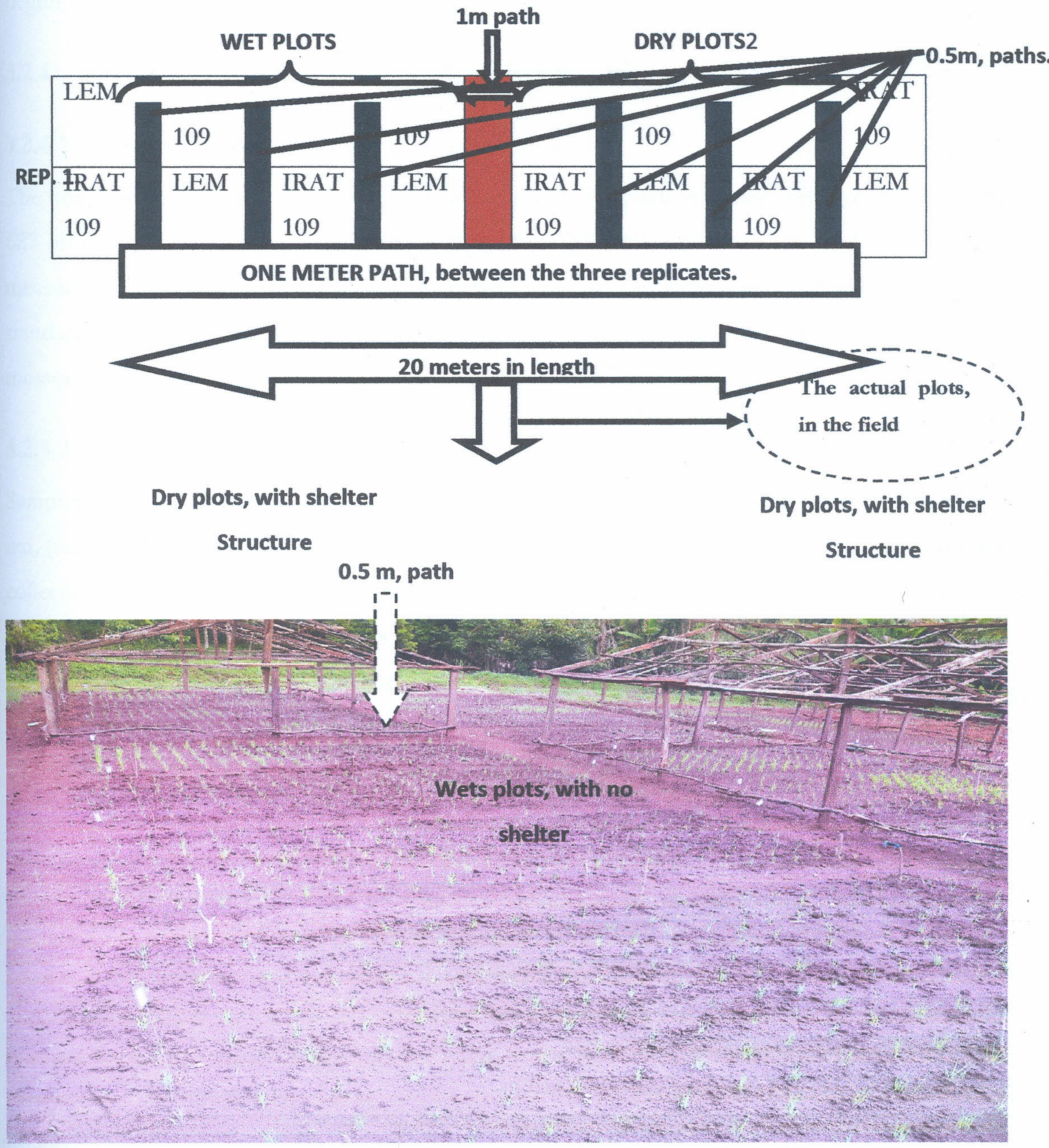


Plate 3. 1 The field experiment (Experiment 1), showing the split plot design

3.2.3 Soil moisture determination

Rainfall, air temperature, relative humidity, and dew points were monitored daily in nearby weather station, located exactly 100 m from my experimental plots. The soil water content was determined by the soil moisture Profile Probe, (Model-PR 2/6). The PR 2 measured at 6 depths down to 100 cm. The soil moisture, measurement, was taken, at the following soil depths 10 cm, 20 cm, 30 cm, 40 cm, 60 cm and finally at 100 cm, from the soil surface. , the measurement begun 21 DAS and was done in the morning hours, 0900 -1000 hours, at an interval of 2 days.

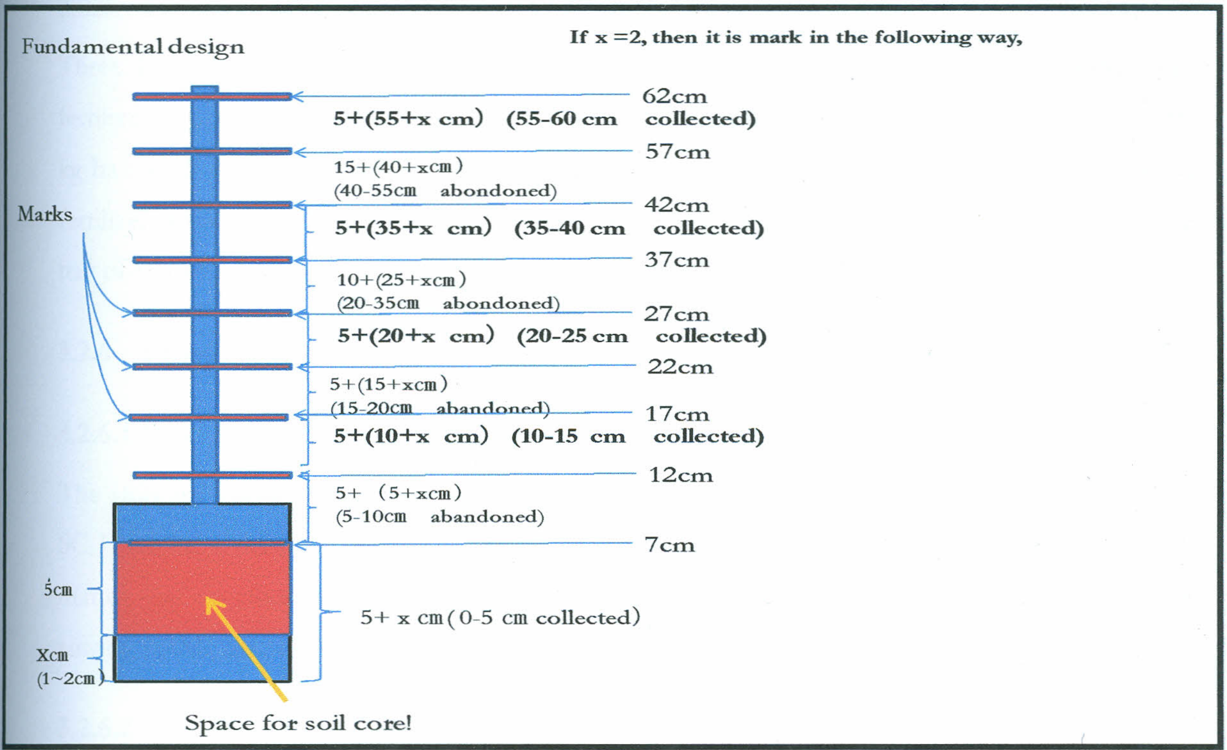
3.2.4 Soil measurements and nutrient load determination

3.2.4.1 Soil compaction

The soil compaction was determined by using a soil compaction meter, (Spectrum -6101-SN 627-MFG code.1002) with a measuring range of 0-6000 PSI, and accuracy of ± 30 PSI. The measurements depths marked at every 3 inches up to 24 inches and designed to ASAE standards. The compaction measurements was done a long side the soil moisture content measurements.

3.2.4.2 Soil nutrient load

Samples of soil from different depths were extracted by using a soil auger, from depths of 0-5 cm, (the top most soil), 10 to 15 cm, 20 to25 cm, 35 to 40 cm and 55 to 60 cm. The soil samples collection was purely based on the homogeneity of the soil across the soil profile pit, rice rooting depths are within the sampled depths. A profile pit dug was 1 m deep, and by the use of a meter rule, demarcation was made from the top surface to the lower end of the pit. The various soil samples were then collected by the use of the soil auger, as described in figure 3.2. The soil laboratory analysis was done at the Kenya Plant Health Inspectorate Services (KEPHIS). The selected sites, were the experimental plots, which was being used by the Nagoya and Maseno university joint rice research project.



3.2.4.3 Soil moisture treatments

Plants were subjected to two soil moisture treatments. Well watered and drought re-watered conditions. Water treatment commenced at 42 DAS, after, the plants had been exposed to the same conditions; received equal amount of rainfall and watered in case of dry spell to ensure proper establishment of the rice plants in the plots. In the dry blocks a shelter consisting of a clear polythene sheets was constructed, as shown in appendix 15, to enclose the plants at night and any time, rain was foreseeable until the plants showed drought symptom, (leaf roll score of 3-5) and measured soil water potential of – 30 kPa at 20 cm depth, this as per the standard irrigation scheme of aerobic rice fields (Peng *et al.,* 2006).A leaf roll score of 3-5 was evidenced by a deep V-shaped leaves orientation. This as per the scale given by Gregorio and Cabuslay (2005), whose description of the leaf roll score runs from 0-9, whereby, 0= healthy leaf, 1= mild stress, with a shallow V shape, 3=moderate stress, the leave exhibit deep V, 5=stressed plant, the leaves shows fully capped leaves, 7=heavily stressed, the leaf margin are tightly held in U shape and 9= the plant is beyond recovery point, the leaves are tightly rolled. Watering of the wet plots was done up to 84th DAS.

3.2.5 Fertilizer treatment

Three fertilizer treatments involved nitrate, phosphate, nitrate-phosphate and a control (no fertilizer). The source of nitrate was urea, with 46% N content, which was applied at a rate of 60 kg ha^{-1} in all the Nitrate fertilized plots. Phosphate source was Triple Supper Phosphate (TSP) fertilizer, applied at the rate of 45 kg ha^{-1}, the N-P was at the rate of 60 kg ha^{-1} of urea and 45 kg ha^{-1} of Phosphate. Fertilizer treatments were done at 42 DAS and 56 DAS.

3.2.6 Physiological measurements

3.2.6.1 Stomatal conductance

The stomatal conductance's (Cs) were quantified by using a portable leaf porometer, (Model – SC-1, sensor serial number-LPS 0004). The measurements was done on the third fully expanded mature leaf on cloud free days between 0930-1130 hours local time at 46, 67 and 88 days after sowing (DAS) and on six randomly selected plants per plot per treatment.

3.2.6.2 N content determination

The foliar chlorophyll content, were measured by using SPAD Konica Minolta SPAD-502, as shown in appendix 14. Chlorophyll meter, SN 79613012, using the principles of closure method, the measurement was done, on the third fully and mature leaf, six leaves were randomly selected per plot, the chlorophyll measurements, was done during the day, from 1030-1230 hours, at interval of 21 days from, 46 DAS till the harvesting period.

3.2.6.3 Plant tissue analysis

The plants leaves were harvested at panicle initiation, dried at 40°C for tissue analysis, (macronutrients analysis), young and fully developed leaves were harvested, twenty within a plot in six hills. The analysis was done at the KEPHIS laboratory, the harvested leaves were dried and then crushed, using a blender, Wonder Blender , a minimum of 200 grams of the crashed plant tissue were subjected to macronutrient analysis, by the atomic absorption spectroscopy (AAS). The result obtained was then compared to the reference sufficiency ranges at panicle initiation, the reference sufficiency table 1 as provided by agronomic division, department of Agriculture and consumer services, 2000. (*http://www.ncagr.gov/agronomi/saaesd/rice.html*.)

Table 3. 1 Reference sufficiency ranges of field crop (Rice)

Reference sufficiency ranges field crop (Rice)					
Panicle initiation					
Plant nutrients					
N	P	K	Ca	Mg	S
3.0-3.4%	0.18-0.29%	1.5-2.7%	0.19-0.39%	0.15-0.39%	0.15+%
IMPORTANT RATIOS					
For adequate N and S, the ratio should be <10, with N<1.6% and S>0.15%					

Adopted from *http://www.ncagr.gov/agronomi/saaesd/rice.html*

3.2.7 Morphological parameters and biomass

3.2.7.1 Plant height

Shoot height was determined on six hills per treatment and per replication at 46, 67, 88, 109, and 130 DAS. Measurements were made using a metre rule from the shoot base to shoot apex in plants.

3.2.7.2 Plant biomass

3.2.7.2.1 Shoot biomass

The shoot biomass was obtained from two plants hills per plot per treatment, the two hills were obtained from the marked six hills, which were being used to obtain the plant height, tiller number, stomatal conductance and the Nitrogen status by the nitrogen meter (SPAD-values). The largest and the smallest hills were selected, then each was harvested separately, and clearly labelled, the shoot biomass was then dried in the oven at a temperature of 80°C for four days until a constant mass was achieved. Each was weighed by using Analytical-weighing balance (FX 300i WP). The weights obtained were used to determine the shoot –root ratios.

3.2.7.2.2 Root biomass

Of the harvested shoots, their roots were removed at different depths, from 0-10 cm, 10-20 cm and 20-40 cm, per hill, as illustrated in appendix 13. Each extracted root was put in a well labelled polythene bag, having the plot number, plant number, and the extraction depth. Once extraction was done, each root samples were washed separately, dried and latter preserved with a 75% ethanol and a methyl blue used as an indicator. The roots were scanned using Scanner (Epson -2200, with optical resolution of 1600DPI x 3200DPI). The scanned roots were put in paper bags, and then dried at 80°C for four days until a constant weight was achieved, then their weights were determined by using Analytical-weighing balance (FX 300i WP). The dry weights determined were used to determine root to shoot ratio and the different weights per depths gave a root density per depth and penetration behaviour of the roots of selected rice cultivars

3.2.8 Yield and yield components

3.2.8.1 Tiller number

Tiller number for all the varieties and the treatments was determined by observing, counting, and recording all emerging shoots in the hills from the time of planting to the flowering stage.

3.2.8.2 Panicle lengths

This was determined using a metre rule. Measurements were done from the panicle base to the tip of six plants per treatment and per replication.

3.2.8.3 Grain yield

The grain yield was determined at harvesting from an area of 1 m^2 in the field. The number of grains per 5g, and filled grains per panicle were determined. The yield was extrapolated in kilograms per hectare.

3.2.9 Statistical analysis of data

Analysis of variance (ANOVA) was carried out on the various data for the variables measured during the study period to test for differences between the treatments and the varieties and their level of interaction by using a statistical computer package (Costat). The initial analysis, to test for the interaction of all the three factors under investigation, fertilizer, water and the variety interaction, the various data both for morphological and physiological was analysed as a split-split plot design analysis, replicates were the block, water was the main plot factor, fertilizer was the sub plot factor and variety was the sub subplot factor. The means were separated by LSD at 5% level of significance. In isolation on the two cultivars response to either water and or fertilizer, the various data involved was analysed as a split plot design, and not as split-split plot design as for the three factors interaction, separation of means was also through LSD, at 5% level of significance. In determining, the performance of the two rice cultivars, under the dry and wet condition, similarly, the dry blocks were completely sheltered off from rain, and could only occasionally receive little and known quantity of water periodically, the application too, was uniform across all the dry blocks, thus, the rice response to these two conditions, the data was analysed as 1 way randomized blocks. The treatment and variety means were separated using the least significant differences (LSD) test at 5% level. Correlation analysis was done, to synchronize the association of the various factors, as either contributors or non-significance in the performance of the various rice cultivars within the study, yield, and biomass accumulation, among other factors.

3.3 PVC-tube experiment

3.3.1 PVC tubes experimental site and site conditions

The study was conducted in the experimental field plots, just adjacent to the field experimental plots, within the University Botanical garden. The weather pattern and conditions were similar to the field experimental plots.

3.3.2 Experimental designs and cultural practices

Plastic being a poor conductor of heat, the challenge was to solve the excessive loss of water from the soil, as a result of direct heating from the sun on to the surface of the plastic pipes, the heating could result into an artificial condition, and thus exposing the rice plants to more stress than the imposed ones. For the success and high level of accuracy in the data obtained, various modifications were done. In dealing with the direct heat from the sun, trenches were dung, 2 meters wide, 6 meters lengthwise, and 1 meter deep, this created a depression like basin, as shown in figure 3.3 and 3.4

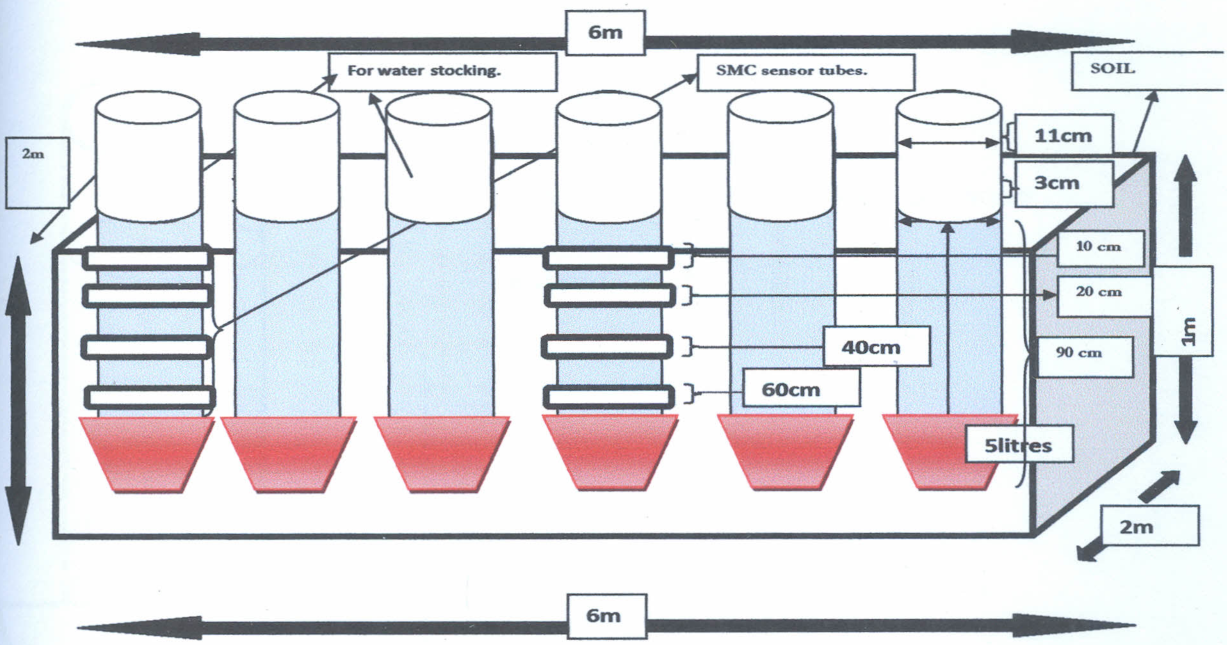


Figure 3. 4 An illustration of the set up and layout of the PVC tubes experiment, to prevent excessive water loss through evaporation.

