EFFECTS OF PLANT DENSITY AND NITROGEN APPLICATION ON LEAF AREA INDEX (LAI) AND MAIZE YIELD IN A RECLAIMED WETLAND OF NYERI COUNTY, KENYA.

BY

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DECLARATION

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To Mom, Alicia and my late Dad.

ABSTRACT

Maize is the main staple food in Kenya. Over 90% of Kenyans rely on maize with an annual per capita consumption of 94 kg. The annual maize production in Kenya is about 2.7 million metric tonnes and is slightly lower than the domestic consumption above which translates to roughly 37.8 million bags (3.4 million metric tons) per year. Kenya's average production per hectare is about one twentieth of that attained in other countries such as Argentina. Maize yield is more affected by variations in plant density than other members of the grass family. The study was carried out to determine the effects of plant density, fertilizer application as well as the wetland conditions on the maize yield. This study investigated the effect of N application at 120 kg N/ha and plant density on the Leaf Area Index and maize yield grown on reclaimed wetland soils in Karatina, Nyeri county during the short rain season of 2012 and long rain season of 2013. Treatments were laid in a randomized complete block design with three replications. Leaf Area Index (LAI) was determined directly using copy method and indirectly using Sun scan. Measurements were carried out every 10 days till physiological maturity. Initial soil sampling was carried out in September 2012 at the start of the trial and subsequent soil sampling at the end of each season (after maize harvesting) and selected analyses done. Maize yield was also determined after harvesting and sub sampling done per plot excluding the guard rows. The treatments applied were as follows: 100 *12.5 (-N), 100 * 12.5 (+N), 100 * 25 (-N), 100 * 25 (+N), 50 * 12.5 (-N), 50 * 12.5 (+N), 50 * 25 (-N), 50 * 25 (+N).

Results indicated that nitrogen application affected total N, C and pH of the reclaimed wetland soil. The leaf area index increased with Nitrogen application and reduced with increase in spacing for most treatments, however grain yield did not change significantly with the application of Nitrogen fertilizer. All treatments correlated positively with the grain yield depending on spacing and availability of N at ($p \leq 0.05$). In relation to grain yield, it is shown that the treatment 50 cm *12.5 cm (-N) had the highest yield ($p \leq 0.05$) of 4.2 t/ha followed by 50 cm * 12.5 cm (+N) (3.6 t/ha). Lowest yields ($p \leq 0.05$) were however recorded in the 100 cm * 25 cm (+N) treatments with 1.7 t/ha. There were no significant differences between the two LAI methods (Copy Method and SunScan). It was concluded that high plant density gives high LAI, which contributes greater grain yield. Application of Nitrogen also increased the grain yield as well as the Leaf area Index. Plant spacing of 50 cm * 12.5 cm (-N) and 50 cm * 12.5 cm (+N) are recommended.

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LIST OF ABBREVIATIONS AND ACRONYMS

LAI	Leaf Area Index
KARI	Kenya Agricultural Research Institute (now KALRO)
FAO	Food and Agriculture Organization
ASALs	Arid and Semiarid Lands
PAR	Photosynthetically Active Radiation
PDA	Personal Digital Assistant
FURP	Fertilizer Use Recommendation Project
DOY	Day of the Year
HCL	Hydrochloric acid
NH_4F	Ammonium Fluoride
Ca	Calcium
Al	Aluminium
NH_4	Ammonium
Mg	Magnesium
P	Phosphorus
Ppm	Parts per million

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CHAPTER ONE

INTRODUCTION

1.0 Background Information

Maize is the main staple food in Kenya. Over 90% of Kenyans rely on maize with an annual per capita consumption of 94 kg (De Groote et al., 2005). The annual maize production in Kenya is about 2.7 million tons and is slightly lower than the domestic consumption needs (FAO, 2008). Growth in maize production in Kenya has also been marginal averaging about 2% which is lower than the population growth rate which stands at 3% and therefore for the country to be self sufficient, domestic production has to grow at a rate of 4% (GOK, 2013). Kenya's average production per hectare is about one twentieth of those attained internationally in countries such as Argentina (Nyoro, 2002). This shortage is attributed to various factors including lack of productivity enhancing technologies for specific sites, high incidence of pests and diseases, erratic climatic conditions and difficulties in accessing credit (Nyoro *et al.,* 2007). In the last one decade, the country has experienced years of heightened food insecurity and dependence on imports and emergency humanitarian assistance. In 2009, Kenya imported 16.8 million bags of maize (GOK, 2013). Most farmers in Kenya grow maize basically for domestic use, apart from the large-scale farmers who grow it for commercial purposes. While yearly country consumption has been going up due to increased population, from 2.4 million metric tons in 2001 to 2.8 million metric tons in 2003, production of this crop has declined from 2.6 million metric tons to 2.4 million metric tons in the country (FAO, 2008) between 1995 and 2004, domestic production has stagnated between 24 and 28 million bags (90 kg bag) (Kibaara, 2005). More recently, maize production has witnessed a much greater technological transformation in both large and smallholder farms across the country compared to other cereals (FAO, 2013), but despite all the efforts to increase its production, the yield is still as low as 1.0 t/ha at small scale level (Nekesa *et al.,* 1999), well below the potential average of 6.8 t/ha (Hassan *et al.,* 1998) an indication of a wide yield gap between farm obtained yield and the potential yields of the country. Kenya for a long period pursued the goal of attaining self sufficiency in food commodities that included maize, wheat, rice, beans, milk and meat. Self sufficiency in maize was achieved during the 1970s when production was high and the surplus was exported (Kibaara, 2005). Unfortunately, attainment of self sufficiency does not automatically imply that household food security is achieved. Empirical evidence shows that solving the food security issue from production (Supply side) point of view, while overlooking the purchasing power (demand side) of the people, does not solve the food security problem, with regard to accessibility of sufficient food by vulnerable groups (FAOSTAT, 2013). To satisfy demand for food, Sub-Saharan African countries have had to rely increasingly on imports. About 30% of cereal consumption is currently imported compared to 5% in late sixties (FAO, 2008).Nitrogen fertilizer is a key nutrient in the production of non legume crops. It is a component of many biological compounds that plays a major role in photosynthetic activity and crop yield capacity (Tollennar, *et al.,* 2006) and its deficiency constitutes one of the major yield limiting factors for cereal production (Shah *et al.,* 2003). Munamava *et al.,* (2006), reported that new maize hybrids were more tolerant than earlier hybrids to limited N supply during the early vegetative phase with respect to rate of leaf appearance, photosynthesis, stomatal conductance and chlorophyll content. Nitrogen is part of the enzymes associated with chlorophyll synthesis and the chlorophyll concentration reflects relative crop N status and yield level (Blackmer *et al.,* 1995).