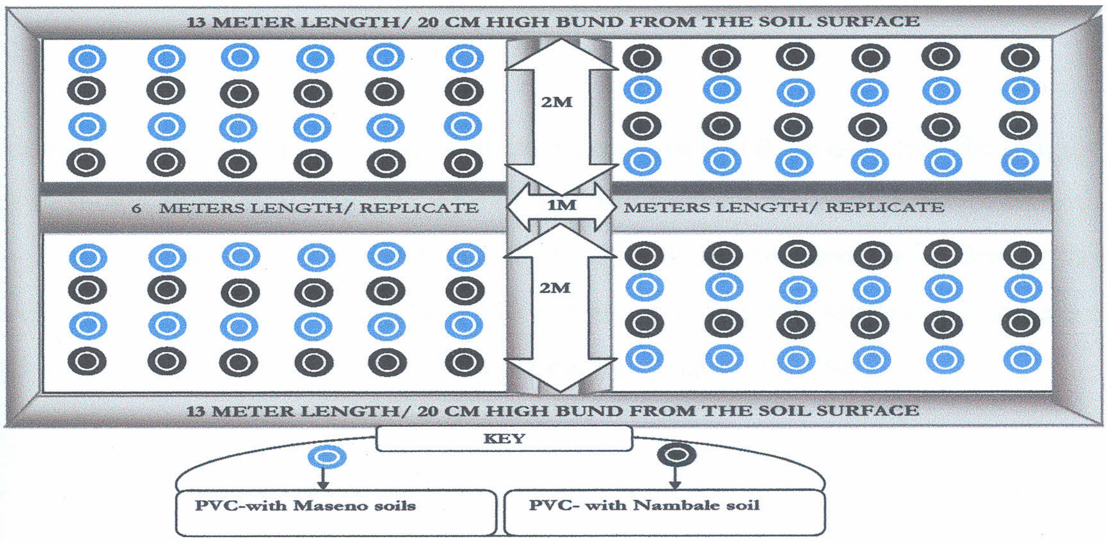
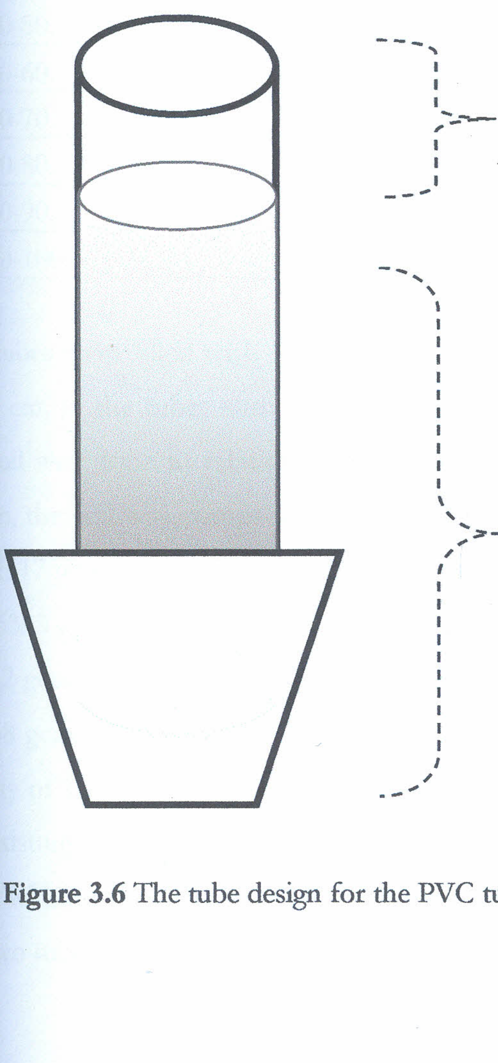


Figure 3. 5 PVC tubes arrangement within the experimental site

Plants, in their natural environment obtain water through various sources, through; precipitation and sub surface water movements. In simulating the water movements within the soil, latent movement was completely cut off, but underground movement was ensured by the existence of water in the five-litre bucket at the base of the tubes, as shown in figure 3.6.



$$\frac{22}{7} X \frac{11}{2} X \frac{11}{2} X3$$

$$= 285.21 \quad Cm^3 \approx 0.285 \quad litres \quad of \quad water \quad watered \quad daily$$

The region occupied by soil (soil

Figure 3.6 The tube design for the PVC tubes experiment, with area for water stocking

The bulk density of Maseno soil was determined from depths of 0-100 cm deep into the soil; the results are as shown in table 3.2. In this type of soil, the level of compaction increases with increase in depth from depth of 0-10 cm up to a depth of 20-30 cm, but highest bulk density was realised at depths of 10-20 cm, which had the bulk density of 1.7958; this implies that, there is a temporary hard pan that impedes the roots from penetrating deep into the soil.

Table 3. 2 Bulk density (BD), of soil in Maseno

Soil depth (Cm)	**The core volume (cm^3)**	**Wgt of container (g)**	**Wet wgt (the soil+container) (g)**	**Dry wgt (soil+container) (g)**	**wgt of water (g)**	**wgt of dry soil (g)**	**Bulk Density (g/cm^3)**
0-10.	73.9	5.37	112.12	99.30	12.82	93.93	1.27
10-20.	73.6	5.10	158.50	137.27	21.23	132.17	1.80
20-30.	73.7	5.22	156.57	131.76	24.81	126.55	1.72
30-40.	73.6	5.08	128.59	107.47	21.11	102.39	1.39
40-50.	73.9	4.93	135.72	113.28	22.44	108.35	1.47
50-60.	73.6	4.91	141.93	117.76	24.17	112.85	1.53
60-70.	73.9	7.02	138.06	114.79	23.26	107.77	1.46
70-80.	73.9	6.66	106.66	88.81	17.84	82.15	1.11
80-90.	73.6	6.12	128.26	105.83	22.43	99.70	1.35
90-100.	72.3	6.56	113.85	93.79	20.06	87.23	1.21

The tubes were filled with different soils, (Nambale and Maseno soil), from the base to a height of 90 cm, in the tubes with Maseno soil (soil obtained within Maseno university), the filling of the soil was done in relation to the various bulk density, as shown in table 1, from 80-90 cm region, the soil was compacted to a bulk density of 1.3547 gcm^{-3} ; 70-80 cm, with a bulk density of 1.1117 gcm^{-3} ; 60 -70 cm, with a bulk density of 1.4583 gcm^{-3} ; 50 – 60 cm, with a bulk density of 1.5333 gcm^{-3} ; 40-50 cm, of bulk density of 1.4661 gcm^{-3} ; 30-40 cm, with a bulk density of 1.3912 gcm^{-3}; 20-30 cm with a bulk density of 1.7170 gcm^{-3}; 10-20 cm, with a bulk density of 1.7958 gcm^{-3} and finally the upper most region of 0-10 cm depth was compacted with a bulk density of 1.2710 gcm^{-3}. The regions along the tubes had different amount of soil depending on the existing bulk density, in the tubes with soil moisture access tubes different significantly with tubes without the soil moisture access tubes, a summary of the soil contained per region between the two tubes are shown in table 2

Filling of the PVC tubes were done to simulate the reality in the field, care and measurements were keenly monitored, and all the layers were filled in with exact amount of soil required, to aid in the filling of the soil, specific soil moisture was maintained, and the amount of water used per given depth, were derived from the weight of water during the bulk density determination

The soil profile within the PVC is as illustrated in the figure 3.6, the level of compaction greatly differs with increase in the soil depth, and this is much evident by the soil bulk density across the soil profile, as shown in table 1, 2 and 3, just giving similar measurements.

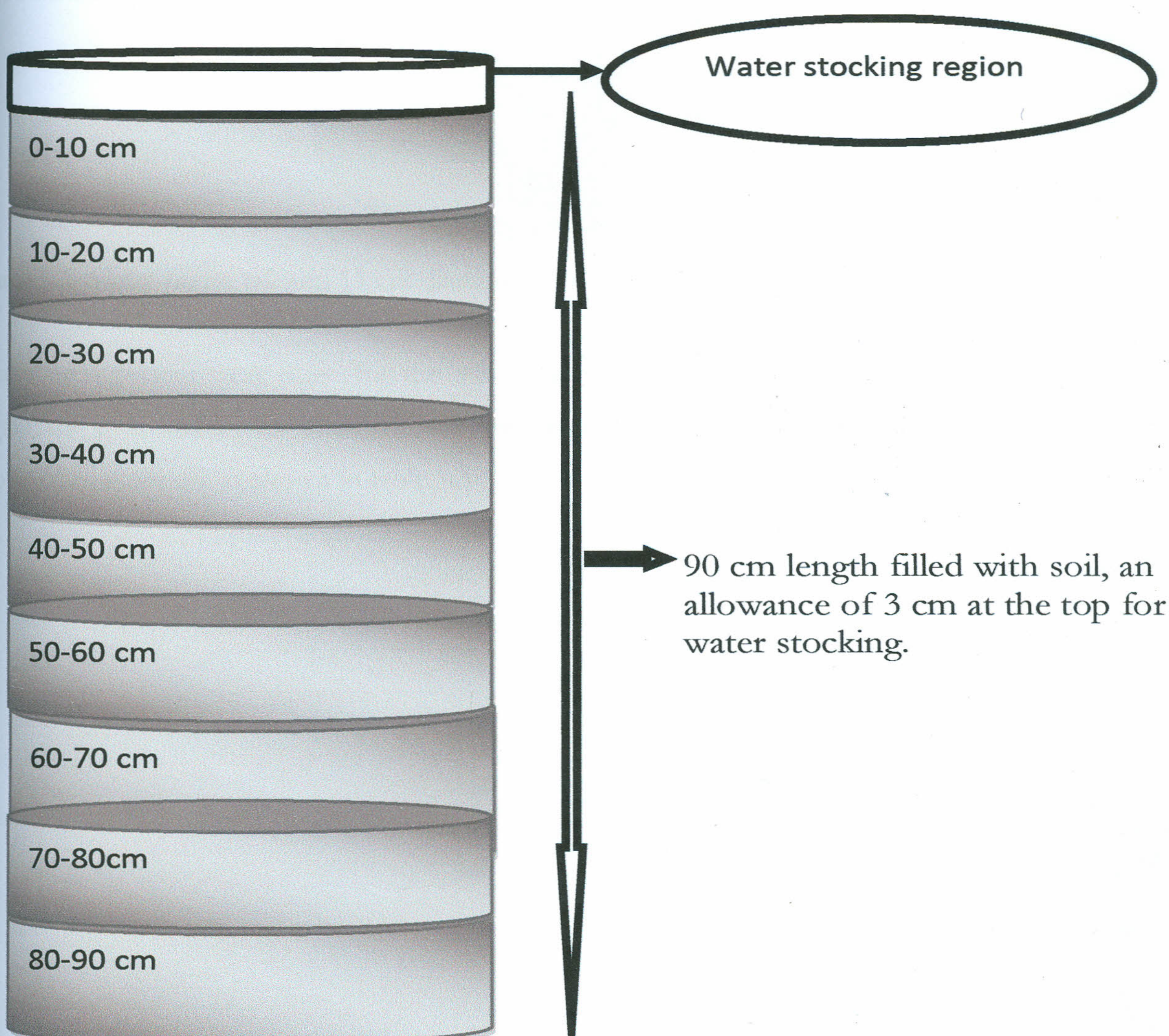


Figure 3. 6 A one meter tall with 11 cm diameter PVC tube, filled with Maseno and Nambale soils, Bulk density of the two soils used

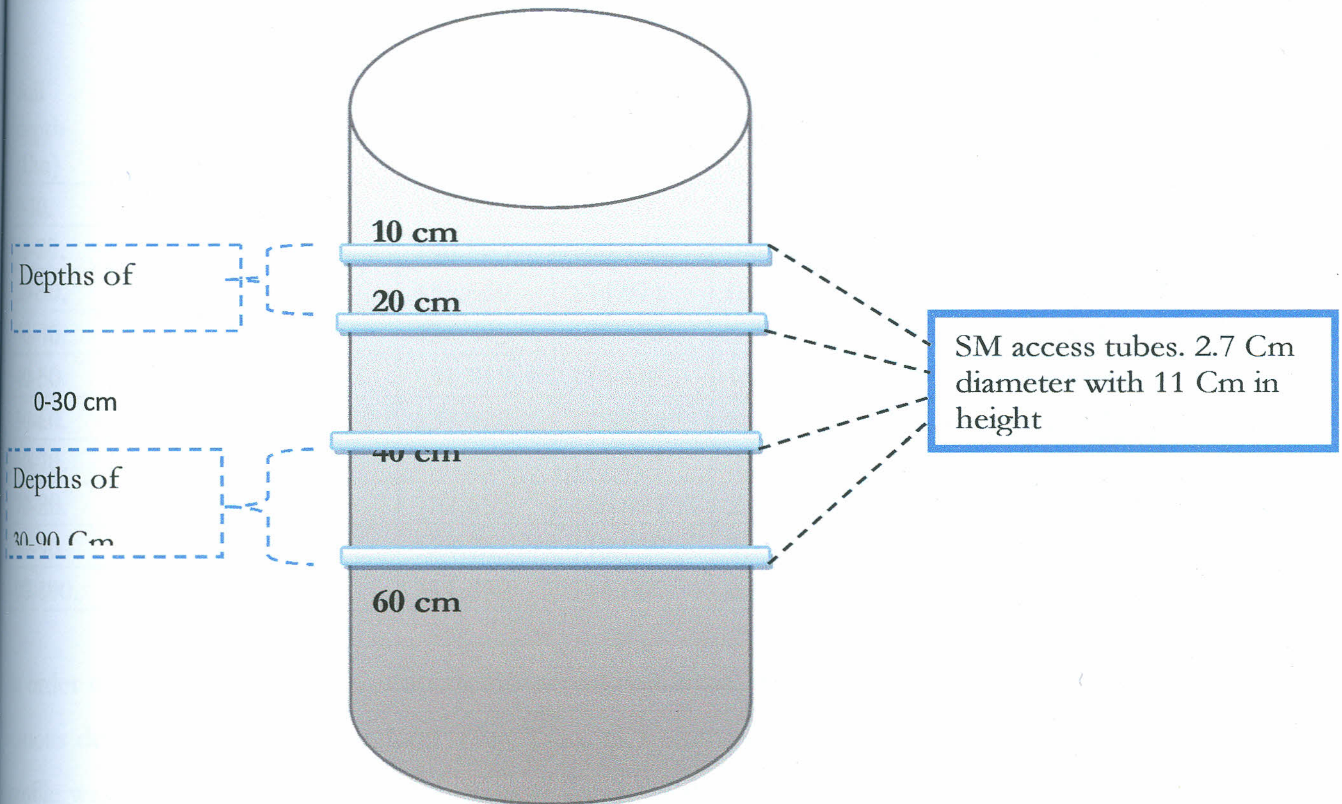


Figure 3. 7 A one-meter tall and 11 cm diameter PVC tube fitted with the soil moisture access tubes.

Similar arrangement were done for the soil obtained from the experimental plot in Nambale region, the bulk density for Nambale soil was determined from 0 – 90 cm depth into the soil profile, the results are as shown in table 3.3

Table 3. 3 Bulk densities (BD), of soil obtained from Nambale

Soil depth (Cm)	core volume (cm^3)	Wgt of container (g)	Wet wgt (the soil+container) (g)	Dry wgt (soil+container) (g)	wgt of water (g)	wgt of dry soil (g)	Bulk Density (g/cm^3)
0-10.	73.9	5.370	115.119	114.509	0.610	109.139	1.477
10-20.	73.6	5.104	140.503	140.482	0.021	135.378	1.839
20-30.	73.7	5.215	135.569	134.971	0.598	129.756	1.761
30-40.	73.6	5.081	124.585	120.684	3.901	115.603	1.571
40-50.	73.9	4.930	131.718	116.488	15.230	111.558	1.510
50-60.	73.6	4.912	137.929	120.974	16.955	116.062	1.577
60-70.	73.9	7.024	120.055	118.001	2.054	110.977	1.502
70-80.	73.9	6.659	122.655	120.021	2.634	113.362	1.534
80-90.	73.6	6.126	124.263	119.039	5.224	112.913	1.534
90-100.	72.3	6.561	111.852	111.001	0.851	104.440	1.445

In order to compact the soil to simulate the actual condition, the soil moisture condition per the various depths had to be maintained, thus, the total volume of water per depths across the soil profile was determined and the volumes were mixed with the soil before being compacted into the PVC tube.

The experimental design adopted for this experiment was Randomized Completely Blocked Design (RCBD). The treatments involved in this experiment were two levels of water treatment, two levels of fertilizer and two soil types. The varieties and the treatments were replicated four times as shown in figure 9. Germination of the three rice varieties was uniform. All the agronomic practices were similar to the field experiment, though weeding was mainly through hand pulling of the weeds, top dressing done 14 DAS; fertilizer application rate was at 80 kg ha^{-1} of N, in nitrogen fertilized tubes and a combination of 80 kg ha^{-1} of N plus 60 kg ha^{-1} of P. The experimental layout is as shown in figure 3.8

Rep 1	Rep 2	Rep 3	Rep 4
Sm,VI,F(N),W	Sm,VI,F(N),W	Sm,VI,F(N),W	Sm,VI,F(N),W
Sn,VN4,F(N),W	Sn,VN4,F(N),W	Sn,VN4,F(N),W	Sn,VN4,F(N),W
Sm,VL,NF(P),W	Sm,VL,NF(P),W	Sm,VL,NF(P),W	Sm,VL,NF(P),W
Sn,VI,F(N),W	Sn,VI,F(N),W	Sn,VI,F(N),W	Sn,VI,F(N),W
Sm,VN4,F(NP),W	Sm,VN4,F(NP),W	Sm,VN4,F(NP),W	Sm,VN4,F(NP),W
Sn,VL,F(NP),W	Sn,VL,F(NP),W	Sn,VL,F(NP),W	Sn,VL,F(NP),W
Sn,VL,F(N),D	Sn,VL,F(N),D	Sn,VL,F(N),D	Sn,VL,F(N),D
Sm,VI,F(NP),D	Sm,VI,F(NP),D	Sm,VI,F(NP),D	Sm,VI,F(NP),D
Sn,VN4,F(N),D	Sn,VN4,F(N),D	Sn,VN4,F(N),D	Sn,VN4,F(N),D
Sm,VL,F(NP),D	Sm,VL,F(NP),D	Sm,VL,F(NP),D	Sm,VL,F(NP),D
Sn,VI,F(NP),D	Sn,VI,F(NP),D	Sn,VI,F(NP),D	Sn,VI,F(NP),D
Sm,VN4,F(N),D	Sm,VN4,F(N),D	Sm,VN4,F(N),D	Sm,VN4,F(N),D
Sm,VI,F(NP),W	Sm,VI,F(NP),W	Sm,VI,F(NP),W	Sm,VI,F(NP),W
Sn,VN4,F(NP),W	Sn,VN4,F(NP),W	Sn,VN4,F(NP),W	Sn,VN4,F(NP),W
Sm,VL,F(NP),W	Sm,VL,F(NP),W	Sm,VL,F(NP),W	Sm,VL,F(NP),W
Sn,VI,F(NP),W	Sn,VI,F(NP),W	Sn,VI,F(NP),W	Sn,VI,F(NP),W
Sm,VN4,F(N),W	Sm,VN4,F(N),W	Sm,VN4,F(N),W	Sm,VN4,F(N),W
Sn,VL,F(N),W	Sn,VL,F(N),W	Sn,VL,F(N),W	Sn,VL,F(N),W
Sn,VL,F(NP),D	Sn,VL,F(NP),D	Sn,VL,F(NP),D	Sn,VL,F(NP),D
Sm,VI,F(N),D	Sm,VI,F(N),D	Sm,VI,F(N),D	Sm,VI,F(N),D
Sn,VN4,F(NP),D	Sn,VN4,F(NP),D	Sn,VN4,F(NP),D	Sn,VN4,F(NP),D
Sm,VL,F(N),D	Sm,VL,F(N),D	Sm,VL,F(N),D	Sm,VL,F(N),D
Sn,VI,F(N),D	Sn,VI,F(N),D	Sn,VI,F(N),D	Sn,VI,F(N),D
Sm,VN4,F(NP),D	Sm,VN4,F(NP),D	Sm,VN4,F(NP),D	Sm,VN4,F(NP),D

Figure 3. 8 Tubes experiment plot layout, showing the two rice cultivars grown, fertilizer-water

VARIETIES

VL-variety Lemont
VI-variety IRAT 109
VN4-variety NERICA

TREATMENT
Sm-soil Maseno
Sn-soil Nambale
F (N)-fertilizer nitrate
F(NP)-fertilizer-nitrate-phosphate
D- Not watered
W-watered.

REPLICATION

R1-replication 1
R2-replication 2
R3-replication 3
R4-replication 4

3.3.3 Meteorological and the hydrological condition

The soil water content was determined by the soil moisture Profile Probe, (Model-PR 2/6) as described in the field experiment.

Plate 3. 2 Weather bucket and its remote controlled data

Plate 3. 3 ET gauge, for measuring reference evapo-transpiration (ET_o).

3.3.4 Soil characteristics

The soil compaction was determined by using a soil compaction meter, (Spectrum -6101-SN 627-MFG code.1002) as described in the field experiment.

3.3.5 Soil moisture treatments

The soil moisture within the tube was measured by using an electric profile probe device (PR 2/6) as in experiment 1., though with little modification, the soil moisture content was determined at 10 cm, 20 cm 40 cm and 60 cm depth, at depths of 40-60 is the maximum region of the rooting zone of rice plant. The moisture measurements, was ensured by cutting the soil moisture access tubes into small pieces of measurement, 11.0 cm in length. These access tubes were inserted latently at every depths in which Soil moisture (SM), was to be determined, the insertion of these tubes was done, during the time of filling the PVC tubes with different soils., the contact point between the access tubes and the PVC tubes was made water tight by sealing it permanently with silicon sealant, an adhesive which ensured strong adhesion between the access tubes and the PVC-tube, as shown in figure 3.9

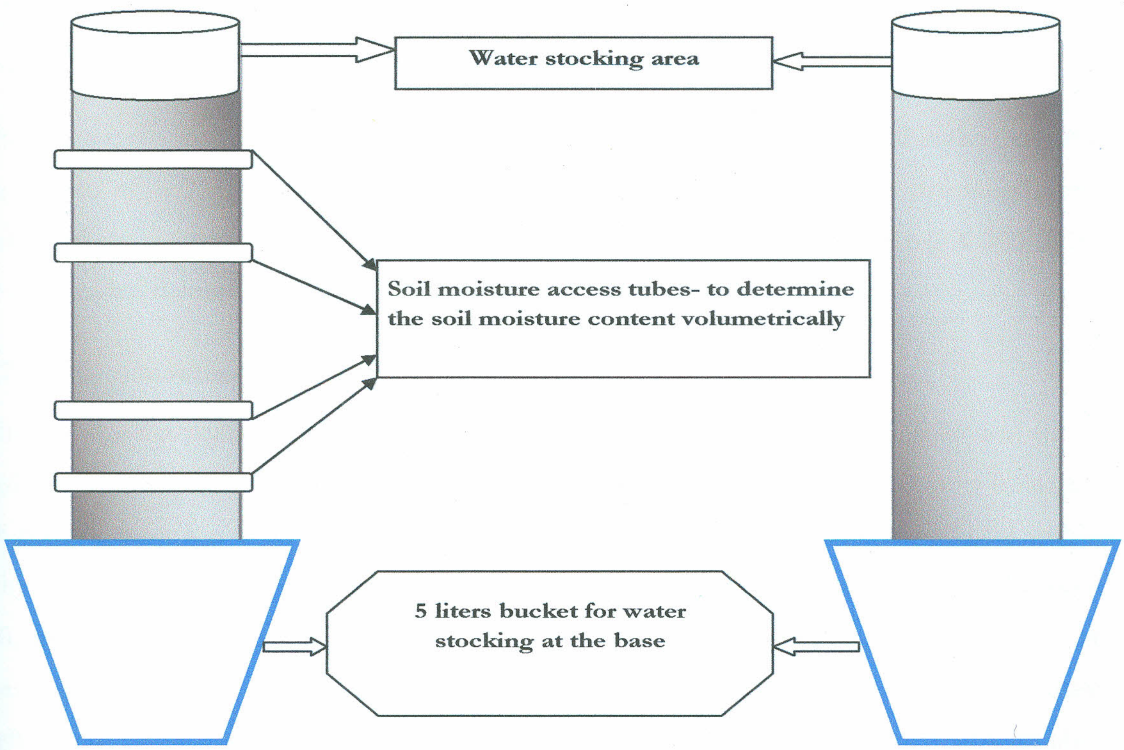


Figure 3. 9 PVC-tubes, with moisture access tubes, inserted.

3.3.6 Fertilizer treatment

Two fertilizer application was done, unlike in the field experiment, Urea, N source, TSP, phosphate source. The fertilizer was applied to the tubes at the rates of 80 $kgha^{-1}$ of N + 60 $kgha^{-1}$ of P, to the N-P fertilized tubes. The N source was urea (with 46% N), and the P source was Triple Super Phosphate (with 46% P) .These fertilizers was applied at 21 DAS and 42 DAS., the application was done by making a ring around the base of the rice hill, and covering with little soil, just like in the filled experiment.

3.3.7 Morphological parameters and biomass

3.3.7.1 Plant height

Shoot height was determined on a hill per tube per treatment and per replication at 21 up to 130 days after sowing. Measurements were made using a metre rule from the shoot base to shoot apex in plants.

3.3.7.2 Plant biomass

3.3.7.2.1 Shoot biomass

At harvesting, the entire plant biomass was harvested; the shoots were then dried in the oven at a temperature of 80°C for four days until a constant mass is achieved. The dry weight was determined my measuring the shoot biomass by using analytical weighing balance (FX 300i WP). The dry weights determined were used to determine root to shoot ratio.

3.3.7.2.2 Root biomass

At harvesting, the pipes were cut horizontally, soil column then removed carefully and cut at lengths of 10 cm, put in polythene bugs and labelled. Eight pieces of soils with roots obtained, each root samples was washed separately, dried and latter preserved with a 75% ethanol with a methyl blue indicator. Upon preservation, all the roots were scanned using Scanner (Epson - 2200, with optical resolution of 1600DPI x 3200DPI), after which, the scanned roots were put in paper bags, then dried at 80°C for four days till a constant weight was achieved, then their weights were determined by using Analytical weighing balance (Fx 300i WP). The dry weights determined were used to determine root to shoot ratio and the different weights per depths gave a root density per depth and penetration behaviour of the roots of selected rice cultivars.

3.3.8 Statistical analysis of data

Statistical analysis, Analysis of variance (ANOVA) was carried out on the data for the variables measured during the study period to test for differences between the treatments and the varieties and their level of interaction by using a Costat statistical computer package. The treatment and variety means was separated using the least significant differences (LSD) test at 5% level. Further analysis was done using the same statistical analysis, but done as split plot design to show the interaction effect of the fertilizer and water treatment on the selected upland rice cultivars used (IRAT 109 , NERICA 4 and Lemont)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Field experiment

4.1.1. Soil measurements

4.1.1.1 Soil compaction

Soil compaction in wet plots was significantly low as compared to dry plots. In the depth of 10 Inches, significantly higher compaction was recorded towards the end of the month of November and early December. Compaction increased with depth in all the plots among the treatments as shown in figure 4.1

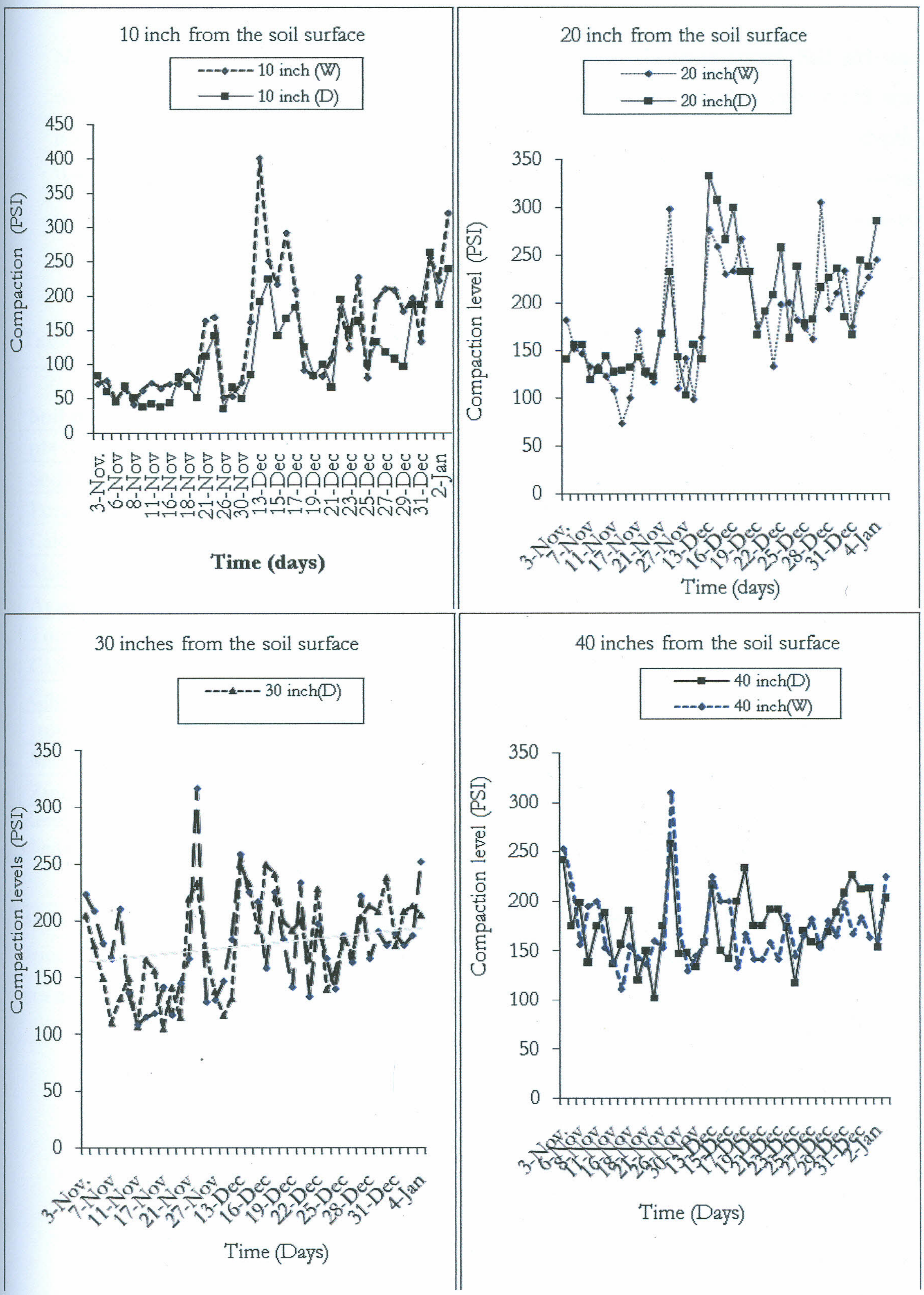


Figure 4. 1 Soil compaction levels in both wet (W) and dry (D) plots from depths of 10 inch to 40 inch.

4.1.1.2 Soil nutrient load

Nutrient load in the field plots varied among the nutrient elements tested. Soil pH was relatively stable in all depths showing minimal differences, though the highest pH was noticed at the depth of 10 to 15 Cm. Sodium levels decreased with increase in soil depth. Potassium, calcium, magnesium, phosphorus and nitrogen, showed fluctuating levels, highest in concentration at depths of 0 to 25 Cm, then reduced with increase in depth as summarised in table 4.1

Table 4. 1 Soil fertility test for the field plots.

	Soil depths				
Soil nutrients	**0-10 cm**	**10-15 cm**	**20-25 cm**	**35-40 cm**	**55-60 cm**
pH (H2O) 1:2.5	4.49	4.81	4.36	4.4	4.5
Sodium (Na)	33.91	20.91	25.91	25.91	26.91
Potassium (K)	0.15	0.21	0.23	0.19	0.39
Calcium (Ca)	126.68	83.42	108.93	6.53	7.14
Magnesium (Mg)	126.68	83.42	108.93	107.54	105.66
Available Phosphorus (P)	37.33	25.56	27.78	40.33	29.44
Total Nitrogen	0.22	0.16	0.12	0.09	0.12
Carbon (C)	1.28	1.15	0.91	0.7	0.67
Copper (Cu	5.61	5.16	4.66	4.4	4.13
Iron (Fe)	89	58.15	54.21	57.52	56.35
Manganese (Mn)	7.43	3.78	4.86	4.5	4.2
Zinc (Zn)	8.64	9.12	7.59	9.46	7.72

Results as obtained from the Kenya Plant Health Inspectorate service (KEPHIS)-analytical chemistry laboratory-ref (KEPHIS/KTL/ACL/170/78.

The pH level of the soil in Maseno, and more so within the botanic garden, it is acidic, with a pH value range of 4.36 - 4.81, this acidity levels implies that, some nutrients will be fixed and thus not available for the plant utilization, illustrated both in figure 4.2 and in table 4.1

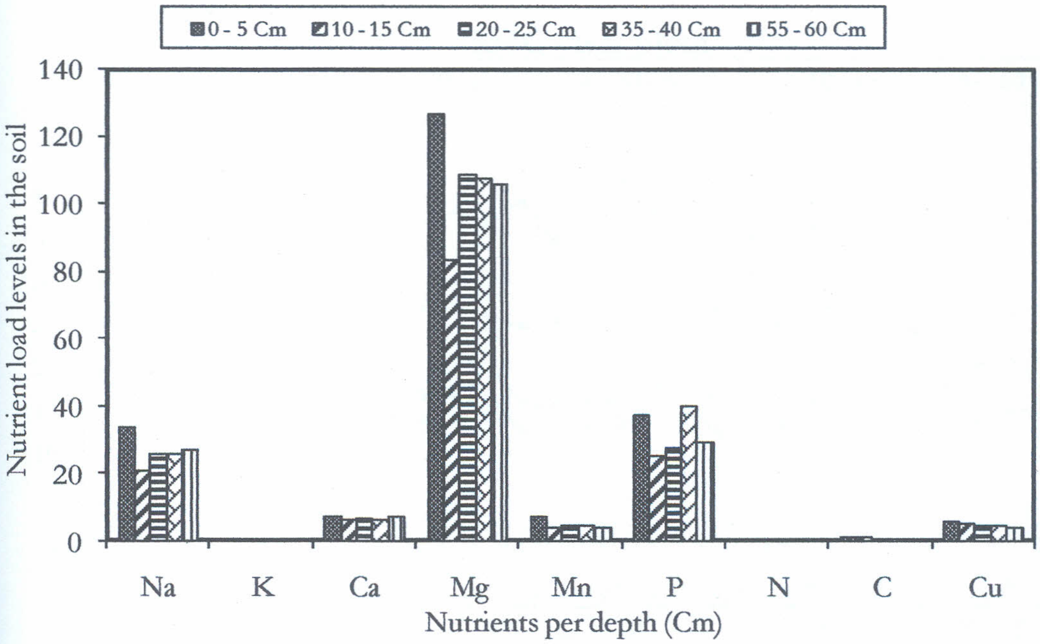


Figure 4. 2 Nutrient loads in the soil obtained from Maseno experimental field.

4.1.1.3. Soil moisture content

The soil moisture content within the wet plots showed the highest percentages at depths of 40 and 60 cm. The lowest soil moisture content was registered in depths of 10 and 20 cm. In the dry plots, the highest soil moisture was recorded in the months of October to November, at depths of 30, 40 and 60 cm, which later showed a sharp decline as from the months of November till the end of the experimental period. The lowest soil moisture content was recorded at depths of 10 cm, of only 20% of moisture content.

There was a significant effect ($P \leq 0.05$) in moisture content among the plots (Figure 4.3 and 4.4). In this study, water was withheld in every subplot of each replication, totally covered with a clear polythene sheet hence the low moisture content. When water is withheld leads to drought stress. This result is in agreement with the results obtained by Sikuku, 2010), and results obtained by Siddique *et al.,* (2000) on wheat plant. Drought stress results into low soil moisture content. Loss of soil moisture from the soil can be associated to either transpiration by the leaves, water uptake by plants and drainage more so in field conditions (Luvaha, 2005). Low soil moisture content in the dry plots, at depths of 10 and 20 cm, could be attributed to drainage or absorption by the plants.

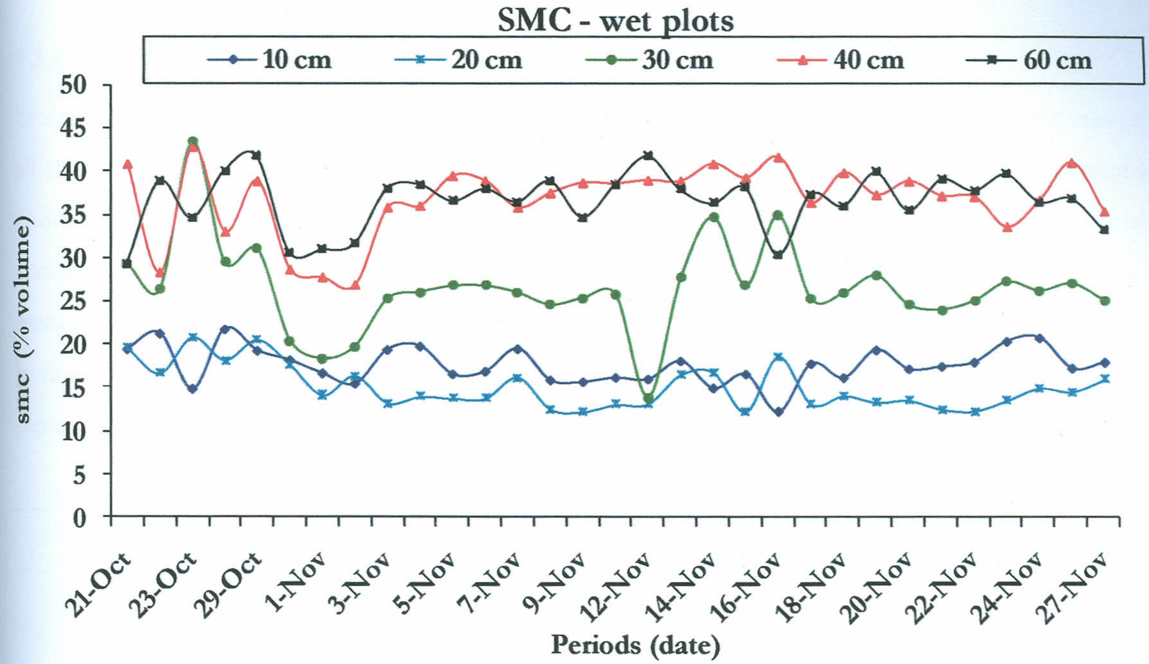


Figure 4. 3 Soil moisture content in well-watered plots. Experiment 1, field experiment

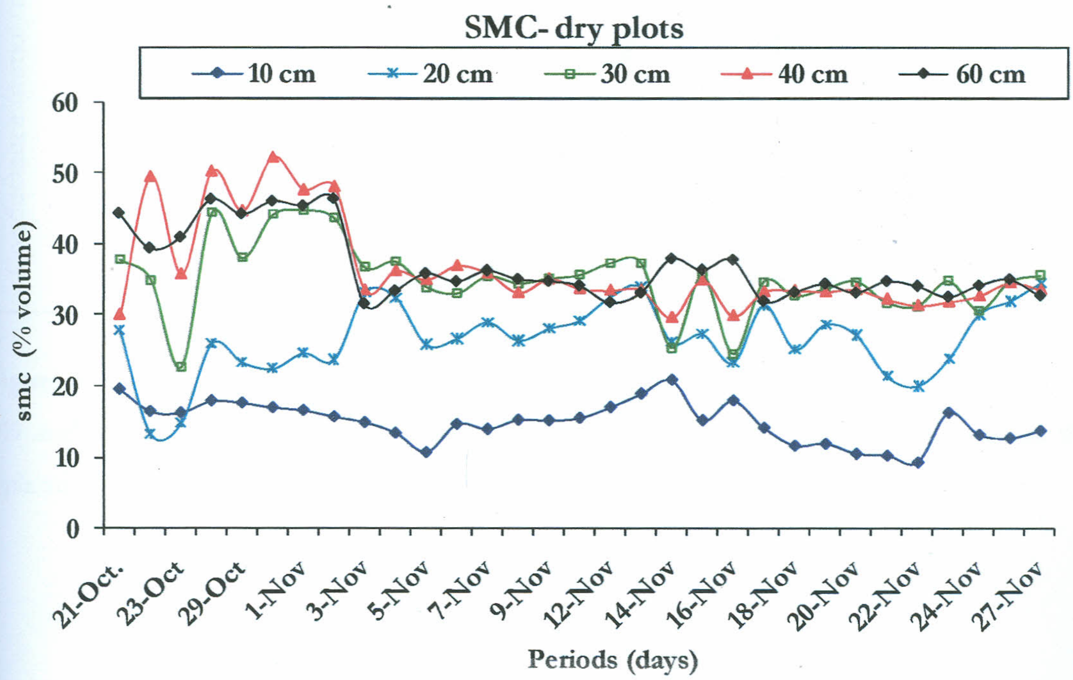


Figure 4. 4 Soil moisture content in drought imposed plots. Experiment 1, field experiment

4.1.2. Physiological parameters

4.1.2.1 Stomatal conductance

Stomatal conductance in the four levels of fertilizer application was significantly different among all the three rice cultivars. In IRAT 109, phosphorus applied plots showed the lowest stomatal conductance at 61 DAS. Higher conductance was at 77 DAS while the lowest stomatal conductance was recorded at 93 DAS. The highest conductance was achieved in nitrogen-fertilized plot while the lowest level was recorded in non-fertilized plots (controlled) as illustrated in figure 4.5. In Lemont, a similar trend as in IRAT 109 was observed, except that, the controlled plots was low but not lower than that of IRAT 109.