Leaf area index (LAI) is a dimensionless variable and is defined as the total one-sided area of photosynthetic tissue per unit ground surface area (Asner et al., 2002). The LAI is a significant ecological attribute that controls vegetation photosynthetic activity. As such, LAI plays an essential role in climate, weather, and ecological studies. In the realm of possible climate change and its influence on landscape's future CO_2 sequestration potential, more precise knowledge about the theoretical production ecology of the various world biomes (wetlands, woodlands, shrublands, or grasslands) is essential. The LAI belongs to the biophysical variables which are useful to the development of knowledge in climate and environmental sciences, to understand the climatic system and ecophysiological processes. Furthermore LAI is strongly dependent on the prevailing site conditions and the management practices. The LAI of vegetation depends on species composition, development stage, and seasonality.

According to an FAO study (FAO, 2011) African soils lose an annual average of 48kg/ha of nutrients, the equivalent of 100kg/year of fertilizer and to compensate for this loss, they receive an average of only 10kg of mineral fertilizer compared to a global average of 90kg. This degradation has led to the decline in the per capita food production which has resulted into more than just an economical problem because this potentially explosive situation resulting from food insecurity threatens the very fabric of social stability in the poorest countries. Land pressure is one of the reasons leading to the decreased availability of food as well as soil depletion and management practices of the farmers. Inadequate management practices to ensure complete replenishment of the soil is also lacking in most cases leading to further degradation and eventually reduced yields, due to nutrient removal during the cropping and harvesting of the crops. Population pressure in high potential areas is pushing human settlement to water catchment areas and also cultivation of the fragile ecosystems (Kamiri *et al.,* 2013). This is evidenced by the large number of people cultivating on the wetlands in the former Central Province pointing to a need for research geared towards assisting farmers obtain better yields from their small pieces of land to enable them improve their livelihoods as well as reduce the yield gap of maize in Kenya. Wetlands cover 2 to 3% of the country's surface area (117,580 km2) and farming is mostly practiced in inland valleys accounting for 87% of all wetlands. Most wetlands consist primarily of hydric soil which supports aquatic plants (Kamiri *et al.,* 2014). Most nutrients, such as sulfur, phosphorus, carbon, and nitrogen are found within the soil of wetlands. Biogeochemical processes in wetlands are determined by soils with low redox potential (Schlesinger, 1997). Anaerobic and aerobic respiration in the soil influences the nutrient cycling of carbon and nitrogen and the solubility of phosphorus (Hans *et al.,* 2001). Some farmers live on wetlands and cultivation here has many challenges because alternate flooding and drying of the soil which is experienced by wetland soils is detrimental to both fertilizer sources and native soil sources of Nitrogen and phosphate. There is therefore need for thorough research to enable farmers benefit optimally from their land.

1.1 Statement of the Problem

In Sub- Saharan Africa, soil fertility depletion and soil degradation present the most serious problems, the major one being food insecurity. Land pressure is one of the major reasons leading to the decreased availability of food as well as soil depletion, and this is evident in Nyeri County with most areas having 304 persons per square kilometer. This has led to farmers encroaching on fragile ecosystems such as wetlands and forests which has consequently resulted to land degradation. Management practices such as fertilizer application and plant spacing have a strong effect on LAI as well as maize yield. Leaf area may be decreased by N deficiency, depending on the severity. In addition crop yield commonly depends on the total amount of photosynthetically active radiation (PAR) intercepted, particularly when crop growth is not limited by other factors such as nutrient, water deficiency or temperature extremes. In spite of the widely recognized importance of PAR and leaf area index (LAI) across such a broad range of physical and ecological research, not much research has been done recently. Despite the abundant individual plot and stand based LAI studies, there are few comprehensive reviews of LAI data in literature and thus the need for research geared towards assisting farmers with information regarding wetland cultivation. These are major factors to consider in order to maximize yields and reduce the yield gaps, maintain soil fertility and acceptable amounts of water in the wetlands.

1.2 Justification

Maize is the main staple food in Kenya with over 90% of Kenyans relying on it. Despite this, its yields are still low in Kenya compared to the potential yields. The yields in the area are still as low as 1.0 t/ha against a potential yield of 6.8 t/ha (Smaling, 1992). This can be attributed to land degradation especially declining soil fertility. Among the major plant and soil nutrients essential for food production in Kenya is nitrogen. It is a key nutrient in the production of non legume crops as it is a component of many biological compounds that plays a major role in photosynthetic activity and crop yield capacity (Tollenar, *et al.,*2006) and its deficiency constitutes one of the major yield limiting factors for cereal production (Shah *et al.,* 2003), and since there is little available information on nitrogen status for Tegu reclaimed wetland in Nyeri County, there is need for comprehensive Soil testing. Crop yield commonly depends on the total amount of photosynthetic active radiation (PAR) intercepted, particularly when crop growth is not limited by other factors such as nutrient, water deficiency or temperature extremes. The availability or deficiency of nitrogen also determines the leaf area index of maize since it is very essential for proper leaf formation and thus very important in determination of the photosynthetic ability of the crop, and hence productivity. Plant density also determines the amount of PAR intercepted by the plant and thus plays a major role in determining the LAI as well as yield. The LAI is a significant ecological attribute that controls vegetation photosynthetic activity. As such, LAI plays an essential role in climate, weather, and ecological studies. In the realm of possible climate change and its influence on landscape's future CO_2 sequestration potential, more precise knowledge about the theoretical production ecology of the various world biomes (wetlands, woodlands, shrublands, or grasslands) is essential. Though wetland soils are fragile in terms of use, research is essential to enable proper management and planning can be done to produce food and yet sustain the capacity of these soils. This study is therefore very important since it enables the determination of productivity using the leaf area index which can be used to predict yield and help in explaining any reduction in yields at harvest.

1.3 Objectives

1.3.1 Main Objective

The main objective of this study was to determine the effects of plant density and nitrogen application on Leaf Area Index (LAI) and hence on maize productivity in reclaimed wetland soils of Karatina in Nyeri County

1.3.2 Specific objectives

1. To determine the effect of nitrogen fertilizer application and plant density on soil pH, N,P,K ,C, and Ca in reclaimed wetland soils.
2. To determine the effect of plant densities and nitrogen application on the Leaf Area Index of Maize.
3. To determine the effect of nitrogen fertilizer application and plant density on maize grain and dry matter yield and tissue nutrient concentration.

1.4 Hypotheses

i. Nitrogen fertilizer application and plant density affects soil pH, N,P,K ,C, and Ca in reclaimed wetland soils.

ii. Leaf Area Index of maize responds to different planting densities and Nitrogen application.

iii. Nitrogen fertilizer application and plant density have an effect on maize grain yield, dry matter, and tissue nutrient concentration.

CHAPTER TWO

LITERATURE REVIEW

2.0 Maize *(Zea mays L.)* production and global trends

Maize *(Zea mays* L.) is one of the most important cereal crops of the world extensively grown in irrigated and rain fed areas (Irshad *et al.,* 2002). It ranks the third position among cereal crops after wheat and rice. Increasing maize production became one of most important goals of the world to face the human and animal demands. It is used as food, feed and forage (Muhammad *et al.,*1990; FAOSTAT, 2013). Maize still continues to be the major staple food and Kenyans have one of the highest rates of maize consumption per capita in Africa (De Groote *et al.,* 2005). This can be achieved through several management systems such as growing new high yielding varieties under the most favorable cultural practices such as the application of the needed nutrients in the right amounts, timely planting, control of common pests and diseases and improved post harvest techniques. (Mfundisi *et al.,* 2014)

2.1 Fertilizer nitrogen application and crop production performance

Nitrogen fertilizer is a key nutrient in the production of non legume crops. It is a component in many biological compounds that plays a major role in photosynthetic activity and crop yield capacity (Pandey *et al.,* 2000) and its deficiency constituents one of the major yield limiting factors for cereal production in the world (Shah, *et al.,* 2003). Nunes and Silva (1996) reported that new maize hybrids were more tolerant than earlier hybrids to limited N supply during the early vegetative phase with respect to rate of leaf appearance, photosynthesis, stomatal conductance and chlorophyll content. Nitrogen fertilizer is universally accepted as a key component to high yield and optimum economic return as it plays a very important part in crop productivity (Ahmad et al., 2000)

2.2 Effects of crop management on Maize yield

There are a number of biotic and abiotic factors that affect maize yield considerably; however, it is more affected by variations in plant density than other members of the grass family (Vega *et al.,* 2001). Plant populations affect most growth parameters of maize even under optimal growth conditions and therefore it is considered a major factor determining the degree of competition between plants (Sangakkara *et al.,* 2004). Stand density affects plant architecture, alters growth and developmental patterns and influences carbohydrate production. Management of maize by varying row spacing has been found to increase maize productivity (Mucheru Muna *et al.,* 2010).

Widdicombe and Thelen (2002) recorded yield increases of maize up to 10% with reducing row spacing. Murphy *et al.,* (1996) recorded that maize planted at 50 cm rows intercepted about 8% more PAR at silking than crop at conventional rows, reducing biomass of late-emerging. Modaress *et al.,* (1998) reported that maize yield differs significantly under varying plant density levels due to difference in genetic potential. Correspondingly maize also responds differently in quality parameters like crude starch, protein and oil contents in grains (Munamava *et al.,* 2006).

It has been discovered that differences in biological yield and N uptake vary partly due to decreased soil N mineralization and partly due to weather conditions. Adequate planting densities can contribute towards significant grain yield increases for farmers (Gaurkar and Bharad, 1998). Maize yield response to density depends on the variety (Chandra and Gautan, 1997) and environmental factors (Bondavalli *et al.,* 1970) and even negative responses of the crop to a given factor can be verified beyond certain limits. Biomass yield is likely to increase with increase in plant density and N rate (Gaurkar and Bharad, 1998).

Plant height and yield in maize increase up to a plant density of 71900 plants ha^{-1} and 280 kg N ha^{-1}, but further increase in both plant density and N rate has no significant effect on the plant height and biomass yield (Turgut, 2000). Leaf area and number are important factors in the estimation of canopy photosynthesis in crop growth simulation models that compute dry matter accumulation from temporal integration of canopies' photosynthesis (Boote *et al.,* 1996; Oguntunde, *et al.,* 2012). Thus leaf area influences interception and utilization of solar radiation of crop canopies and consequently crop dry matter accumulation and yield.

2.3 Leaf Area Index (LAI)

There are several definitions and interpretations of leaf area index (LAI) which have been proposed. These vary depending on the technique used to measure LAI. For example Asner et al., (2002) defined LAI as the total one-sided area of photosynthetic tissue per unit ground surface area. Myneni *et al.,* (1997) are reported to have defined LAI as the maximal projected leaf area per unit ground surface area. Other authors for example Chen and Black, (1992) defined LAI as one half the total leaf area per unit ground surface area. It is important to note that these different definitions can result in significant differences between calculated LAI values.

In this study the definition by Asner et al., (2002) is applied and thus LAI is broadly defined as the amount of leaf area (m^2) in a canopy per unit ground area (m^2). LAI is a dimensionless quantity and thus can be measured, analysed and modeled across a range of spatial scales, from individual tree crowns or clusters to whole regions or continents. As a result, LAI has become a central and basic descriptor of vegetation condition in a wide variety of physiological, climatological, and biogeochemical studies (Asner, 1998). LAI is widely used to characterize canopy light climate. A canopy where LAI equals one (1) has a leaf area equal to the soil surface area on which it grows, but this does not mean all PAR is intercepted because some leaves overlap, leaving gaps. Moreover, not all leaves are positioned at right angles to incident radiation. A crop under favourable growing conditions increases LAI rapidly during early development. As a general rule, maximum LAI is achieved just prior to flowering in cereal crops. By that stage, growing points are differentiating floral rather than leaf primordial, and initiation of new leaves has ceased. Some cereal crops lose leaves and LAI decline during grain filling as crops mature (Running & Coughlan, 1988).

2.4 Canopy Cover

Canopy cover or closure is a measure of the fraction of the landscape covered by vegetation. Like LAI (leaf area index), canopy cover is an important factor determining the amount of light intercepted or absorbed by the canopy, and photosynthetic rates. Canopy cover also determines how much rainfall is intercepted by vegetation before hitting the ground, a property that affects evaporation and erosion rates and consequently is important in hydrological studies (Asner, 1998).

Measurement of canopy cover can be done using the same methodologies used for the optical measurement of LAI. The canopy coverage is simply *1 minus total gap fraction*. Part of the interest in this canopy descriptor is that it avoids the need to make assumptions about leaf spatial distribution required to calculate LAI from the gap fraction data (Birch *et al.,* 1998).

2.5 Importance of LAI measurements

The LAI is a significant ecological attribute that controls vegetation photosynthetic activity. As such, LAI plays an essential role in climate, weather, and ecological studies. In the realm of possible climate change and its influence on landscape's future CO_2 sequestration potential, more precise knowledge about the theoretical production ecology of the various world biomes (wetlands, woodlands, shrublands, or grasslands) is essential (Asner, 1998). LAI is widely used as input variable for land surface modelling of biosphere processes, and especially for predictions of photosynthetic primary production.

The LAI belongs to the biophysical variables which are useful to the development of knowledge in climate and environmental sciences, to understand the climatic system and ecophysiological processes. The biophysical parameters are also indispensable as input to environmental services that use these data, at the same time as other data types (*in situ*, agrometeorological models, to produce environment monitoring indicators (water quality, drought or famine risks, desertification, deforestation/reforestation, etc). Published values of LAI for grassland species are in a range between 0.3 to 2.0. Leaf Area index of woody parts of trees can be assumed to be around 0.5, covering a range of 0.2 to 0.9 (Breuer *et al.,* 2002).