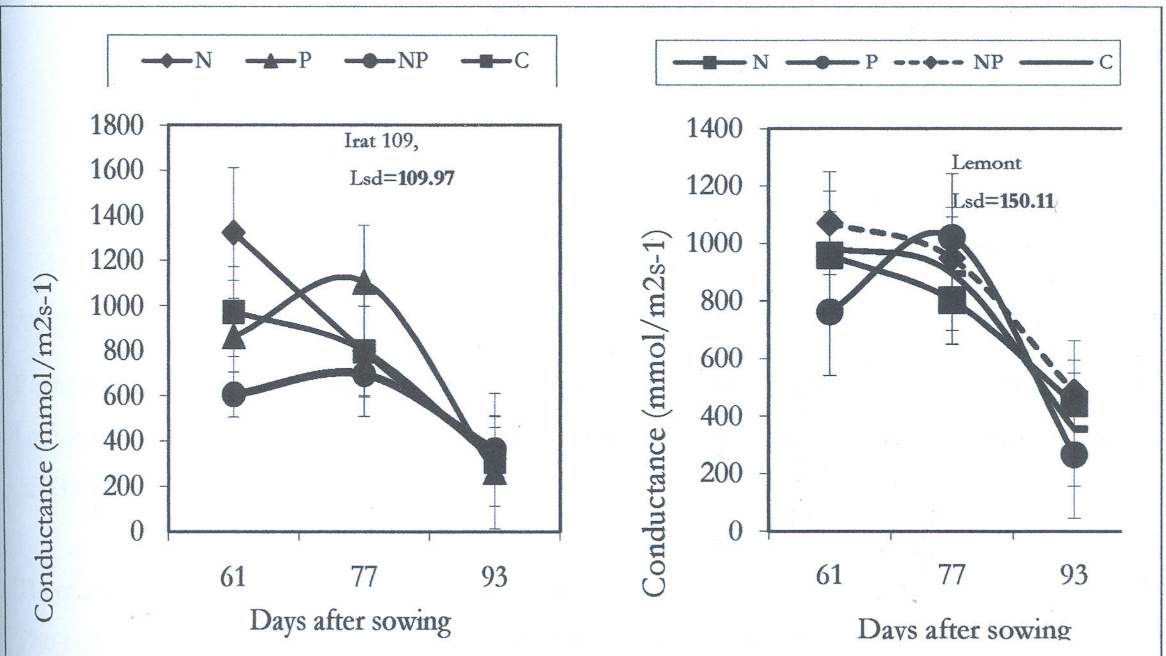


Figure 4. 5 Effects of fertilizer application on stomatal conductance ($mmol/m^2s^{-1}$) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

Water application regime showed a significance difference, in either of the two cultivars, a higher stomatal conductance was observed in well-watered plots, denoted as the (W). Lemont showed a significance higher stomatal conductance in both conditions as compared to IRAT 109, as shown in figure 4.6.

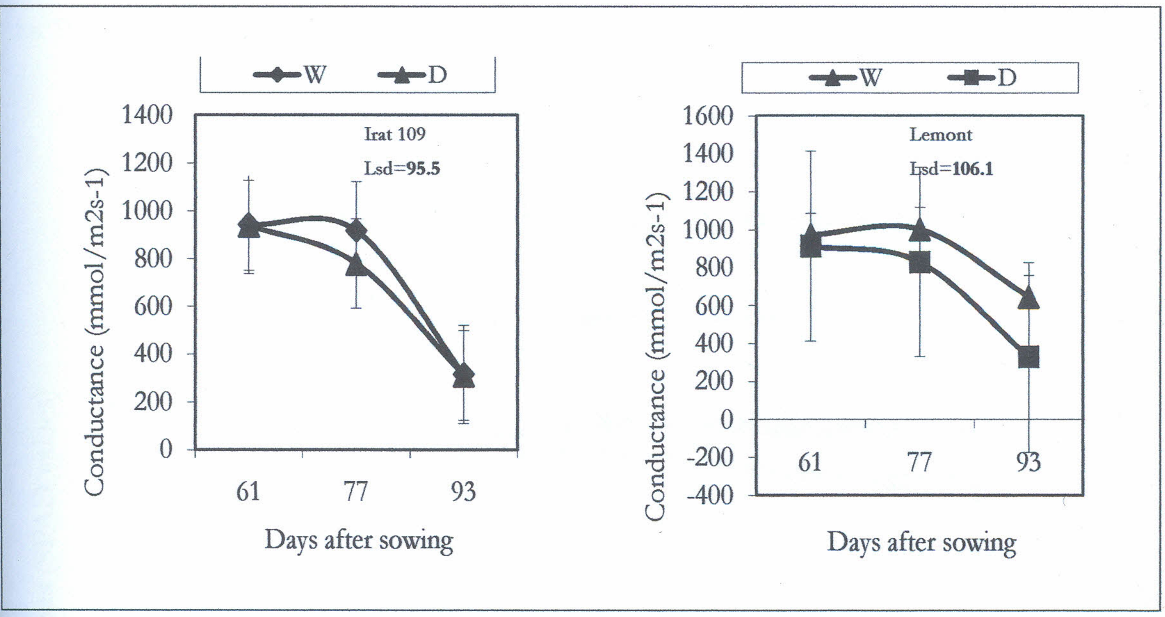


Figure 4. 6 Effects of water stress on stomatal conductance (mmol/m^2s^{-1}) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

There was a general decline in stomatal conductance between the two cultivars. (Fig. 4.5 and 4.6). The reduction in stomatal conductance could be attributed to scarcity of water in the soil, which affects the equilibrium between water uptake and transpiration, thus triggered stress in the plant. IRAT 109 recorded slightly higher stomatal conductance at higher soil moisture deficit (Fig 4.6). This result implies that IRAT 109 is tolerant to water deficit and has ability to maintain leaf turgor at low leaf water potential (Richard *et al.,* 1987), and thus able to give higher stomatal conductance and higher transpiration rates at low soil water potentials. Similar results have been observed by Ackerson (1981), observed that in cotton, the stomata of adapted plants become less sensitive to low water potentials thereby giving higher stomatal conductance at low water potentials. The higher the stomatal conductance, the higher the rate of CO_2 diffusion into the leaf, which in turn leads to, increased rate of photosynthesis (Jones and Lazanby, 1988)

4.1.2.2 N content determination

The two rice cultivars were significantly different at $p \leq 0.05$. In IRAT 109, had the highest foliar nitrogen content in Nitrogen and Nitrogen-Phosphorus fertilized plots. The lowest nitrogen content levels were recorded in non-fertilized plots (controlled experiment). In Lemont, the nitrogen content levels were similar to those of IRAT 109, this as illustrated in figure 4.7 and 4.8, for IRAT 109 and Lemont respectively.

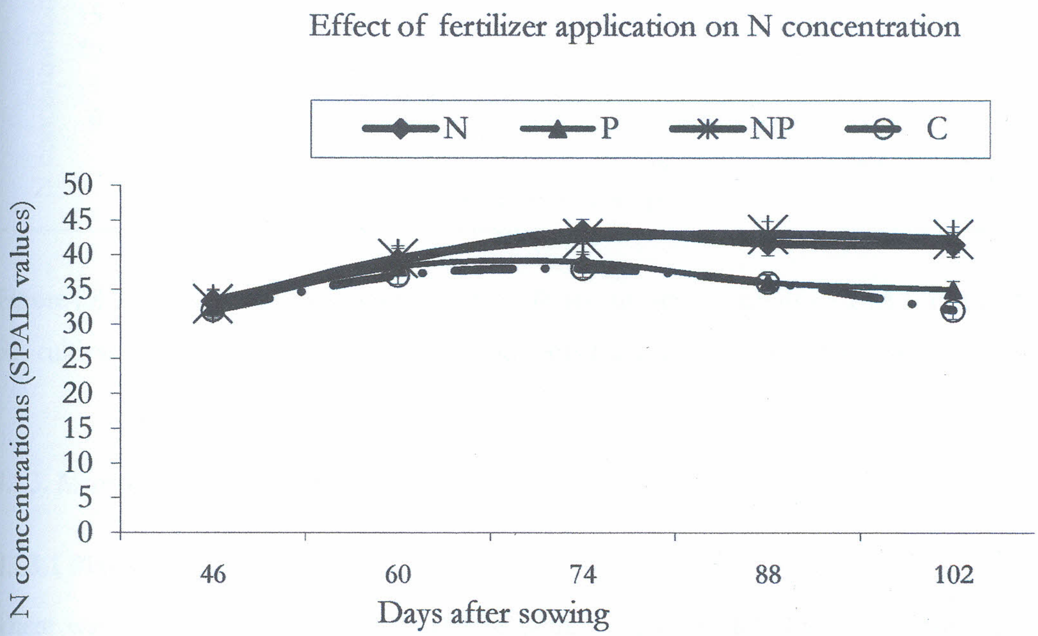


Figure 4. 7 Effects of fertilizer application on foliar nitrogen content of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

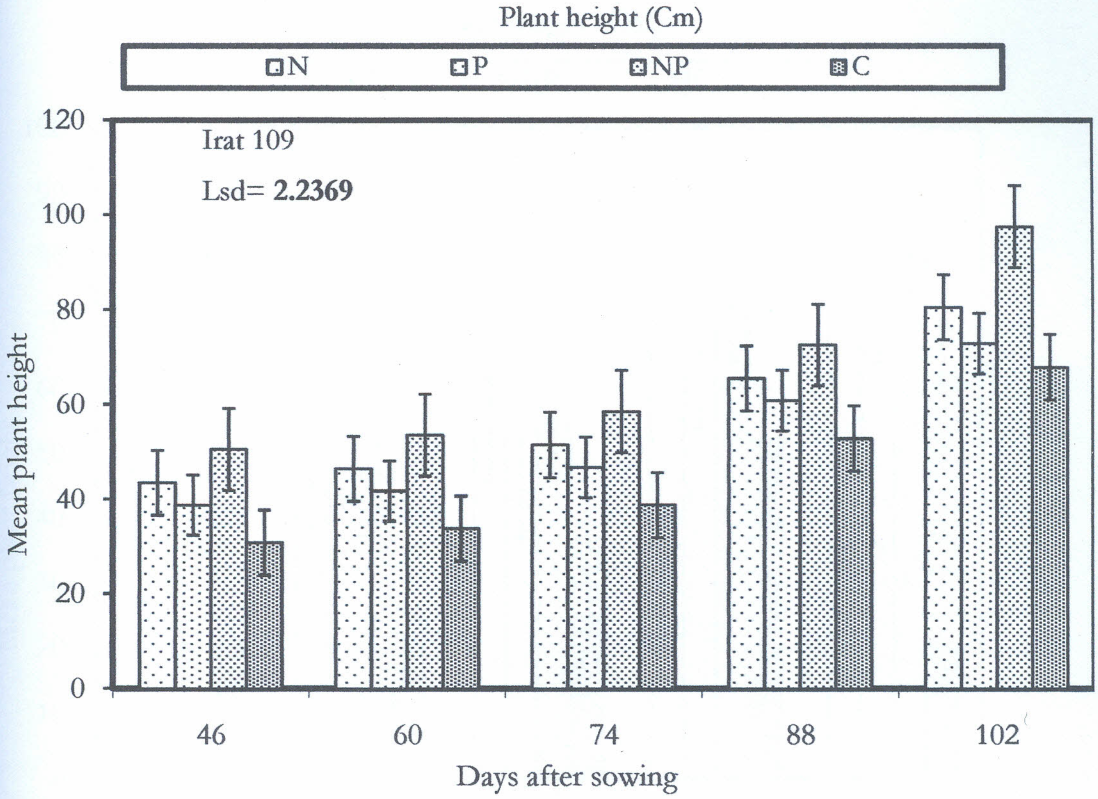


Figure 4. 9 Effects of fertilizer application on plant height (Cm) of IRAT 109 rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

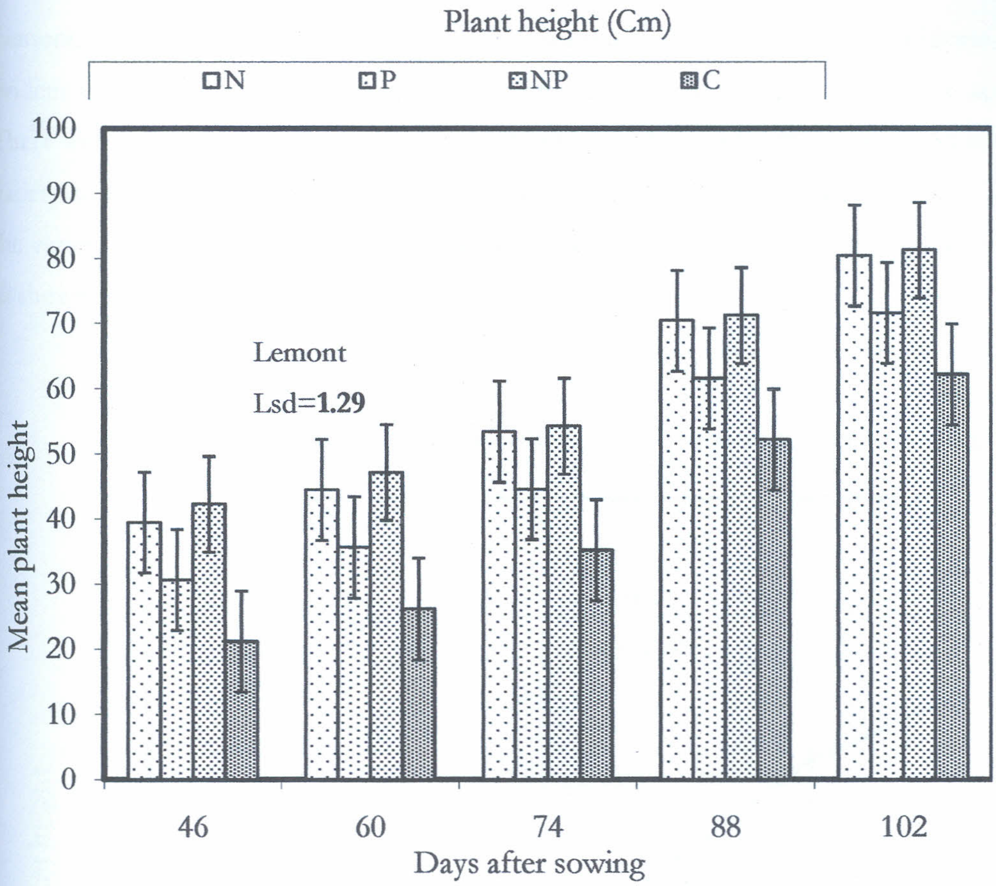


Figure 4. 10 Effects of fertilizer application on plant height (Cm) of IRAT 109 rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV.

There is significant effect ($P \leq 0.05$) in plant height among the two watering regime, there was general decline in plant height with decline in soil moisture availability. Plants under daily water application showed a higher plant height as compared to the plant under water stress condition. The reduction in plant height with decline in soil moisture availability was in Lemont, with height less than 20 cm. there was a general increase in height over time in the two cultivars within the irrigated plots, figure 4.10.

Maximum growth is achieved in Nitrogen-phosphorus applied plots; both in IRAT 109 and Lemont, fertilizer application levels had significant effect on the two-rice cultivars growth as evident in their differences in their plant height, as illustrated in table 4.2 in the appendix 19. There was a significant interaction between; fertiliser and water (FxW), variety and water (VxW), variety and fertilizer (VxF) but there was no significant interaction between Water, fertilizer and the variety (WxFxV), from 46 das to 109 das, as illustrated in table 4.2, 4.3 and in the ANOVA as shown from appendix 2 to appendix 11.

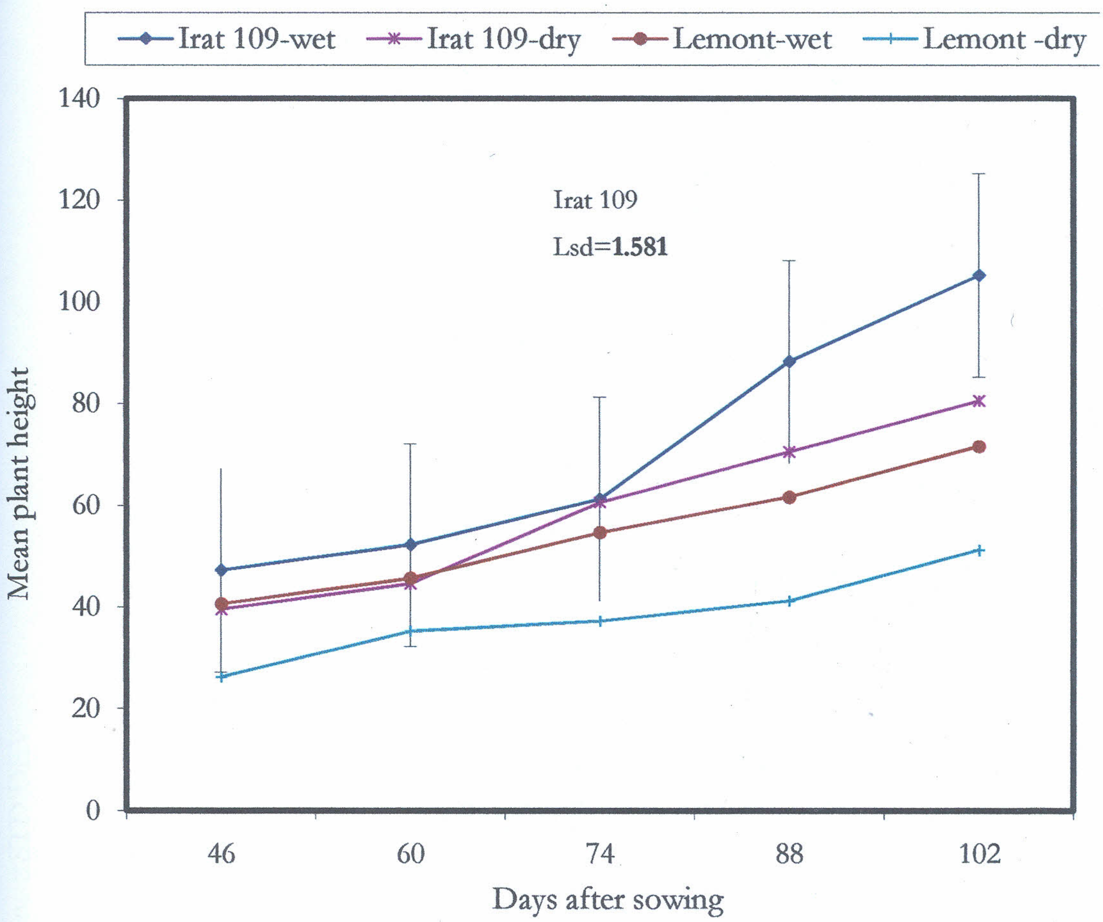


Figure 4. 11 Effects of water application on plant height (Cm) of IRAT 109 rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV.

Table 4. 2. Effects of fertilizer application on plant height (Cm) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

Cultivars	IRAT 109						Lemont						
	Fertilizer levels				Mean	CV (%)	Fertilizer levels				Mean	CV (%)	V*F
Das	C	N	P	NP			C	N	P	NP			
46	40.8c	43.5b	38.8c	50.5a	43.4a	4.0	31.2b	39.5a	30.6b	40.3a	35.4b	2.6	0.0007***
53	43.7c	46.4b	41.8c	53.5a	46.4a	3.7	34.2b	42.5a	33.6b	43.3a	38.4b	2.4	0.0007***
60	45.8c	48.5b	43.8c	55.3a	48.4a	3.6	36.2b	44.5a	35.6b	45.3a	40.4b	2.3	0.0007***
67	48.7c	51.4b	46.8c	58.5a	51.4a	3.4	39.2b	47.5a	38.6b	48.3a	43.4b	2.1	0.0007***
74	54.8c	57.5b	52.8c	64.5a	57.4a	3.0	45.2b	53.5a	44.6b	54.3a	49.4b	1.9	0.0007***
81	62.8c	65.5b	60.8c	72.5a	65.4a	2.7	53.2b	61.5a	52.6b	62.3a	57.4b	1.6	0.0007***
88	71.8c	74.5b	69.8c	81.5a	74.4a	2.3	62.2a	70.5a	61.6b	71.3a	66.4b	1.4	0.0007***
95	77.8c	80.5b	75.8c	87.5a	80.4a	2.2	68.2b	76.5a	67.6b	77.3a	72.4b	1.3	0.0007***
102	79.8c	84.5b	79.8c	91.5a	84.4a	2.1	72.6b	80.5a	71.6b	81.3a	76.4b	1.2	0.0007***
109	85.8c	88.5b	83.8c	95.5a	88.4a	2.0	76.6b	84.5a	75.6b	85.3a	80.4	1.1	0.0007***

Das' days after sowing; C, non fertilized plot; N urea fertilized plot; P, TSP fertilized plot and NP, combination of urea and TSP. Alphabetical letters which are not the same within the rows are significantly different. *** Significant at the P≤0.05 level of probability.