2.6 Factors influencing leaf area index in field crops

The time-course of radiation interception during crop growth can be manipulated to some extent by farmers. However several factors are thought to have an effect on leaf area index. Leaf area influences the interception and utilization of solar radiation of top canopies and consequently the yield. Rate of leaf expansion, maximum leaf and rate of leaf senescence are important factors in the estimation of canopy photosynthesis in crop growth simulation models. Leaf area is influenced by several factors including genotype, plant population, climate and soil fertility (Birth, *et al.,* 1998).

2.6.1 Plant density

Seeding rate is an important management option which affects interception and subsequent crop growth and yield. A higher seeding rate would produce a higher plant density and a higher LAI at crop establishment. This hastens canopy interception and hence biomass production would be promoted. Narrow plant spacing compared to broad plant spacing in crop stands leads to rising LAI. Any advantage of a high plant density may disappear with time during crop growth because radiation interception of a medium plant density may eventually catch up with that of the high density (Pandey *et al.,* 2000). He also reported that maize varieties differ in its ability to maintain Leaf Area Index (LAI) and above ground dry matter biomass at different levels of water deficit and nitrogen supply. Plant height, inter-node length and ear height is greater under high density and leaf area decreases with increase in plant density in maize (Modarres *et al.,* 1998).

2.6.2 Species composition

The LAI of vegetation depends on species composition. The LAI is well adapted for flat leaves as, for example, grass, crops, and deciduous forests. For instance in coniferous woodland and grasses, shoot is considered as the foliage element, and the assembly of needles (e.g., angle, shape) should be taken into account.

2.6.3 Stage of development of the crop

The annual trend of LAI for major crops and trees, peaks during the height of growing season. LAI of plants, especially grasses and cereals, consists of photosynthetically active green and senescent leaves. Even though old leaves do not influence photosynthesis, they still play an important role in intercepting precipitation . Oguntunde *et al.,* (2012) in their experiment carried out on wheat, found LAI to vary with the stage of growth of the crop and that there was a clear trend in all the treatments of gradual rise (in the LAI) till the crop reached the flowering stage. Thereafter LAI continued to decline until the crop attained the maturity stage.

2.6.4 Seasonality.

The accurate estimation of vegetation biochemical and biophysical variables is important in many agricultural, ecological, and meteorological applications (Darvishzadeh *et al.,* 2008). Three of these variables Leaf Area Index (LAI), height, and biomass, can be used to describe the architecture of plants, monitor changes in canopy structure, and predict growth and yield. The reliable estimation of these variables during the growing season would improve planning, the management of grain production, the handling of the grain, and marketing (Boote *et al.,* 2003). Moreover, because these variables vary seasonally and respond rapidly to stress factors and changes in climatic conditions, it is important to estimate their values frequently, but this can be difficult when the vegetation covers large areas.

2.6.5 Prevailing site conditions

A high value of LAI indicates a denser or healthier crop canopy, while a low value represents sparse and/or drier canopy. LAI, therefore, can be used to assess crop conditions or drought severity (Boote *et al.,* 2003).

Traditionally, LAI is measured for point locations using a leaf area meter. These measurements are averaged in order to estimate LAI for an area; but the average value may be subject to significant errors depending on sampling and spatial variability in

LAI. These errors tend to expand when the spatial variation in crop canopy, and hence in LAI, increases. Arid areas experience larger spatial variation in LAI mainly due to a high coefficient of variation in precipitation (Kumar, 1998). With the advent of satellite remote sensing, it has become possible to improve accuracy in aerial estimates of LAI.

2.6.6 Crop Management

Development of adequate leaf area index is essential for a crop canopy with respect to light interception and utilization *vis-a-vis* CO_2 fixation and dry matter production. At early stage of crop growth, rapid leaf area development not only covers the ground to enhance light interception but also checks soil water loss through evaporation and weed growth. Subsequently, several researchers have shown that decreased leaf area and dry matter production due to N limitation were mainly responsible for reduction in seed yield at maturity (Nevin & Loomis 1970). Hageman and Below (1990) proposed that one of the key roles of nitrogen in producing high crop yields is through the establishment of fully-grown crop canopy.

In determinate crop plants such as maize, sorghum, rice and wheat, variation in leaf number in response to N application is restricted whereas leaf size increases with increase in N supply (Sivasankar, 1992). Adequate N supply increased the rate of production of new leaves and duration of leaf expansion in sunflower and sugar beet (Steer & Hocking, 1983). In *Brassica,* N supply increased the number of leaves per plant by 25-40%; however, variation in leaf expansion brought about by difference in N supply was more than leaf number (Ogunlela *et al.,* 1989). Thus, leaf size is influenced by N supply more than leaf number in different agricultural crops. It appears that leaf number is more under genetic rather than environmental control. The degree of response to N supply in terms of leaf area expansion vary with plant growth stage. In determinate crop plants such as maize, sorghum, rice and wheat, variation in leaf number in response to N application is restricted whereas leaf size increases with increase in N supply. In leaves with low nitro- gen content, the potential photosynthetic nitrogen use efficiency is low and it increases with increasing nitrogen , but its content in leaves may become low because of the deficient soil and/or when the uptake of nitrogen from the soil is insufficient. (Lemcoff & Loomis, 1986)

According to Valentinuz and Tollenaar, (2006) breadth of the area per leaf profile decreases under high soil nitrogen level and high plant density and that leaf area and yield increased with higher rate of N. The sum of these factors, combined with the difference in assessment methods, may therefore lead to widely varying LAI values. Management practices such as fertilizer application or thinning may have a strong effect on LAI, and . leaf area can be decreased by N deficiency, depending on the severity.

2.7 Methods of measuring leaf area index

There are a variety of methods for measuring LAI. The major methods for estimating LAI employ either “direct” measures (involving destructive sampling, litter fall collection, or point contact sampling) or “indirect” methods (involving optical instruments and models). Direct destructive sampling methods have been used successfully in agriculture research (Deblonde *et al.,* 1994, Wilhelm *et al.,* 2000, Broadhead *et al.,* 2001)

2.7.1 Direct methods

The most straight forward, usually used in herbaceous or grassy canopies, is to simply define an area on the ground, clip off all the leaves, and measure their area. Dividing the total area of all the leaves by the ground area gives LAI. Another method is the copy method whereby the plants are cut, leaves are stripped and photocopied. The weight of the copied leaves and the area of the paper are used to calculate the leaf area index. The two methods are time-consuming and have the added disadvantage of destroying the plants being studied. Usually the methods are done just on small samples of the total area of interest (Oguntunde *et al.,* 2012).

2.7.2 Indirect methods of LAI measurements

2.7.2.1 In forest systems

One of the indirect methods used in forests, is to directly measure a series of individual trees spanning a range of sizes (done for one species at a time). Leaf area is directly measured for each individual tree (this usually means cutting down the tree), along with several other plant measurements such as trunk diameter, tree height, and depth of the crown. A mathematical relationship is then developed between the measurements of diameter, height and crown, and the leaf area for each species. This relationship is referred to as an allometric equation; each separate species has its own allometric relationship or equation. Once an allometric equation has been developed, LAI can be estimated elsewhere in a tree stand using just the simple measurements of height, diameter and crown depth (Myneni *et al.,* 1997).

2.7.2.2 In grassland and field crops

A common method used in grasses and field crops to measure LAI is to measure the fraction of incoming light that passes through the plant canopy. This is done by making assumptions about how leaves are distributed in the canopy, then measuring the size and number of gaps between the leaves. These two pieces of information can then be used to calculate LAI. Canopy gaps can be measured by recording the intensity of light transmitted down through a canopy. The advantages of these optical approaches is that they can be collected fairly quickly with minimal disturbance to the vegetation, allowing repeated observations over time. However, there are some uncertainties with these methods. The optical measurements do not distinguish between leaves and other materials in the canopy, such as branches or tree trunks, nor can they separate live and dead leaves (Boote *et al.,* 1996).

2.7.2.3 The Sunscan Probe

The SunScan canopy analysis system (Delta-T Devices, Cambridge, UK) was designed to measure the photosynthetically active radiation (PAR), the interception of solar radiation and make estimates of LAI in plant canopies. SunScan probe estimates LAI indirectly from measurements of radiation above and below the canopy, based on a theoretical relationship between leaf area and canopy transmittance. Its optical sensor is the light sensitive “wand” of one meter long, containing 64 photodiodes equally spaced along its length (Potter *et al.,* 1996). It relies on the strong dependency between canopy structure and gap fraction or size distribution of the canopy (Potter *et al.,* 1996). Canopy structure is usually quantified in terms of leaf area and the spatial geometric organization of individual elements within a defined canopy envelope (Broadhead *et al.,* 2001).

2.7.2.4 Optical Canopy Gap Method

A third method used to determine LAI is measuring the fraction of incoming light that passes through the plant canopy. This is done by making assumptions about how leaves are distributed in the canopy, then measuring the size and number of gaps between the leaves. These two pieces of information can then be used to calculate LAI. Canopy gaps can be measured using high contrast photographs looking up at the sky through a canopy, or by recording the intensity of light transmitted down through a canopy (Asner, 1998).

The advantages of these optical canopy gap measurement approaches is that they can be collected fairly quickly with minimal disturbance to the vegetation, allowing repeated observations over time. However, there are some uncertainties with these methods. The optical measurements do not distinguish between leaves and other materials in the canopy, such as branches or tree trunks, nor can they separate live and dead leaves. Also, if the assumptions used to describe leaf distributions are incorrect, the calculation of LAI will be in error. By contrast, indirect methods hold great promise because of the potential to obtain quick and low-cost measurements over large areas (Mynemi, 1997).

2.8 Wetlands and their utilization

A wetland is a land area that is saturated with water, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem (Howard, 1992 ; Ramsar, 2006). Wetlands are among the most productive ecosystems on earth. They allow interaction between water, soil, vegetation and light all the year round or during a greater part of the year. The depth of the water is such that it allows photosynthesis to occur, making wetlands productive life-supporting ecosystems. A substantial proportion of Kenya's water resources is found in wetlands, which cover 2 to 3% of the country's surface area. These wetlands are diverse in type and distribution (Olindo, 1992).

In ecological, social and economic terms, wetlands are among the most valuable and productive ecosystems on earth, providing important opportunities for sustainable development. Despite these values, however, wetlands in East Africa are rapidly being lost or degraded as a result of human activities (Kamiri *et al.,* 2013).

In East Africa, humans have lived with and within wetlands throughout history. Over the years, large-scale swamp conversion and population pressure on small wetlands has threatened the integrity of many wetlands, precipitated local declines in indigenous wetland organisms, and altered ecosystem functions (Sakane *et al.,* 2011). Scope of extension of agriculture in lowlands and slopes is very limited. Hence, agricultural land use is bound to extend on wetland areas if the increasing demands for food and building materials are not met from land use intensification.

Wetlands may be successfully categorized into clusters using biophysical, economic and soil quality attributes (McCartney et al., 2005; Sakane *et al.,* 2011). Flooding or lack of it together with land use can affect soil chemical characteristics of the wetland soils (Kamiri *et al.,* 2014). Low nitrogen and phosphorus levels are an indicator of possible N and P deficiency in majority of intensively cultivated wetlands in central Kenya and North western Tanzania (Kamiri *et al.,* 2013).

Agriculture has long been practised on wetlands. However, wetland farming in inland valleys is a more recent activity as compared with that in the floodplains in general (Verhoeven and Setter 2010). Wetlands in the eastern African highlands have also been used for agricultural purposes, but their use changed dramatically over the last three decades (Dixon and Wood, 2003). After the initial extensive use for hunting and gathering, the collection of thatching material, and extensive grazing (McCartney et al., 2005), wetland use for agricultural production has recently intensified. This comprises in a first step an extensive cultivation of upland food crop during the dry season or of food crops on the wetland fringes, and of rainfed lowland rice during the wet season. Only after drainage, a complete conversion of the wetland for permanent upland crop production becomes possible. Drained and intensively used wetlands contribute significantly in many parts of eastern and central Africa to local and regional food security (Dixon and Wood, 2003) and offer increasing potential for income generation through a range of market-oriented production activities (Olindo, 1992). However, many of the drained wetlands show declining productivity and, after several years of intense use, may be abandoned to fallow or extensive grazing (McCartney *et al.,* 2005).

2.8.1 General characteristics of wetland soils and possible constraints

Wetlands cover 2 to 3% of the country's surface area (117,580 km2) and farming is mostly practiced in inland valleys accounting for 87% of all wetlands. Most wetlands consist primarily of hydric soil which supports aquatic plants (Kamiri *et al.,* 2014). The variety of wetlands found in East Africa reflects the prevailing diversity in climate, geomorphology and hydrology (Dixon and Wood, 2003, Sakane *et al.,* 2011, Kamiri *et al.,* 2014).

Most nutrients, such as sulfur, phosphorus, carbon, and nitrogen are found within the soil of wetlands. Biogeochemical processes in wetlands are determined by soils with low redox potential (Schlesinger, 1997). Anaerobic and aerobic respiration in the soil influences the nutrient cycling of carbon and nitrogen and the solubility of phosphorus

(Hans *et al.,* 2001). Wetlands with low pH and saline conditions may reflect the presence of acid sulfates (Minh *et al.,* 1998) and wetlands with average salinity levels can be heavily influenced by calcium or magnesium.