Table 4. 3 Interaction effect of variety, fertilizer, and water on plant height (Cm) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

Growth periods.		Interactions			
(Days after sowing)	CV	F*W	V*W	V*F	V*F*W
46 das	3.9485	***	**	***	Ns
53 das	3.6691	***	**	***	Ns
60 das	3.5038	***	**	***	Ns
67 das	3.2820	***	**	***	Ns
74 das	2.9132	***	**	***	Ns
81 das	2.5336	***	**	***	Ns
88 das	2.2097	***	**	***	Ns
95 das	2.0361	***	**	***	Ns
102 das	1.9348	***	**	***	Ns
109 das	1.8431	***	**	***	Ns
Variety ***					
Fertilizer ***					
Water **					
Lsd (variety)=0.9519					
Lsd (fertilizer)=1.3462					
Lsd (water)=0.9519					

F*W, fertilizer and water interactions; V*W, variety and water interactions; V*F, variety and fertilizer interactions; V*F*W, variety, fertilizer and water interactions. Ns, not significant at the 0.05 level of probability. ** Significant at the 0.01 level of probability and *** significant at 0.1 level of probability.

There was generally slow growth in all the two cultivars in the dry plots, plots with higher moisture deficit, (Fig. 4.11). Similar results have been evident on mango rootstock seedlings growing under water deficit conditions (Luvaha, 2005). The sluggish increase in plant height under condition of high water deficit could perhaps due to reduced cell turgor that affects cell division and expansion (Jones, 1992). Fertilizer were applied in different levels, and utilization could only be possible if uptake was effective, reduction in the nutrient uptake by plants under water deficit condition is also a possible cause in reduction in plant height, since most elements are absorbed via roots (Boyer, 1985).

There was slow growth rate at early stages of the plant, 46 DAS. The initial slow growth rate realised could be possibly due to the germinating seeds had fewer cells capable of growth but growth progressively increased as more cells were formed (Salisbury and Ross, 1992). IRAT 109 and Lemont are significantly different in their plant height. The difference in height may be due to genetic characteristics.

4.1.3.2. Shoot biomass

There was significant difference at $P \leq 0.05$ from 53rd DAS to 95th DAS, among the three levels of fertilizer application, between the two cultivars, IRAT 109 and Lemont. The highest biomass weight of IRAT 109, was attained in the Nitrogen-phosphorus applied plot, attaining amass of 40 grams while in Lemont, the maximum biomass accumulation was evident in Nitrogen applied plots, and in Lemont, being at 32 grams, as shown in figure 4.3 and 4.4, for IRAT 109 and Lemont respectively. There was no significant effect at $P \leq 0.05$, on the interaction between variety and fertilizer, (V*F) on shoot biomass weight, at 53 DAS and 74 DAS, but higher significant interaction between variety and fertilizer, (V*F) from 95th DAS to 121 DAS, as shown in table 4.4.

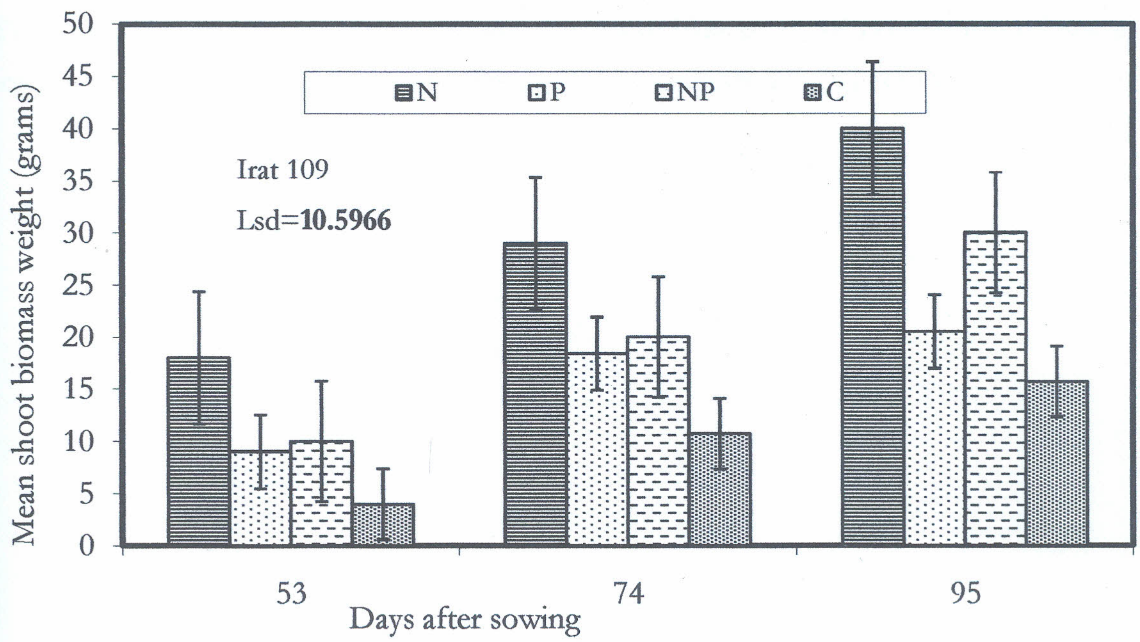


Figure 4. 12 Effects of fertilizer application on shoot biomass (g) of IRAT 109 rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

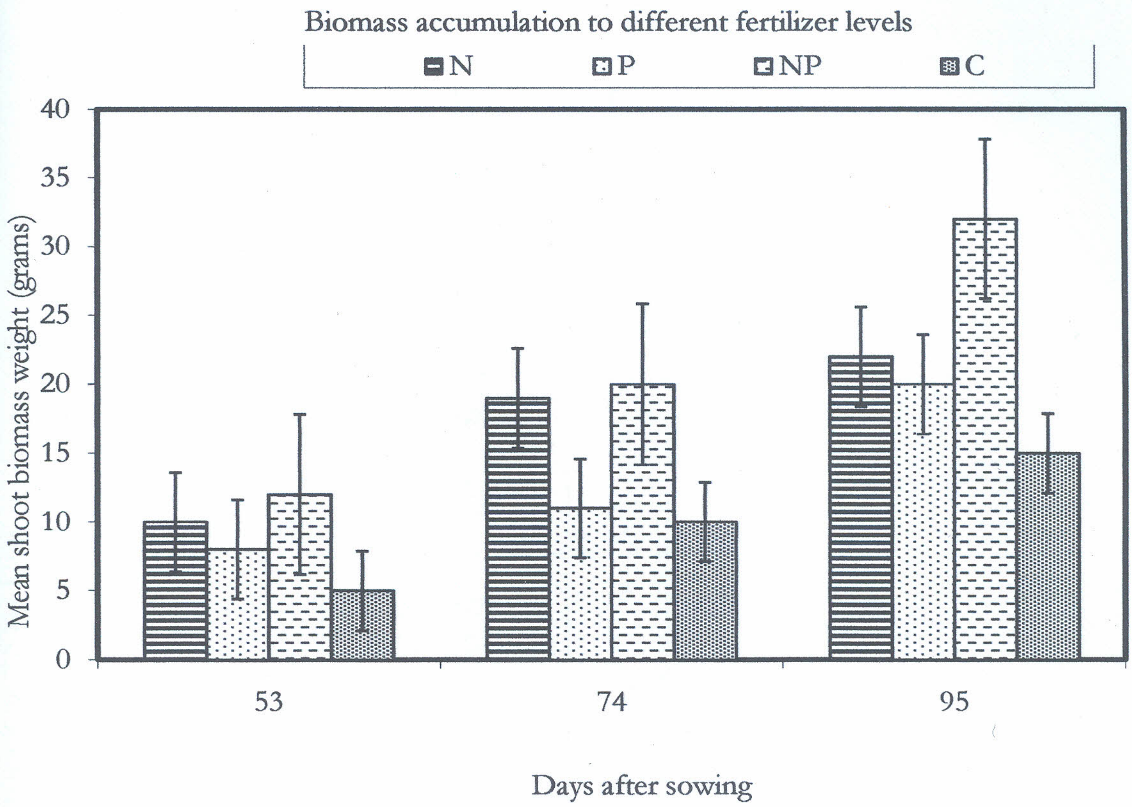


Figure 4. 13 Effects of fertilizer application on shoot biomass (g) of Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

Table 4. 3 Effects of fertilizer application and interaction effect between the variety and fertilizer on shoot biomass (g) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

	IRAT 109						Lemont						
	Fertilizer levels				Mean	CV (%)	Fertilizer levels				Mean	CV (%)	V*F
Das	C	N	P	NP			C	N	P	NP			
53	3.7a	4.7a	3.6a	4.8a	4.2a	29.4	2.1b	2.9ab	2.6ab	3.5a	2.8b	31.8	.7104ns
74	10.7b	17.1a	18.4a	17.6a	16a	29.3	7.5b	11.9a	9.3ab	12.3a	10.2b	27.1	.2596ns
95	15.7c	35.5a	20.5bc	27.5ab	24.8a	31.9	19.6a	16.1a	17.1a	24.5a	19.3b	35.6	.0332*
121 Harvest	45.7c	54.2b	43.4c	68.2a	52.9a	5.5	24.3c	28.8bc	37.7a	29.6b	30.1b	14.2	.0000***

Das' days after sowing; C, non fertilized plot; N urea fertilized plot; P, TSP fertilized plot and NP, combination of urea and TSP. Alphabetical letters which are not the same within the rows are significantly different. *** Significant at the P≤0.05 level of probability.

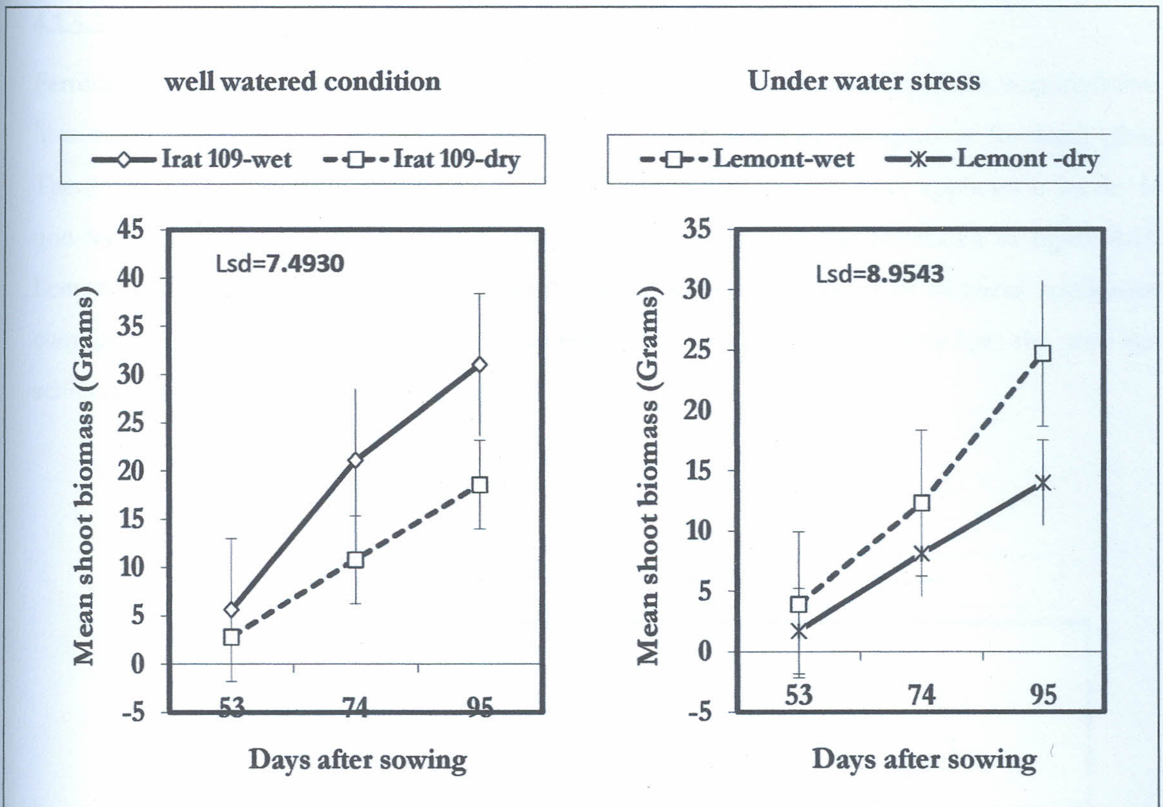


Figure 4. 14 Effects of water on shoot biomass (g) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

The whole plant dry weight declined in water stressed plots in the two cultivars (Fig 4.14). Similar results have been observed in potatoes subjected to water deficit (Nadler and Bruvia, 1998). The reduction in biomass under water deficit may be because of reduction in leaf expansion which in turn affects the supply of the assimilates to the growing parts of the plant (Munns and Termaat, 1986). The two rice cultivars differed significantly ($P \leq 0.05$) in plant biomass (Fig.4.10, 4.12 and 4.13) and table 4.4

IRAT 109 recorded the higher biomass. This implies that IRAT 109 is tolerant to moisture deficit than Lemont; hence, IRAT 109 is able to accumulate more biomass under moisture deficit. The high total biomass accumulated by IRAT 109 may be because of the high root penetration, thus able to absorb water in levels where the roots of Lemont could not reach (Jones, 1996).

4.1.3.3. Root biomass

Fertilizer application had a significant different at P$\leq$ 0.05 on root biomass accumulation. Maximum root biomass was achieved in nitrogen combined with phosphorus fertilized plots. There was a steady rise in root biomass in all the four levels of fertilizer application levels. In non-fertilized plot showed the lowest root biomass accumulation as illustrated in figure 4.13. Lemont had a lower root biomass accumulation in all the four levels of fertilizer application compared to IRAT 109. Increase in root biomass accumulation was relatively low; the peak was achieved after 95 DAS, as shown in figure 4.15

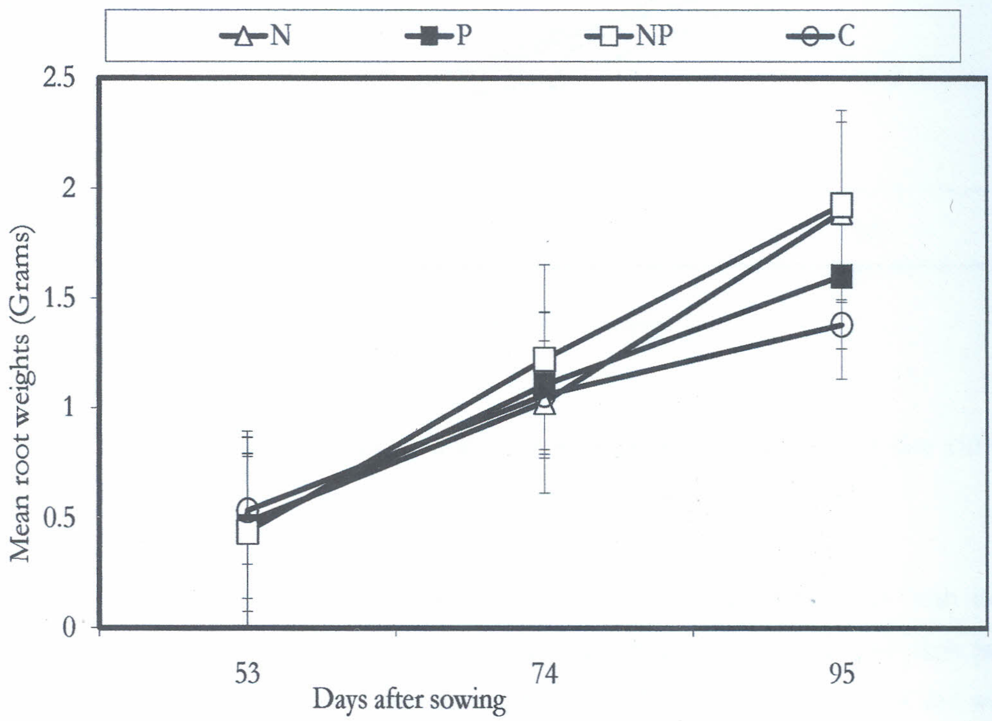


Figure 4. 15 Effects of fertilizer application on root biomass (g) of IRAT 109 rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

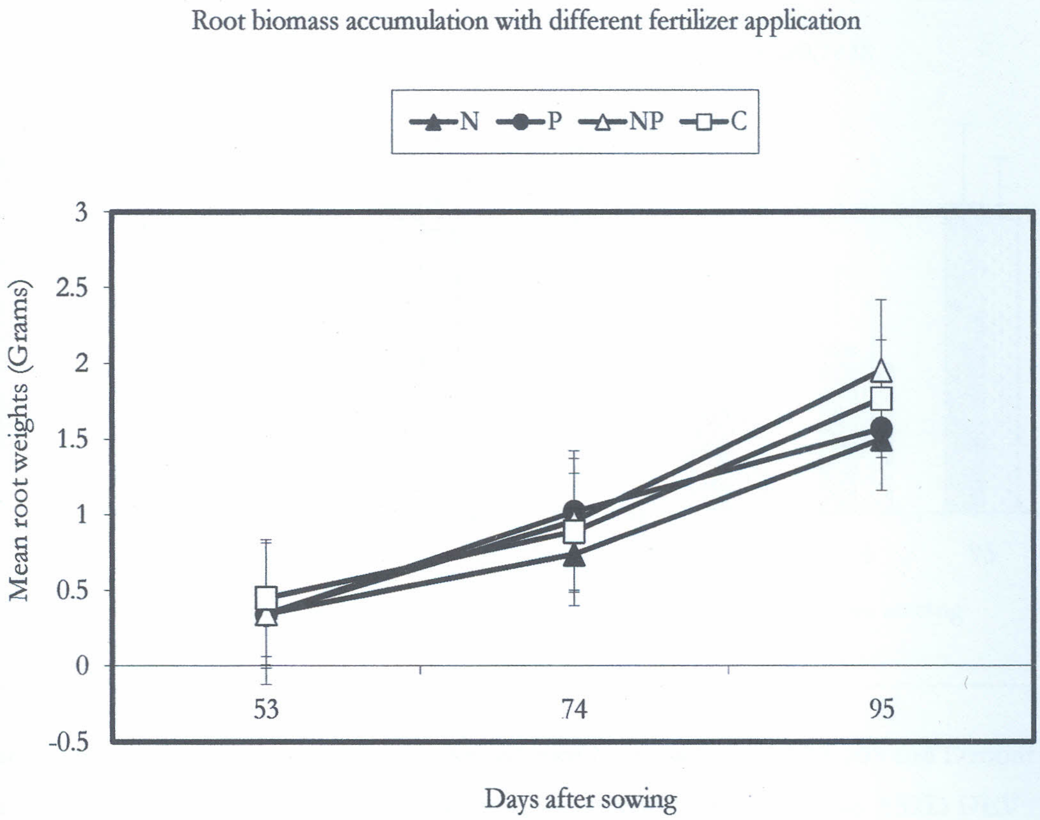


Figure 4. 16 Effects of fertilizer application on root biomass (g) of Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

Water application had a significant effect on root biomass accumulation. In both the two cultivars, showed accelerated root biomass accumulation among the well-watered plots (wet), as compared to the non-irrigated plots, this as per figure 4.16. Lemont in either of the watering regimes had a lower root biomass accumulation as opposed to IRAT 109.

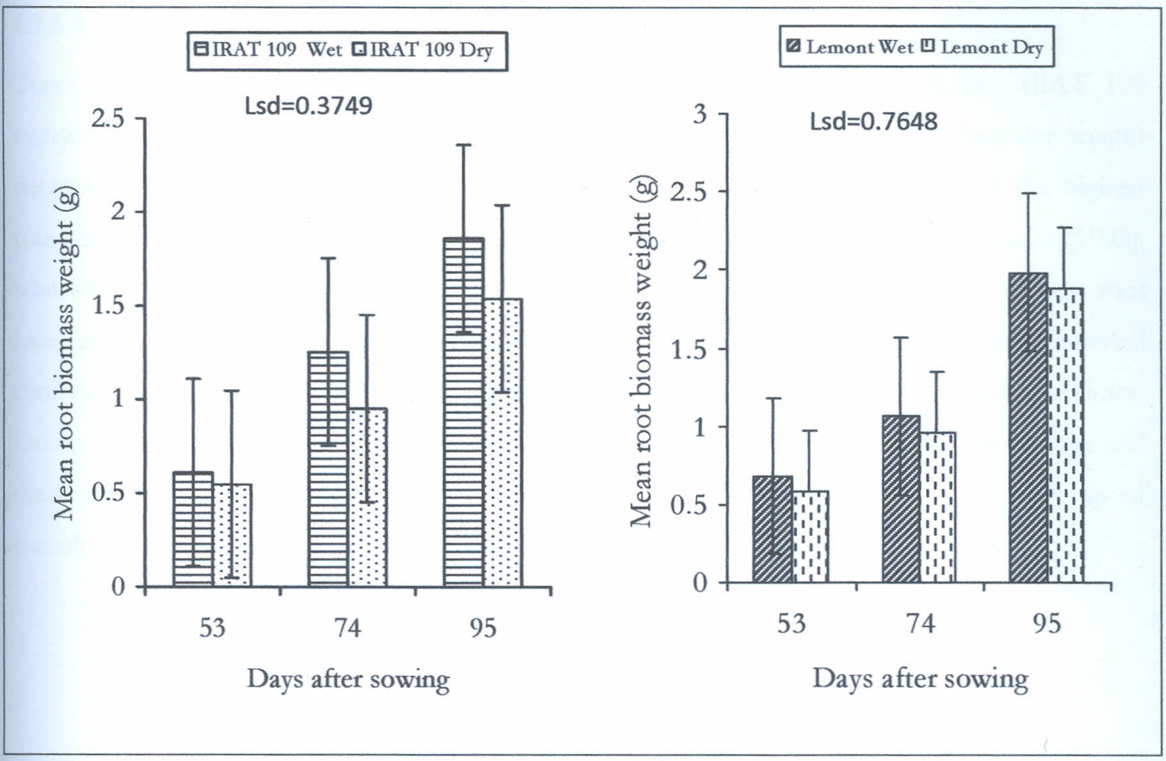


Figure 4. 17 Effects of fertilizer application on root biomass (g) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

There was a significant effect ($P \leq 0.05$) in plant root biomass between the two cultivars in the two watering regimes (Fig. 4.17). The roots decreased with increase in water deficit, plants in well-watered plots recorded higher root biomass. Similar results were obtained by Willumsen (1993), reported that large and vigorous root system and continued production of new root hairs are required for maximum response to nutrients supply and optimum environmental conditions and that this positively correlates with the dry matter accumulation within the shoot. The decline in root dry weight under water deficit may be due to root damage and death thereby reducing the sink activity of the roots leading to the built up of carbohydrates (Munns and Termaat, 1986). There was inhibition of root growth, which may be attributed to reduced extensibility of the root tip tissue due to hardening of the expanding cell walls (Boyer, 1985). In this study, IRAT 109 was more tolerant to water deficit in terms of root biomass accumulation.

4.1.3.4. Shoot-root ratio

There was significant different in shoot-root biomass among the two cultivars. IRAT 109 registered the highest biomass Fig. 4.18. The shoot, leaf, root and whole plant dry weight decreased with increased water deficit. Plants in the well irrigated plots registered the highest plant biomass than plants grown in dry plots. Similar results were obtained Willumsen (1993), who reported that large and vigorous roots system and the continued production of new root hairs are required for maximum response to nutrient supply and optimum environmental conditions and that this positively correlates with the dry matter accumulation within the shoot. Decline in root and shoot dry weight under water deficit may be attributed to root damage and death which in turn interferes with the sink activity of the roots leading to the built up of carbohydrates (Munns and Termaat, 1986).

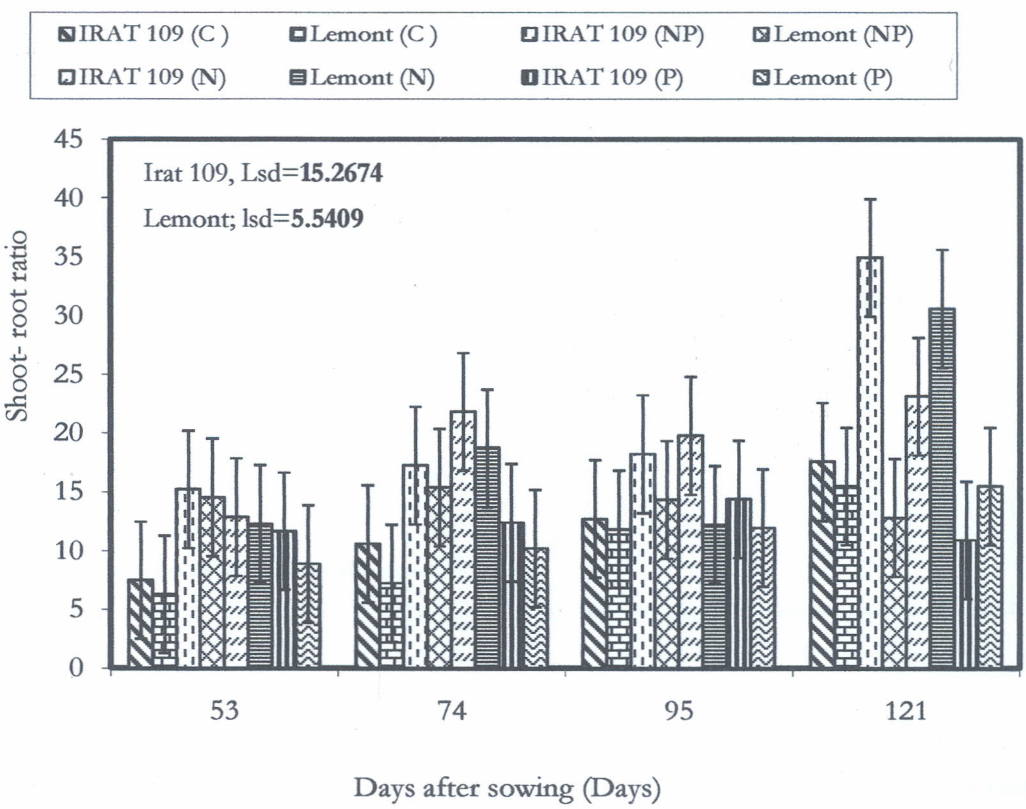


Figure 4. 18 Effects of fertilizer application on root biomass (g) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV.

4.1.4 Yield and yield components

4.1.4.1. Tiller number

There was significant effect ($P \leq 0.05$) in plant tiller number among the watering regime and the cultivars. Fig 4.19 and 4.20. Plants in well-irrigated plot registered the highest tillering ability in terms of the number per hill as compared to the same cultivars grown in dry plots, plots under water deficit conditions. IRAT 109, showed the highest tiller number in both wet and dry plots and across the four fertilizer levels. Plots fertilized with phosphorus showed the highest tiller number both in IRAT 109 and in Lemont as illustrated in Fig. 4.19. The lowest tiller number was registered in nitrogen and non-fertilized plots.

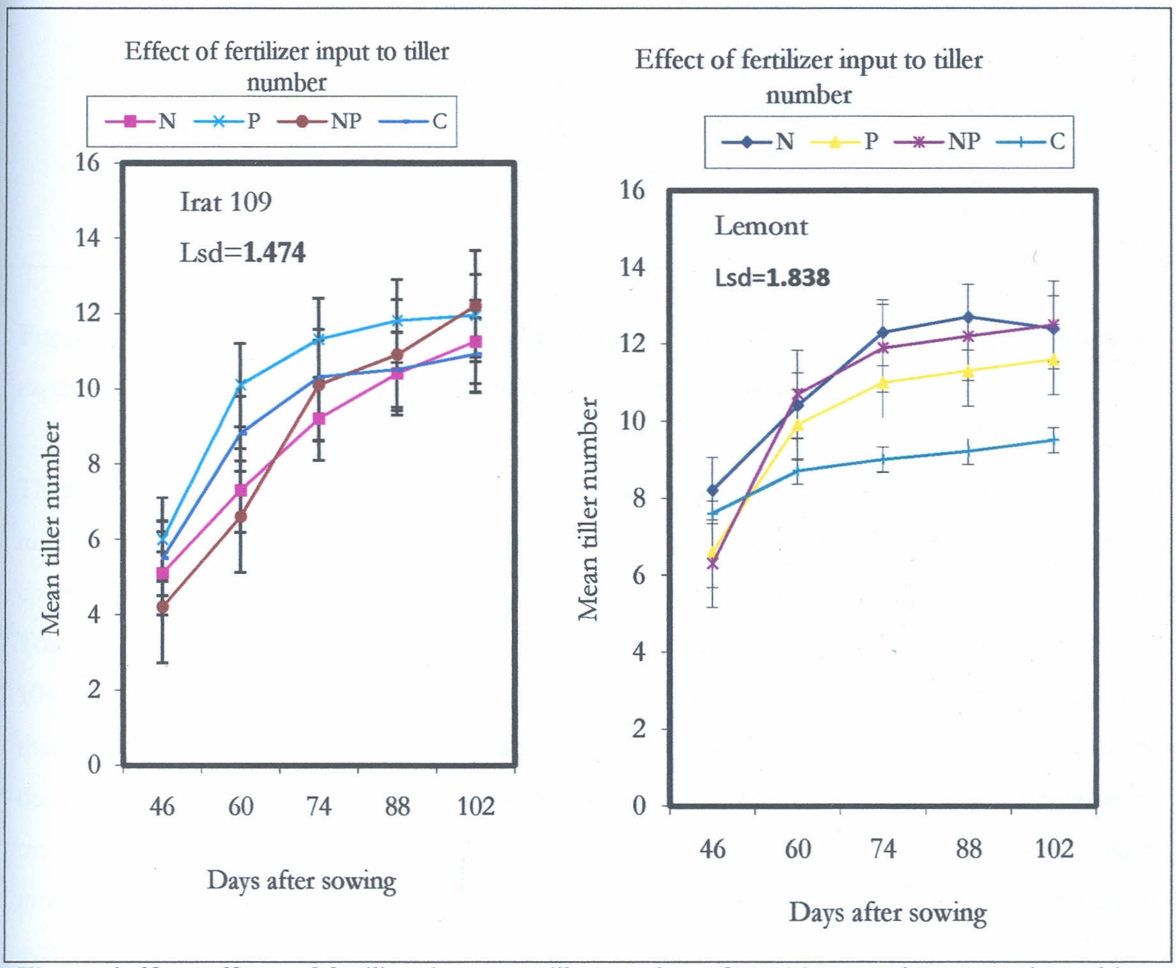


Figure 4. 19 Effects of fertilizer input on tiller number of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

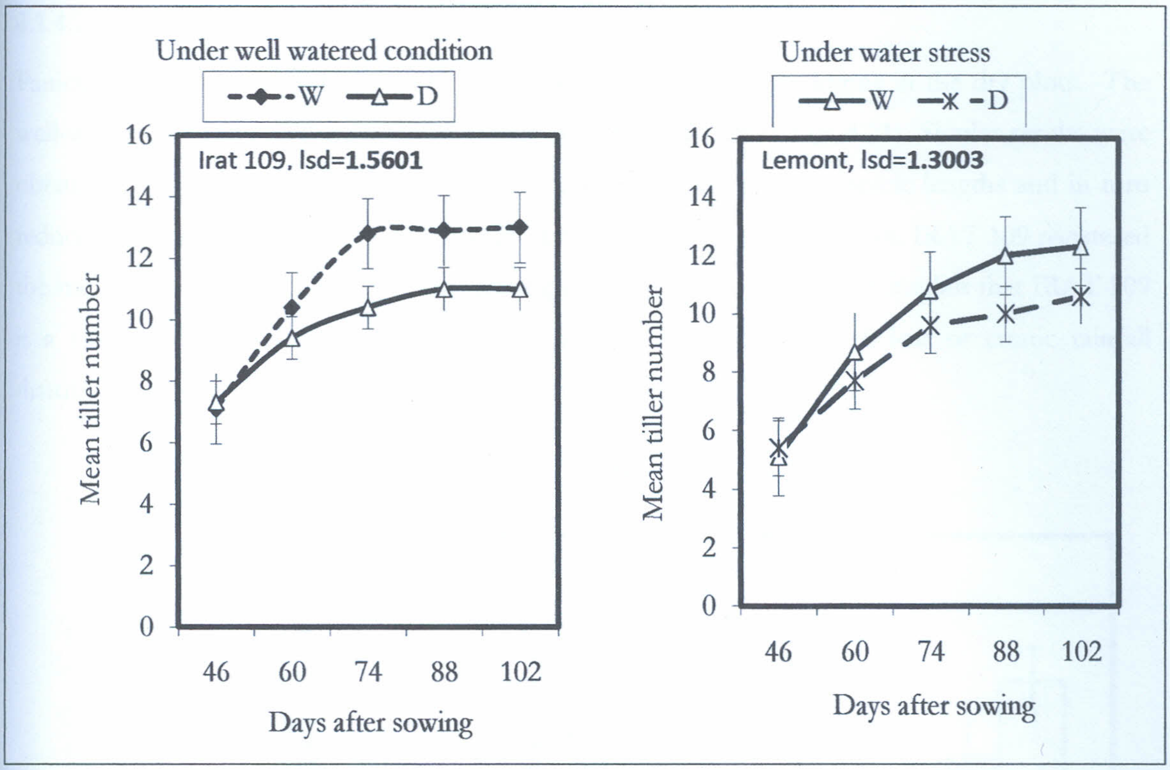


Figure 4. 20 Effects of water input on tiller number of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

There was significant effect on tiller number between the two cultivars at P≤0.05. The tiller number was affected by the treatment and it tended to decrease with decline in soil moisture content (Fig. 4.19). Water deficit during vegetative stage reduces tiller number. Bouman and Toung (2001) found that drought before or during tillering, reduce the number of tillers. IRAT 109 recorded higher tiller density in dry plot as compared to Lemont (Fig. 4.19). This implies that IRAT 109 is drought tolerant and is able to maintain higher tiller density than Lemont under drought condition. Turgeon (1980), noted that the number of aerial roots per unit area depends on genotype (G), environment (E) and management (M), enhancing the principle of GxMxE interaction. Tillering in crops indicates favourable rainfall amounts, temperature and response to available nitrogen.

4.1.4.2. Panicle lengths

Panicle lengths were significantly affected by the water deficit conditions in the dry plots. The well-watered plants had longer panicles than the stressed plants (Fig. 4.21). Similar results were obtained by Yeo *et al.,* (1996), he observed that drought affects the panicle lengths and in turn reduces the grain setting which significantly contributes to low yields in rice. IRAT 109 registered the highest panicle lengths in dry plots among all the fertilizer levels. This implies that IRAT 109 is a tolerant cultivar to water deficit. Thus suitable for locations with low or erratic rainfall distribution.

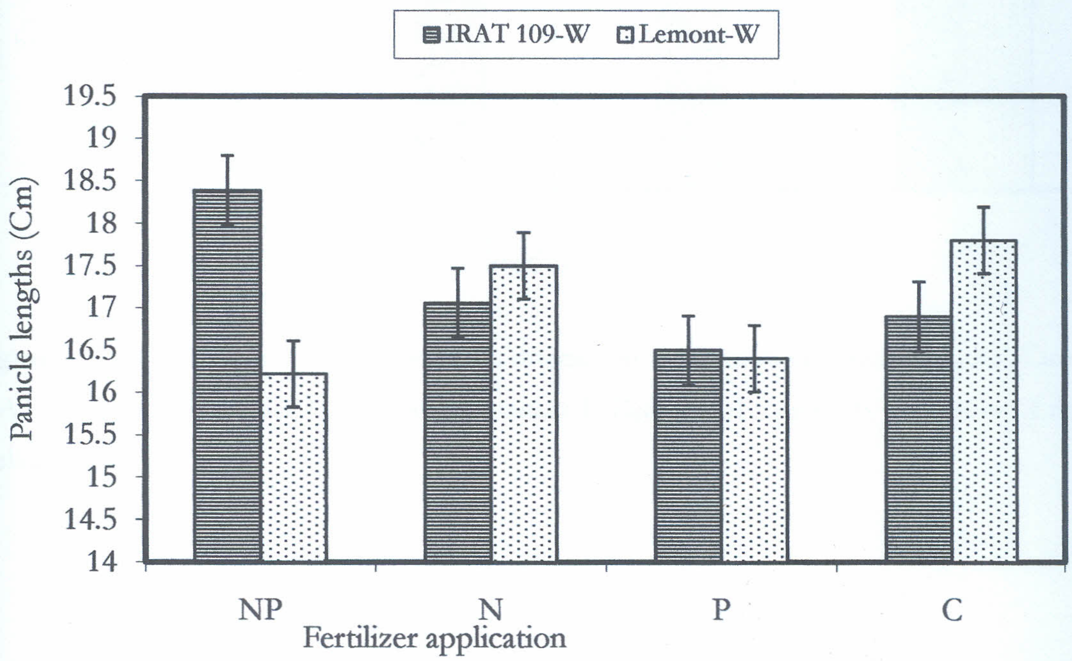


Figure 4. 21 Effects of fertilizer and water interaction application on panicle lengths (Cm) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

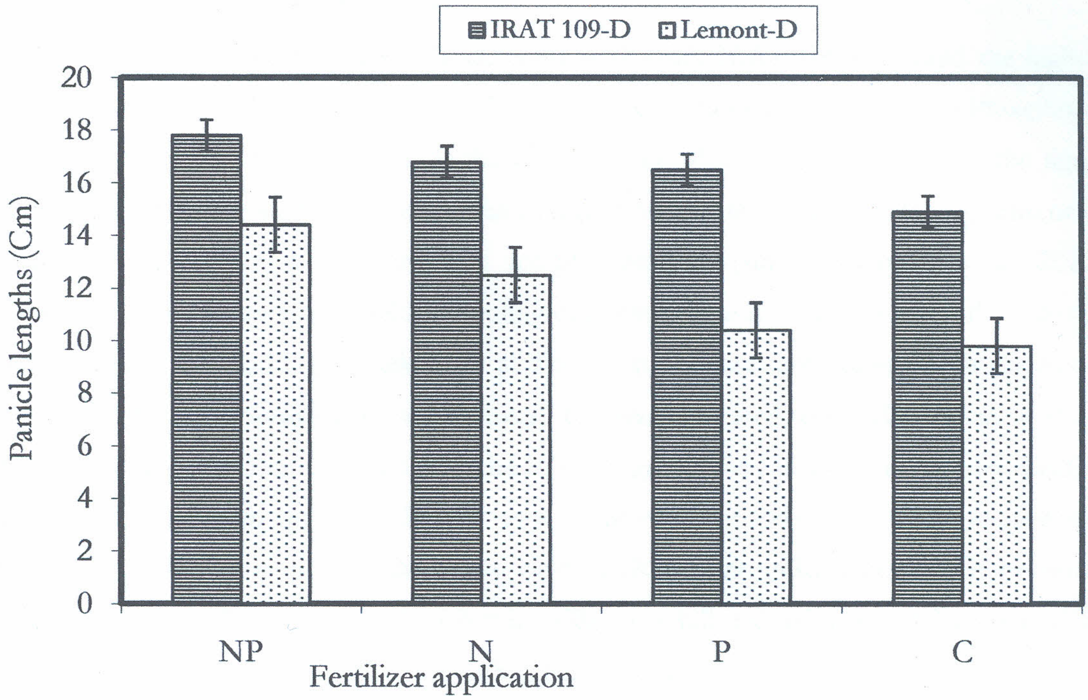


Figure 4. 22 Effects of fertilizer and water interaction application on panicle lengths (Cm) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

4.1.4.3 Yield at 14% moisture content

The two rice cultivars were significantly different at $P \leq 0.05$. IRAT 109 registered the highest yield at 14% in all fertilizer levels. The highest yield was obtained from Nitrogen-Phosphorus fertilized plots and the least yield was in the non-fertilized plots, designated as C, in the figure 4.21. Grain yield of rice may be limited by the supply of assimilates to the developing grain or by the capacity of the reproductive organ to accept assimilates (sink capacity), (Sikuku, 2010). Significant variation in yield and yield attributing characters were recorded between the cultivars (Fig 4.23). IRAT 109 had higher yield both at the lowest soil moisture (water deficit condition) and at the highest soil moisture (no water stress), this was replicated too in all the four levels of fertilizer application modes. In as much as the cultivars greatly vary or differ in inherent yielding ability, yield losses from the normal levels as a result of water deficit are useful in assessing drought tolerance (Pirdashti *et al.*, 2004).low yield of IRAT 109 under water deficit treatment may be attributed to less number of ear bearing tillers per hill, reduction in total grain number per panicle. IRAT 109, showed superior sink capacity under low soil moisture content in terms of relatively longer panicle length as compared to Lemont.