Both biotic and abiotic constraints limit crop production in wetland soils. Serious abiotic constraints include variable rainfall, with drought and flood occurrences in the same year and low temperature in the high altitude areas which may hinder crop growth (Chapman *et al.,* 2001). Among biotic factors, weeds are the most serious. Wetlands support weeds which are well adapted to soil flooding or to alternate wetting and drying cycles, resulting from seasonal rainfall variation. Alternate flooding and drying of the soil is especially detrimental to both fertilizer sources and native soil sources of nitrogen and phosphate. These changes in plant nutrient availability are due to the biological oxidation-reduction processes brought about by the exclusion of oxygen in the soils. It is these biological reduction reactions and the chemical reactions accompanying them that are responsible for much of the change in nutrient behavior in flooded soils (Patrick and Mickelson 1968). Estimated yield losses due to weeds range from 30-100% (Becker, 2006).

Changes in the soil strength during the wet and dry seasons render the soil difficult to till (Dixon and Wood 2003). Particularly during the rainy season, the soil is sticky and difficult to work with hand tools. When dry, the soil is hard to till because of high cohesive forces and strength. It also requires water removal (drainage) during the rainy season or elevation of rooting depth above the standing water (ridge cultivation), which mostly requires mould tillage and /or ridge tillage both of which are labor and time intensive (Ogban *et al.,* 2003).

CHAPTER THREE

MATERIALS AND METHODS

3.0 Site description.

The research was carried out in a ‘small wetland’ in Karatina - Mathira constituency Nyeri county, 1° 0' 0" South, 36° 46' 0" East at an elevation of 1868 metres above sea level. Karatina is on the Nairobi – Nyeri highway, 20 kilometres southeast of Nyeri town and south of Mount Kenya. The town lies on a plateau directly below the southern side of Mount Kenya. It is fed by radially flowing streams running from Mount Kenya towards the lower slopes of the mountain that are marked by the river Tana, the longest river in Kenya. The area receives an annual bimodal rainfall of 1450mm, with temperature ranges between 21- 27^0C The area is also characterised by small scale tea, coffee, dairy and horticultural farms around Karatina (Table 1). The study area, Tegu (Fig 1) was selected from previous research on small wetlands of East Africa as a continuation of the research on the wetlands and their potentials (Sakane *et al.,* 2011). This was done to serve as a basis for the treatments to be applied during the experiment. The soils of the site are classified as hydric gleysols/ fluvisols (FAO system) with clay textural class. The site had been previously used by the farmer to carryout farming activities and had planted nappier grass, maize and beans on the farm prior to the setup of the experiment.

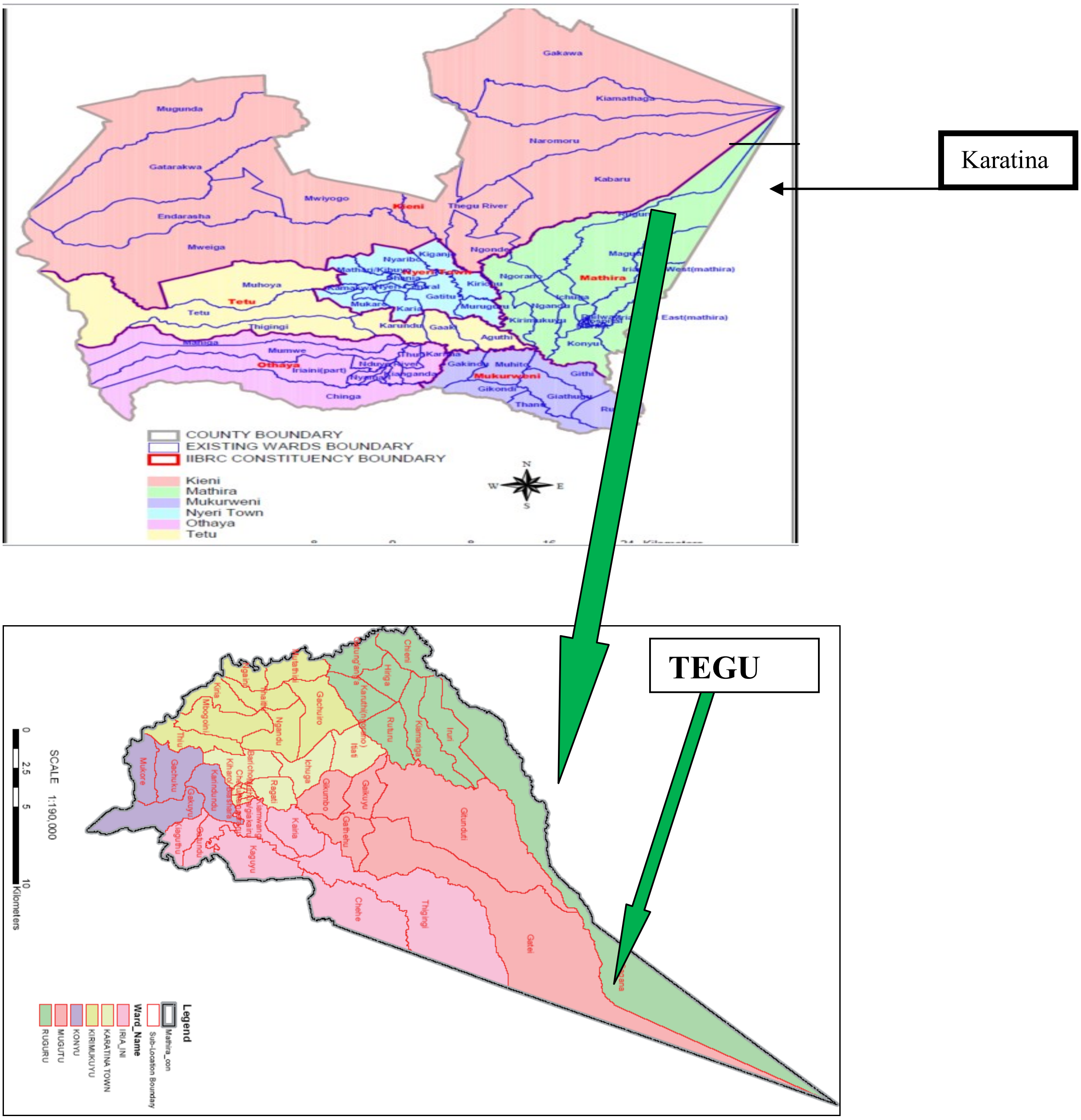


Figure 1: Map of Nyeri County and Mathira constituency map showing study sites.

Source: Kamiri *et al.,* (2011).

Table 1: Biophysical characteristics of the study site.

The table below describes the geographical and climatic conditions of the site.