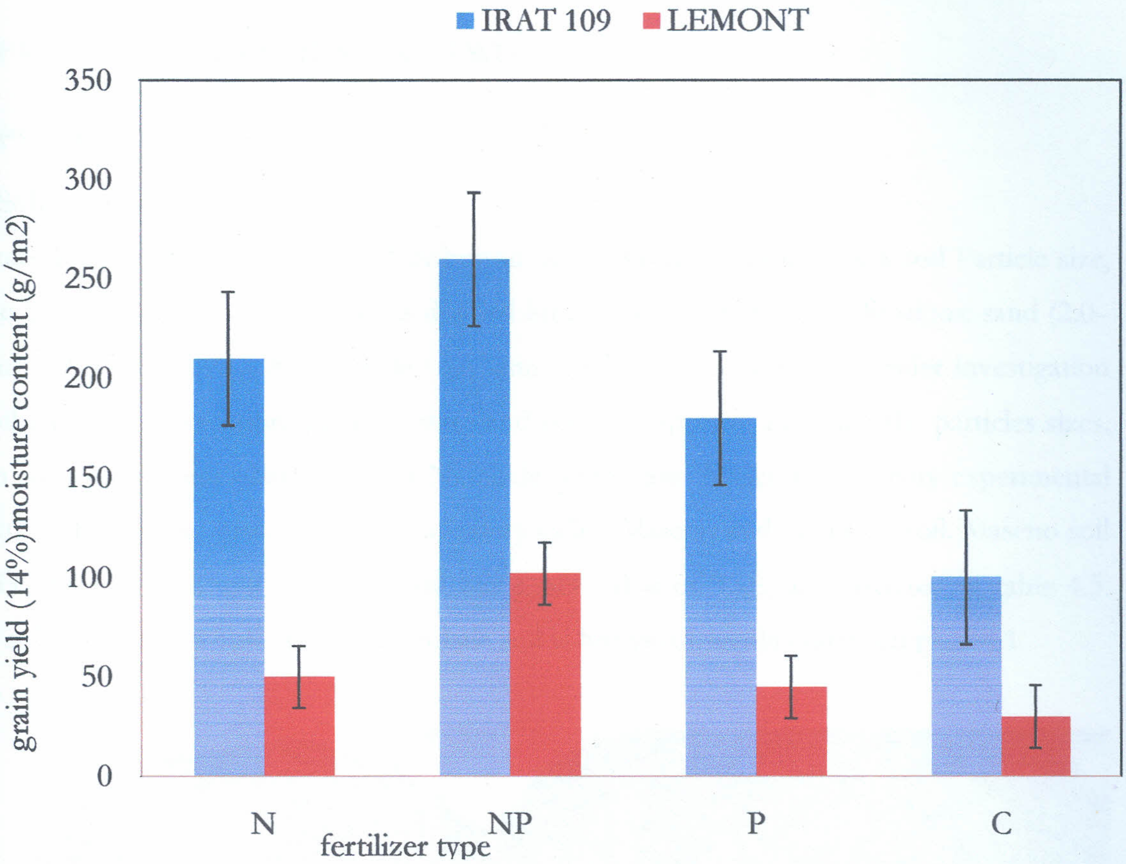


Figure 4. 23 Effects of fertilizer and water application on grain yield at 14% moisture content of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications ±STD DEV

4.2 PVC TUBES: - EXPERIMENT TWO

4.2 PVC-TUBE Experiment.

4.2.1 Soil texture determination

Soil texture refers to the relative size distribution of the primary particles in a soil Particle size, using the USDA classification scheme, is divided into three major size classifications: sand (2.0–0.05 mm), silt (0.05–0.002 mm). Particle size, using Soil physical properties under investigation were, soil particles aggregation, particles sizes and the soil types by analysing the particles sizes. The two soils used, were obtained from Nambale region and Maseno University experimental plots, within the botanic garden, thus are arbitrary called Maseno and Nambale soil. Maseno soil has a pH value of 4.78 and Nambale soil has a pH value of 3.68, as illustrated in table 4.5. Maseno soil is reddish in colour while Nambale soil is brownish, as illustrated on plate 4.1

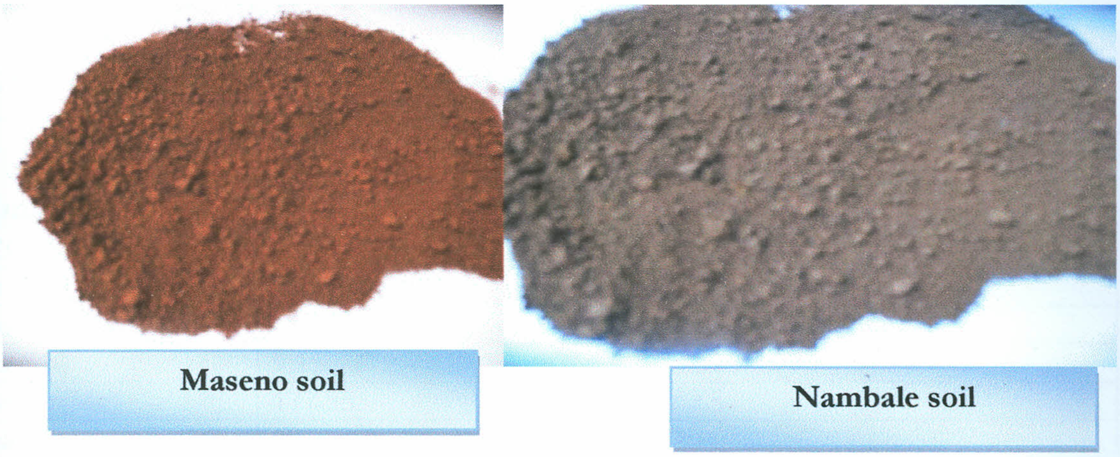


Plate 4. 1 Soils obtained from Maseno and Nambale field experiment respectively

Table 4. 4 Soil particle content and description of Maseno and Nambale soils

	Maseno soil		Nambale soil	
	Quantities	% particles	Quantities	% particles
Whole particles mass (g)	130.7	-	124.8	-
Course particles(2.0–0.05 mm),-Sand	0.4	0.4	0.6	0.5
Medium particles0.05– 0.002 mm-silt	46.2	35.3	88.2	70.7
Fine particles(, 0.002 mm)-Clay	84.1	64.3	36.0	28.8
Permeability Cm/h)	0.8*(0.25-1.5)		5*(2.5-25)	
Total pore space	49*(47-51)		38*(32-42)	

Bulk density (g/Cm3)	1.35*(1.30-1.40)	1.65*(1.55-1.80)
Field capacity	27*(23-31)	9* (6-12)
Permanent wilting point (%)	13*(11-15)	4* (2-6)
Water content (mm/m soil)	19* (17-22)	8* (7-10)
Description of the soil used	Clay loam	Silt loam

*Average figures and range (between brackets). The moisture content on a volume basis (mm water per meter of soil) was obtained by subtracting weight percentages at field capacity and permanent wilting point, multiplied by bulk density.

The analysis of the soil nutrient load showed a similar analysis trend as in the field experiment, more specifically the soil obtained from the experimental field within the Botanical Garden, Maseno University, soil obtained from Maseno gave a definite value of pH=4.79 while soil obtained from Nambale had a pH of 3.69. The two soils are acidic, though Maseno soil has a slightly higher pH value than Nambale soil; this implies that, soil from Nambale is highly acidic as compared to Maseno soil, as shown in table 4.5

Table 4. 5 Soil fertility analysis of the soils used in the PVC tubes.

Soil nutrients	**Soil from Maseno experimental site Maseno soil)**	**Soil from Nambale experimental field (Nambale soil)**
pH (H2O) 1:2.5	4.79	3.69
Sodium (Na)	22.91	16.91
Potassium (K)	0.31	0.07
Calcium (Ca)	9.15	3.51
Magnesium (Mg)	177.55	52.5
Available Phosphorus (P)	58	20
Total Nitrogen (N)	0.27	0.15
Carbon (C)	1.61	0.99
Manganese (Mn)	3.48	0.07
Copper (Cu)	4.6	1.85
Iron (Fe)	59.22	76.52
Zinc (Zn)	13.68	4.8

Results as obtained from the Kenya Plant Health Inspectorate service (KEPHIS)-analytical chemistry laboratory-ref (KEPHIS/KTL/ACL/170/78.

Nambale soil is highly acidic compared to soil of Maseno. The soil has a pH range of 3.69 - 4.77. The pH decreases with increase in soil depth, the lower soil layers has relatively higher pH than the surface soil, which has a pH range of 3.69-4.01. The lower pH implies that most of the vital plant nutrients are highly fixed and not readily available for the plant use. Nitrogen, carbon,

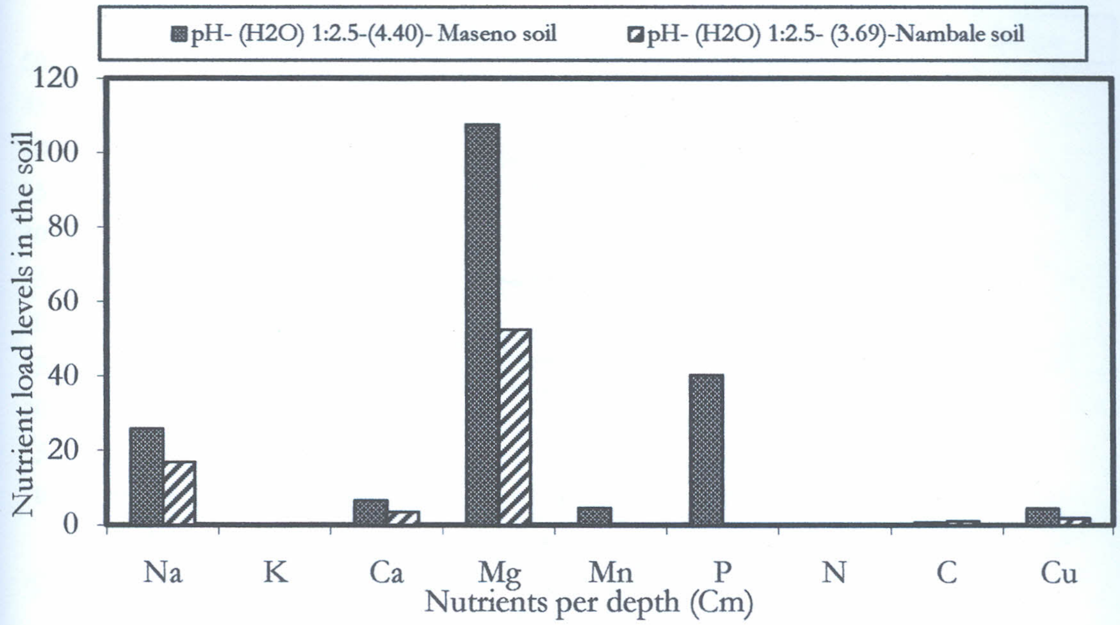


Figure 4. 24 Soil nutrient analysis results of Maseno and Nambale soils used in the PVC tubes.

4.2.2. Soil moisture measurements

The soil moisture content within the wet plots showed the highest percentages at depths of 40 and 60 cm. The lowest soil moisture content was registered in depths of 10 and 20 cm. in dry plots, the highest soil moisture was recorded in the months of October to November, at depths of 30, 40 and 60 cm, which later showed a sharp decline as from the months of November till the end of the experimental period. The lowest soil moisture content was recorded at depths of 10 Cm. In this study, water was withheld to specific tubes, in a single replication of 48 tubes, only 24 tubes were watered and the other 24 tubes were watered on daily basis. Withholding of water led to drought stress. This is in agreement with results obtained by Siddique *et al.,* (2000) on a wheat plants. Drought stress reduces the soil moisture content. Loss of moisture from the soil may be attributed to surface evaporation, transpiration through the leaves and water absorbed by the roots (Luvaha, 2005).

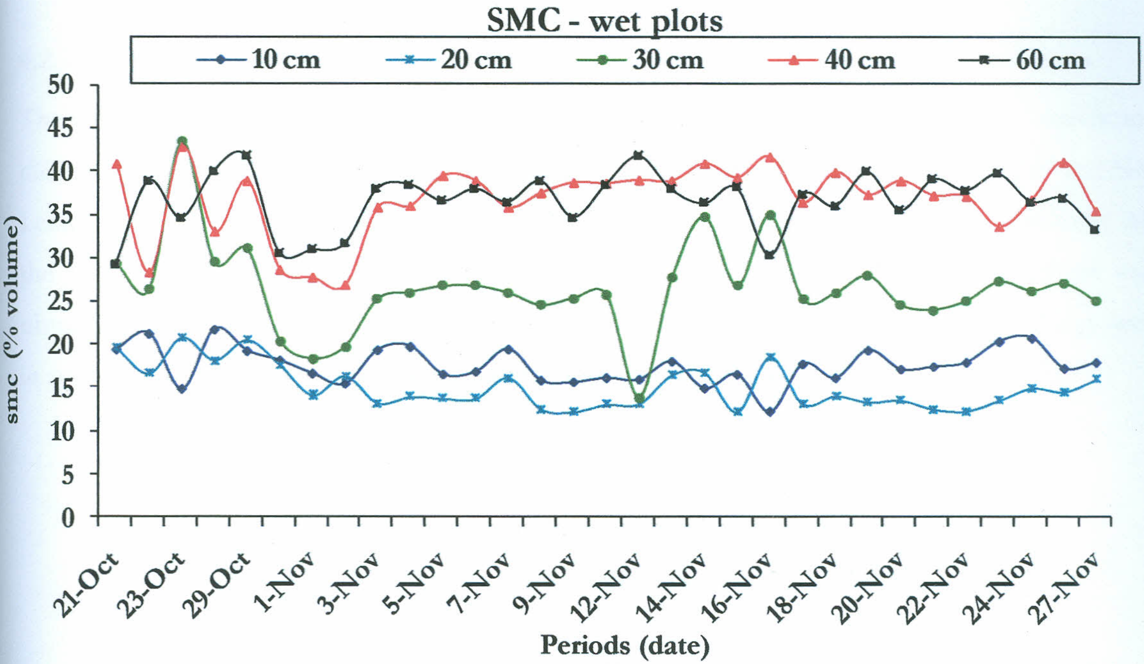


Figure 4. 25 Soil moisture content levels as per depth, in wet tubes

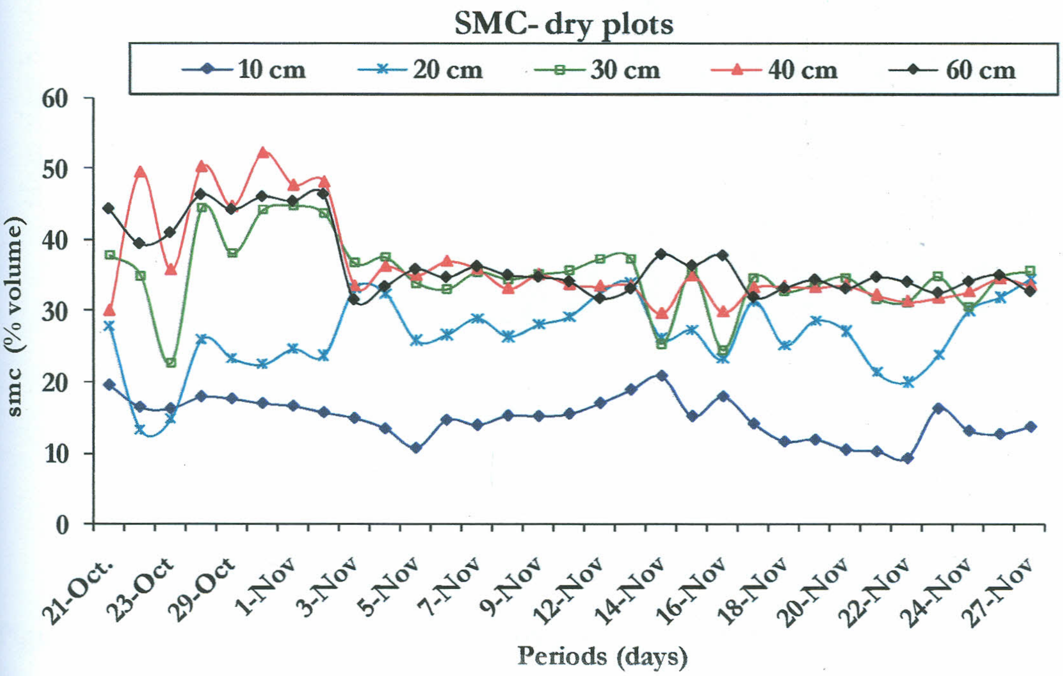


Figure 4. 26 Soil moisture content levels as per depth, in dry tubes

4.2.3. Morphological characteristics

4.2.3.1 Plant height

There is significant difference between the three cultivars. IRAT 109 and N4 have no significant difference but Lemont had a significant difference compared to two cultivars, IRAT 109 and N4. Lemont is genetically dwarf cultivar while IRAT 109 and N4 are taller cultivars genetically. All the three cultivars registered progressive growth. N4 registered the highest growth in soil obtained from Maseno experimental field plot Fig. 4.27, while IRAT 109, had the highest growth in soils obtained from Nambale experimental field plot as illustrated in Fig. 4.28 and 4.29.

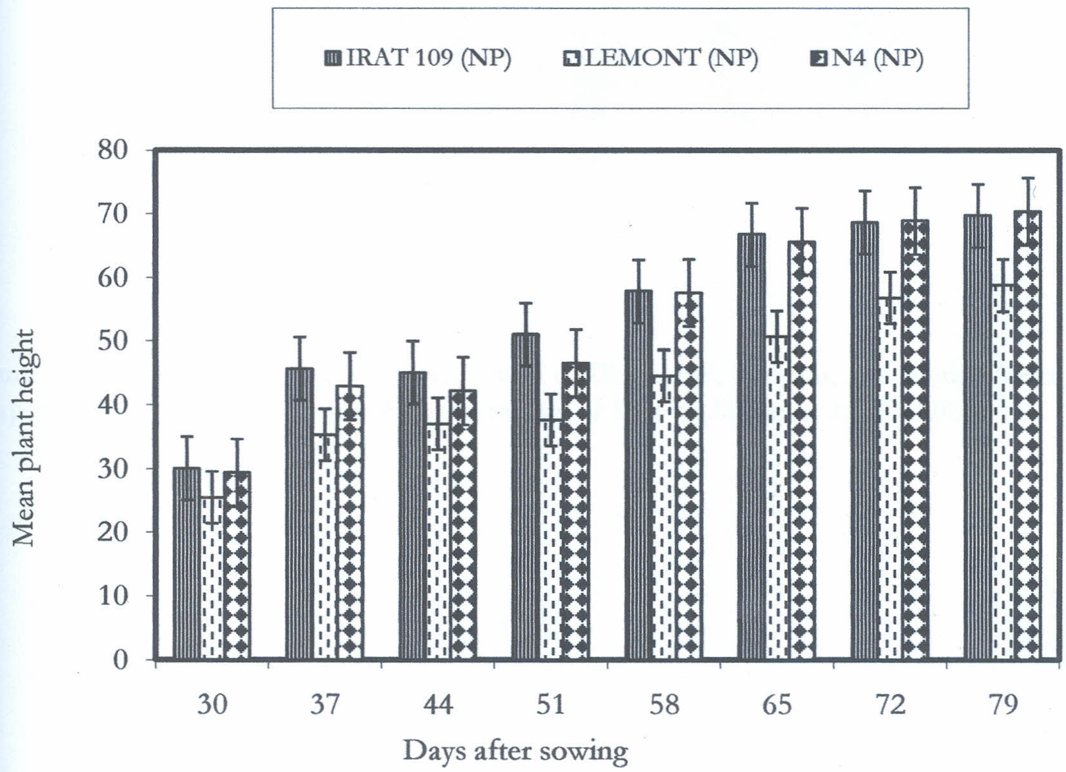


Figure 4. 27 Effect of fertilizer application on plant height of IRAT 109, Lemont, and Nerica 4 rice cultivar in experiment 2. Each point represents the means of four replications ±STD DEV.

SOIL OBTAINED FROM MASENO

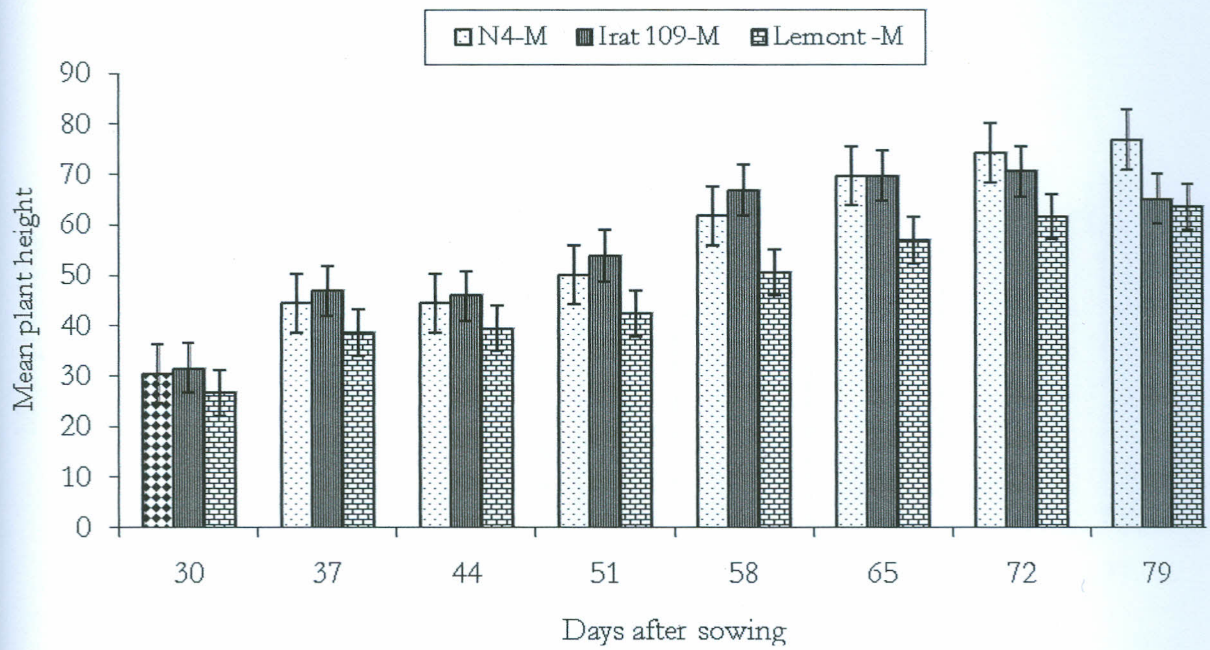


Figure 4. 28 Effect of soil type on plant height of IRAT 109, Lemont, and Nerica 4 rice cultivar in experiment 2. Each point represents the means of four replications ±STD DEV.

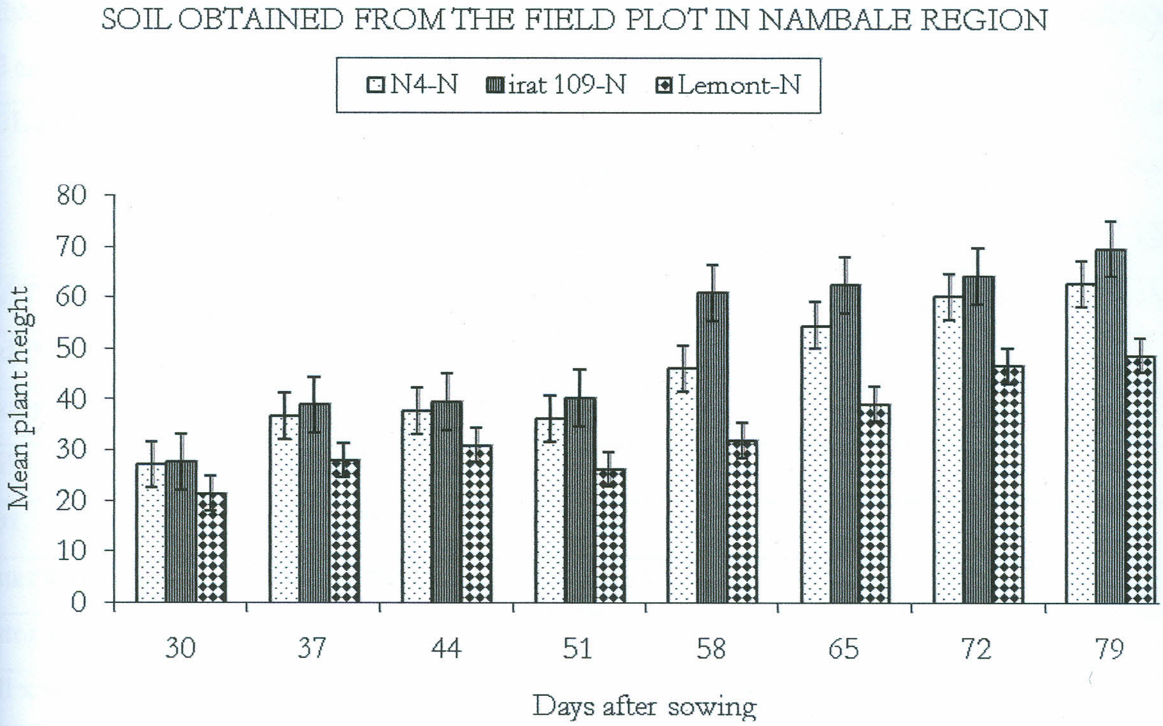


Figure 4. 29 Effect of soil type on plant height of IRAT 109, Lemont, and Nerica 4 rice cultivar in experiment 2. Each point represents the means of four replications ±STD DEV.

4.2.5.2. Shoot biomass

The shoot biomass accumulation in the three rice cultivars were significantly different, with NERICA 4 , with a mean shoot biomass of 63.2776875 while Irat 109 and Lemont were not significantly different, even though Irat 109 had the highest biomass of 48.75065625 and Lemont with 46.06221875. The response of the three cultivars to the various treatments were also significantly different at P≤0.05, there were significance difference in the various interaction levels as summarized in table 4.6

Table 4. 6 Shoot biomass of Irat 109, Lemont and NERICA 4 grown under different fertilizer a, soil and water, as at 121 das.

CULTIVAR	TREATMENT					
	FERTILIZER		SOIL		WATER	
	N	NP	MASENO	NAMBALE	WET	DRY
IRAT 109	43.438b	54.063a	53.782a	43.719b	52.475a	45.026b
Lsd (%)	3.1884					
Water	.0001 ***					
Soil	.0000 ***					
Fert	.0000 ***					
water x soil	.0000 ***					
water x fert	.2902 ns					
soil x fert	.6520 ns					
water x soil x fert	.0001 ***					
CULTIVAR	TREATMENT					
	FERTILIZER		SOIL		WATER	
	N	NP	MASENO	NAMBALE	WET	DRY
LEMONT	50.768b	57.705a	58.748a	50.592b	61.829a	47.0493b
Lsd (%)	7.2874		6.8167		6.9258	
Water	.0001 ***					
Soil	.0235 *					
Fert	.2806 ns					
water x soil	.9452 ns					
water x fert	.9113 ns					
soil x fert	.0163 *					
water x soil x fert	.8766 ns					
CULTIVAR	TREATMENT					
	FERTILIZER		SOIL		WATER	
	N	NP	MASENO	NAMBALE	WET	DRY
NERICA 4	55.882b	70.673a	70.523a	56.032b	72.814a	53.742b
Lsd (%)	2.9098					

Water	.0000 ***
Soil	.0000 ***
Fert	.0000 ***
water x soil	.9228 ns
water x fert	.0016 **
soil x fert	.8368 ns
water x soil x fert	.5919 ns

Ns-not significantly different,* significantly different, *** highly significantly different. Means followed by the same letters are not significantly different

4.2.3.3 Root biomass

The cultivars are significantly different at P≤0.05, with Irat 109 having a mean root biomass of 26.9115, Lemont with 14.7614 and NERICA 4 with a mean root weight of 21.4028, with a coefficient variance of 53.21%. Their performance in the two soils too are significantly different, Maseno soil contribution is 23.5105 of the overall root biomass of the three cultivars while in Nambale soil has a contribution of 18.5399., this shows that Maseno and Nambale soils are significantly different in terms of the rice root establishment and eventual biomass accumulation, this further summarised in figure 4.30 and further illustrated in table 4.7 for all the three cultivars with respect to soil depths.

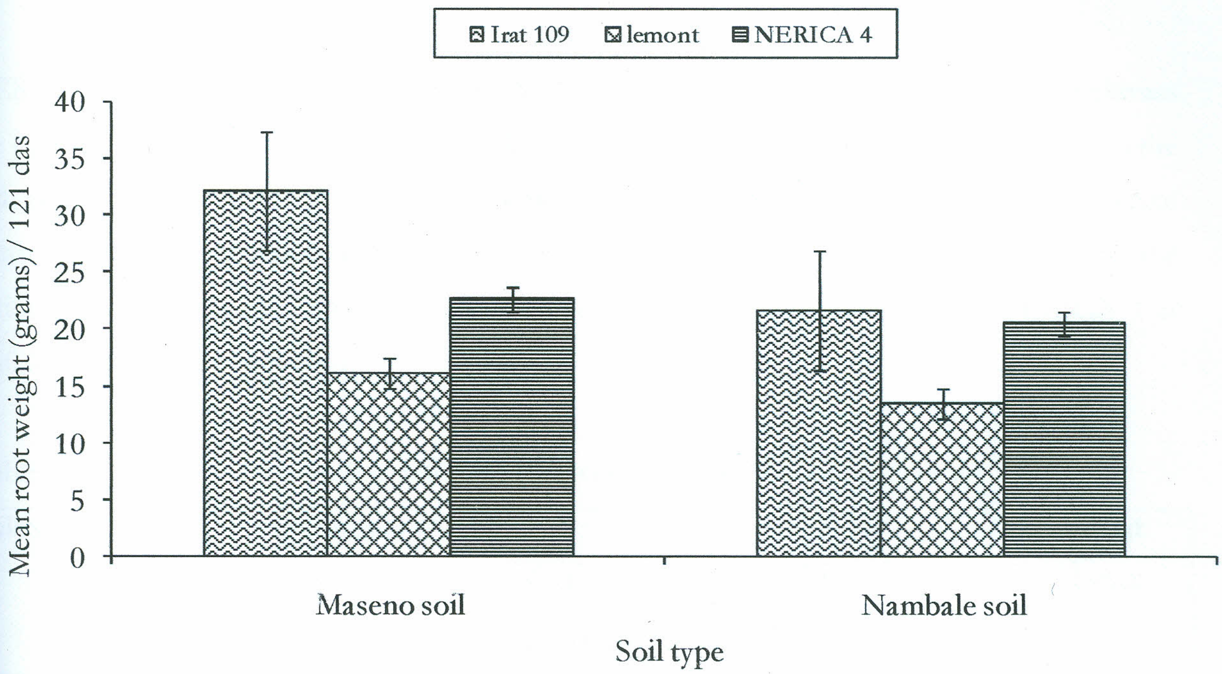


Figure 4. 30 Effects of soil type on root mean weights of IRAT 109, Lemont, and Nerica 4 rice cultivar in experiment 2. Each point represents the means of four replications ±STD DEV

Table 4. 7 Rice roots distribution within the soil column as at 121 das, at depths of 0-40 cm.

Cultivar	Root depth	Treatments.(F*S*W)						Lsd (%)
		Fertilizer		Soil		Water		
		N	NP	Maseno	Nambale	Wet	Dry	
IRAT 109	0-10	8.6554b	12.6025a	12.0159a	9.2419b	11.6213a	9.6366b	1.2405
	10-20	6.6606b	8.7178a	9.5676a	5.8308b	8.1108a	7.2876b	0.1777
	20-30	3.5538a	3.2052a	4.561a	2.1979b	3.4118a	3.3471a	0.8357
	30-40	2.2971a	1.9769a	2.6256a	1.6484a	2.1024a	2.1716a	1.0787
Lemont	0-10	5.8793a	5.6481a	5.8339a	5.7223a	5.8808a	5.6688a	0.9605
	10-20	3.9418a	4.5518a	4.4535a	4.1164a	3.9188b	4.6747a	0.7046
	20-30	2.5749a	2.6674a	3.2918a	1.9621b	2.5928a	2.6632a	0.6959
	30-40	1.7414a	1.6817a	1.9209a	1.4948a	1.5991a	1.8235a	0.7099
NERICA4	0-10	6.3361b	7.7899a	6.7286b	7.3973a	7.3311a	6.7949b	0.2525
	10-20	4.5085b	6.0588a	4.9923b	5.5749a	5.3016a	5.2657a	0.1883

	20-30	2.8002a	3.2016a	3.9984a	2.0033b	3.3741a	2.6276a	0.8901
	30-40	1.8393a	2.0917a	2.3328a	1.5982a	2.2339a	1.6972a	0.9023

Means followed by the same letters are not significantly different

NERICA 4 was used as a checker cultivar, the response to the various treatments by the cultivars are significantly different more so within the root extraction depths of 0 - 40 cm deep into the soil table 4.8, and minimal differences occurs from the depth of 40 cm to the maximum measured depth of 90 cm below the soil surface as in appendix 17. Figure 4.31, illustrates the various measured means of the roots of three cultivars, Irat 109, Lemont and NERICA 4 at $P \leq 0.05$, as illustrated in table 4.8

Table 4. 8 Rice roots distribution within the soil column as at 121 das, at depths of 0-40 cm.

Cultivar	**Root depth**	**Treatments.(F*S*W)**						**Lsd (%)**
		Fertilizer		**Soil**		**Water**		
		N	**NP**	**Maseno**	**Nambale**	**Wet**	**Dry**	
Irat 109	**0-10**	**8.6554b**	**12.6025a**	**12.0159a**	**9.2419b**	**11.6213a**	**9.6366b**	**1.2405**
	10-20	**6.6606b**	**8.7178a**	**9.5676a**	**5.8308b**	**8.1108a**	**7.2876b**	**0.1777**
	20-30	**3.5538a**	**3.2052a**	**4.561a**	**2.1979b**	**3.4118a**	**3.3471a**	**0.8357**
	30-40	**2.2971a**	**1.9769a**	**2.6256a**	**1.6484a**	**2.1024a**	**2.1716a**	**1.0787**
Lemont	**0-10**	**5.8793a**	**5.6481a**	**5.8339a**	**5.7223a**	**5.8808a**	**5.6688a**	**0.9605**
	10-20	**3.9418a**	**4.5518a**	**4.4535a**	**4.1164a**	**3.9188b**	**4.6747a**	**0.7046**
	20-30	**2.5749a**	**2.6674a**	**3.2918a**	**1.9621b**	**2.5928a**	**2.6632a**	**0.6959**
	30-40	**1.7414a**	**1.6817a**	**1.9209a**	**1.4948a**	**1.5991a**	**1.8235a**	**0.7099**
NERICA4	**0-10**	**6.3361b**	**7.7899a**	**6.7286b**	**7.3973a**	**7.3311a**	**6.7949b**	**0.2525**
	10-20	**4.5085b**	**6.0588a**	**4.9923b**	**5.5749a**	**5.3016a**	**5.2657a**	**0.1883**
	20-30	**2.8002a**	**3.2016a**	**3.9984a**	**2.0033b**	**3.3741a**	**2.6276a**	**0.8901**
	30-40	**1.8393a**	**2.0917a**	**2.3328a**	**1.5982a**	**2.2339a**	**1.6972a**	**0.9023**

Means followed by the same letters are not significantly different

Root biomass Irat 109 and Lemont are significantly different in terms of their total root biomass weights, under field condition at $P \leq 0.05$; the significance difference is evident at 53rd and 74th das but no significance difference at 95th and during harvesting at 121st das.

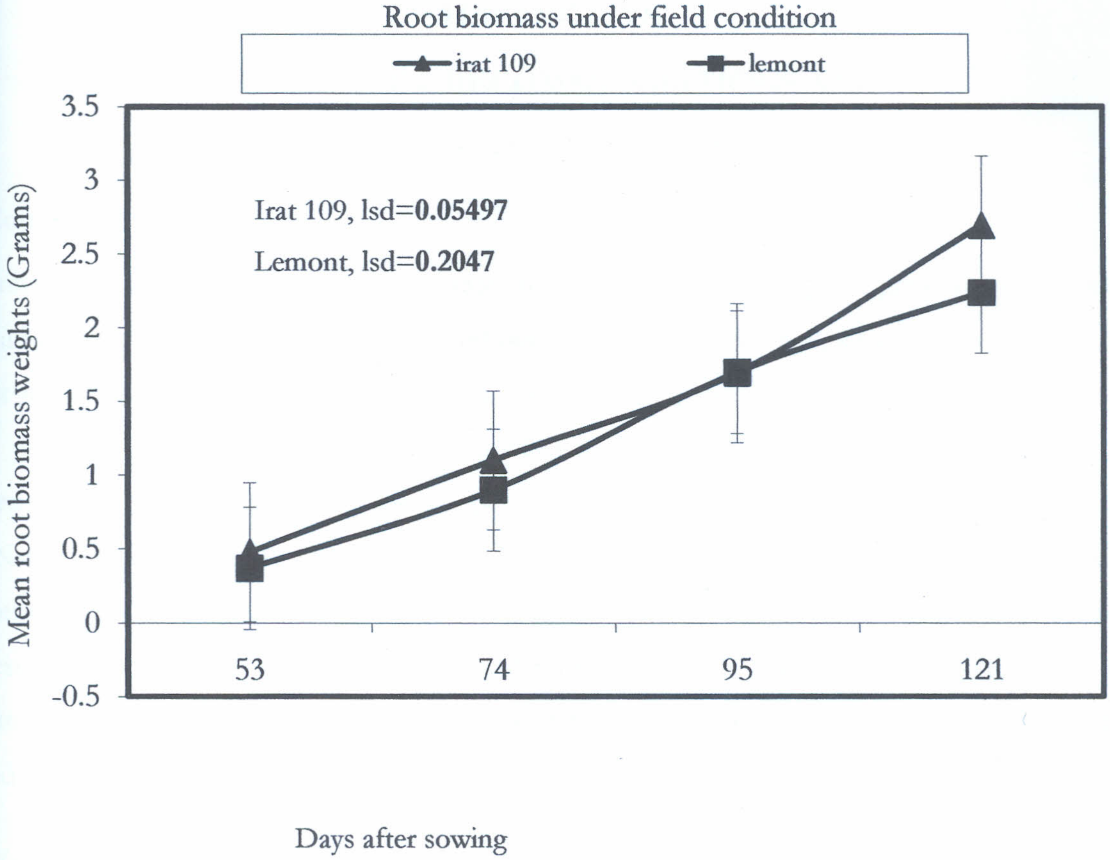


Figure 4. 31 Irat 109 and Lemont total root biomass under field condition

CHAPTER FIVE

CONCLUSION, RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

5.1 Conclusions

The results in this study indicates that water-nutrient stress affects plant growth, development and ultimately the yield of the three selected rice genotypes, IRAT 109, Lemont and NERICA 4. Water-nutrient stress leads to a decrease in plant height, plant biomass and greatly affects the grain yield by decreasing tiller number, panicle length and filled grain percentage. The water-nutrient stress affects the physiological aspects of the plant, reduces the stomatal conductance and N foliar content levels. IRAT 109 can tolerate moisture deficit. There was a variation in the performance of the three selected rice genotypes, IRAT 109 is early maturing and exhibited the highest tolerance to water-nutrient deficit. IRAT 109 being early maturing cultivar, it has coherent physiological traits to escape late drought and the ability to maintain growth during period of drought that may occur late in the season.

5.2. Recommendation

IRAT 109 showed greater tolerance to water-nutrient stress as compared to the other two rice cultivars, Lemont and N4. It may be recommended for cultivation in the upland agro-ecological zones of Kenya under rainfed condition.

5.3 Suggestions for further research

For further research on upland rice in relation to physiological and developmental response to water and nutrient stress under different soil types, the following should be considered.

1. The soil and plant water potentials to be determined in order to establish the wilting point, absorption and transpiration of IRAT 109, Lemont and NERICA 4.
2. Bottom up approach by determining the various root types in IRAT 109, Lemont and NERICA 4 and their root lengths in order to prove whether root lengths confers some advantage in drought tolerance among the three rice cultivars.
3. Nutrient analysis determination in order to establish which cultivars has higher nutrient sink and thus effective nutrient utilization.
4. Perform closed type of experiment on the three rice cultivars in order to determine the net effect of phosphorus on root establishment in drought environment

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