Description	**Characteristics**
Longitude	$37^0$05'57"E
Latitude	$00^0$27'58"S
Altitude (masl)	1868
Agroecological zones (AEZ)	Upper Midland Zone
Annual rainfall (mm)	1450
Temperature range (^{0}C)	11-27
Density (persons/Km^2)	304
Main activity	Subsistence cropping-vegetables, maize, beans, arrowroots
Soil properties	
Sand (%)	16
Silt (%)	26
Clay (%)	58
Textural class	Clay
Soil type	Fluvisols/ Gleysols
Moisture Regime	Hydric

Source: Kamiri *et al.,* (2011).

3.1 Treatments, field experimental layout and management

The experimental field was randomly selected within the farmer´s fields in the wetland that had previously been identified for research by the SWEA 1 project (Sakane *et al.,* 2011; Kamiri *et al.,* 2013). The selected wetland in Karatina (Tegu) where the current research was carried out is in the fourth class which was completely drained, had been under intensive cultivation for more than 50 years and the water table depth was below 90 cm. The experimental plots each measuring 5 m by 1.5 m were selected randomly and planted with maize (Hybrid 516 - Kenya Seed Company). Different spacing was applied on the plots with some plots receiving nitrogen while others remained without (Table 2). They were laid in a randomized complete block design (RCBD) (Figure 2). A basal application of muriate of potash (MOP) at 75kg K/ha was applied to provide phosphorus for maize. Nitrogen (Urea) was applied at 120KgN/ha considering farmer practices in the area since most farmers had been using the recommended FURP amount of 75Kg N/ha and sometimes up to 100Kg N/ha (Kamiri *et al.,* 2013) and yet not obtaining the expected high yields and so the applied amount was to ensure that there was enough N applied to cover for any that maybe lost during the growing period.

Table 2:Description of the treatment application in the experiment.

Treatment description	Plant population (density/ha)	Nitrogen applied (Urea)
100 *12.5 (-N)	80000	0
100 * 12.5 (+N)	80000	120 kg N/ha
100 * 25 (-N)	40000	0
100 * 25 (+N)	40000	120 kg N/ha
50 * 12.5 (-N)	160000	0
50 * 12.5 (+N)	160000	120 kg N/ha
50 * 25 (-N)	80000	0
50 * 25 (+N)	80000	120 kg N/ha

The table shows the treatments as they were applied on the different plots within the experiment site. Eight treatments were applied, each replicated three times and blocking done due to the effect of slope. Land preparation was done by hand digging before the start of each season. Fertilizer application (Urea) was done during planting except for urea which was applied in split application during top dressing. Weeding was done every twoo weeks to prevent its efect on production as well as on LAI.

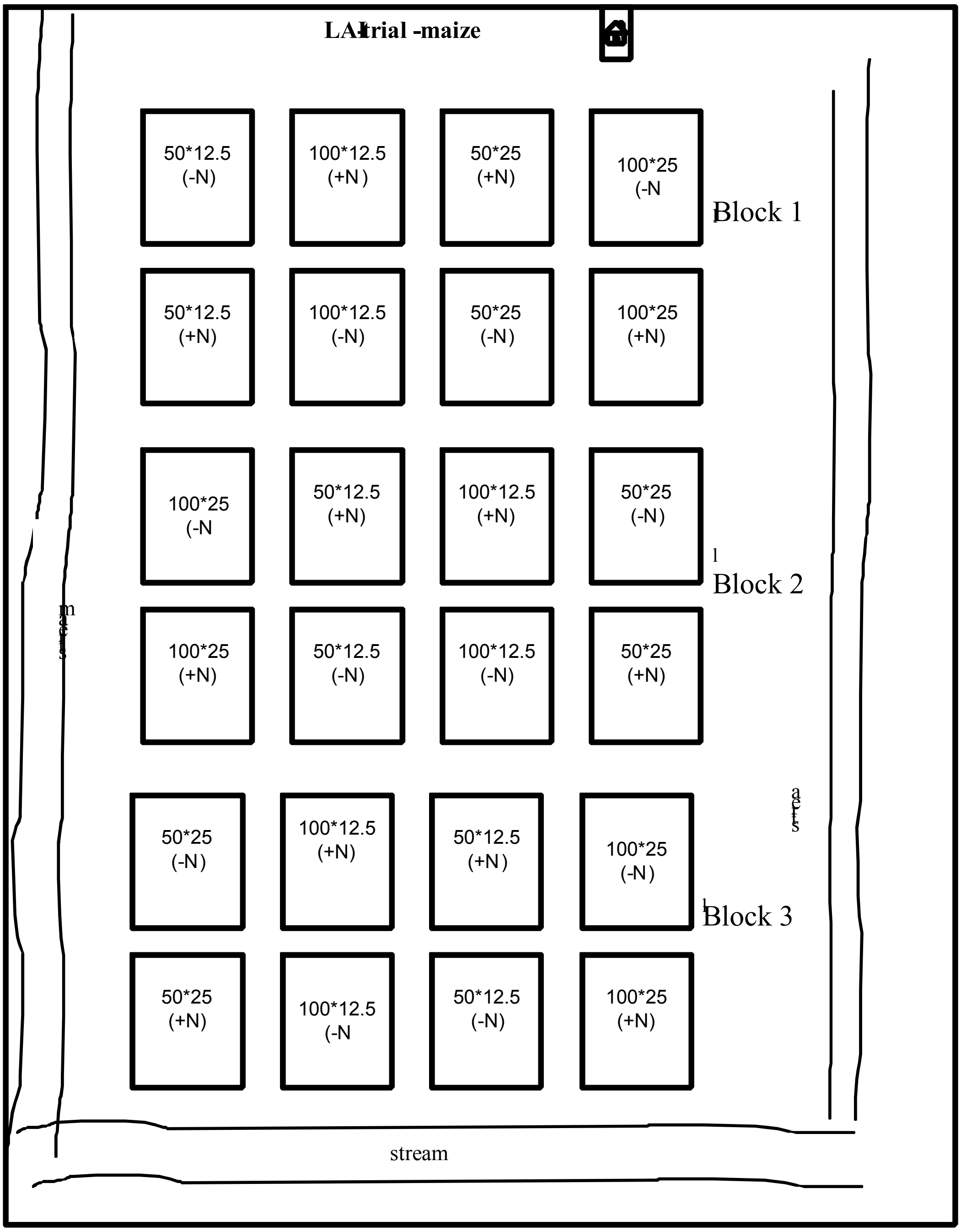


Figure 2: Field layout showing the position of the plots and treatment distribution.

3.2 Data collection

3.2.1 Soil analysis

Initial soil sampling was carried out in September 2012 at the start of the trial and subsequent soil sampling at the end of each season (after maize harvesting). Eight soil cores were sampled randomly from each plot from the top 0-20cm soil layer using a 5-cm diameter stainless steel hand-held soil auger. These were then bulked and taken for analysis in the laboratory. Soils were air-dried and sieved through a 2mm stainless steel sieve before the laboratory analysis for soil parameters. Laboratory analyses of selected parameters (pH, Soil Nitrogen, Phosphorus, Carbon, Exchangeable cations, Moisture content, Particle size) were carried out according to the methods described by Okalebo *et al.,* (2002).

3.2.1.1 Soil pH

Soil pH was measured on 2.5:1 soil water suspension. Fifty (50ml) of deionised water was added to 20g of 2mm sieved air dry soil and the mixture stirred for 10 minutes. It was allowed to stand for 30 minutes and stirred again for 2 min. The pH was then measured using a pH meter (Okalebo *et al.,* 2002)

3.2.1.2 Total Nitrogen and Phosphorus

The content of total nitrogen and phosphorus was measured in a digest obtained by treating soil and plant sample with hydrogen peroxide + sulphuric acid selenium and salicylic acid. The principle takes into account the possible loss of nitrates by coupling them with salicylic acid in an acid media to form 3-nitrosalicylic and or 4-nitrosalicylic. The compounds are reduced to their corresponding amino acid forms by the soil organic matter Analysis of total nutrients requires complete oxidation of organic matter. The hydrogen peroxide oxidises the organic matter while the selenium compound acts as catalyst for the process and the H_2SO_4 completes the digestion at elevated temperatures. A sample weighing 0.3g of soil sieved through 0.02mm sieve was put into a labelled, dry and clean digestion tube and 2.5ml digestion mixture added to each tube. The content was digested at 110^0c for 1 hour, removed, cooled and three successive 1ml portions of hydrogen peroxide added. The temperatures were raised to 330^0C and heating continued until it was colorless and any remaining sand white. 25 ml distilled water was added and mixed well until no more sediment dissolved. This was allowed to cool and made up to 50 ml with water and allowed to settle. With a micro pipette 0.2ml of the digest was put in a clearly labelled test tube. 5ml of the reagent N1 and N2 was added and vortex consecutively and then allowed to stand for 2 hours. The absorbency was measured at 650 nm wavelength and concentration of N in the solution was calculated and the total N determined (Okalebo *et al.,* 2002).

3.2.1.3 Organic Carbon

Organic carbon was determined by the sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture. After complete oxidation from the heat of solution and external heating (Nelson and Sommers, 1973), the unused or residual $K_2Cr_2O_7$ (in oxidation) is titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$, the difference between added and residual $K_2Cr_2O_7$, gives a measure of organic C content of soil. The chemical reaction in the method is;

$$2Cr_2O_7^{2-} + 3C + 16\,H^+ \rightarrow 4Cr^{3+}\ 3CO_2 + 8\,H_2O \qquad \ldots\ldots\ldots\ldots\ \textit{Eqn 1.}$$

A sample weighing 0.5g of ground soil, sieved through 0.02mm soil was weighed into a block digester tube and 5ml potassium dichromate ($K_2Cr_2O_7$) solution and 7.5ml concentrated sulphuric acid was added and placed in a preheated block at 145-155^0C for 30 min then removed and allowed to cool. After complete oxidation from the heat of the solution and external heating, the digest was quantitatively transferred to a 100ml conical flask, and 0.3ml of the indicator solution added. The residual potassium dichromate was mixed and then titrated with ferrous ammonium sulphate solution; the end point is a colour change from greenish to brown. The difference between the added potassium dichromate and the residual gave a measure of the organic C content of the soil, (Okalebo *et al.,* 2002).

3.2.1.4 Soil available Phosphorus: (Bray 2)

The combination of HCl and NH_4F is designed to recover easily acid-soluble forms of P, largely the Ca phosphates and a portion of the Al and Fe phosphates. The NH_4F dissolves Al and Fe phosphates by its complex formation with these metal ions in acid solution. In general, the method has been reported widely to be useful on most acid soils. The colorimetric procedure for measuring P proposed here is similar to the one used in Olsen P method. A 2.5g of air dry soil passed through a (2 mm) sieve was weighed into a 250 ml shaking bottle and placed on a mechanical shaker for 30 minutes. The suspension was filtered through the Whatman paper No. 42. 10 ml of the sample filtrates and 2 reagent blanks were pipette into a 50ml volumetric flasks and 5 ml of 0.8M boric acid followed by 10ml of the ascorbic acid reagent was added to each flask, filled to the 50ml mark with distilled water, and the contents shaken and left for one hour. The absorbance of the solution was measured by calorimetric method, at wavelength setting of 880nm. The P concentration is expressed in P mg kg^{-1} (Okalebo *et al.,* 2002)

3.2.1.5 Exchangeable cations in soils

A soil sample was extracted with an excess of 1 M NH_4OAc (ammonium acetate) solution such that the maximum exchange occurs between the NH_4 and the cations originally occupying exchange sites on the soil surface. The amounts of exchangeable sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg) in the extract were determined by flame photometry (Na and K) and by atomic absorption spectrophotometry (Ca and Mg). Lanthanum or strontium is added as a releasing agent to prevent formation of refractory compounds, which may interfere with the determinations (e.g. phosphate). 5 g of air dry (2mm) soil was weighed into a clean plastic bottle. 100ml of 1M (NH4OAc) ammonium acetate solution was added and contents shaken for 30 min and filtered through No. 42 Whatman filter paper to obtain a soil extract. For K and Ca determination, the soil extract solution was diluted ten (10) times, then 5 ml of the soil extract solution pipette into a 50 ml volumetric flask. One ml of 26.8% lanthanum chloride solution was added and the contents diluted to the mark with 1M ammonium acetate extraction solution (Okalebo *et al.,* 2002).

3.2.1.6 Soil texture determination

The particle size analysis of a soil estimates the percentage sand, silt and clay contents of the soil and is often reported as percentage by weight of oven-dry and organic matter-free soil. The analyses are usually performed on air-dry soil. Based on the proportions of different particle sizes, a soil textural category may be assigned to the sample. The first stage in a particle size analysis is the dispersion of the soil into the individual particles. These are the sand (2.00 - 0.05 mm), silt (0.05 - 0.002 mm) and clay (< 0.002 mm) fractions. Individual soil particles are often bound into aggregates hence the requirement for dispersion. The hydrometer method of silt and clay measurement relies in the effects of particle size on the differential settling velocities within a water column. The settling velocity is also a function of liquid temperature, viscosity and specific gravity of the falling particle.

In brief 50 g of air-dry < 2 mm soil was weighed into a 400 ml beaker. It was saturated l with distilled water and 10 ml of 10% Calgon solution. It was allowed to stand for 10 minutes. It was then transferred to the dispersing cup and made to the mark in the cup with distilled water. The suspension was mixed for 2 minutes with an electric high speed stirrer and ordinary bottles were used. It was transferred into a graduated cylinder and rinsed to remove remaining soil into the cylinder with distilled water. The hydrometer was inserted into the suspension and added with water to 1130 ml, then removed. It was then covered with a tight-fitting rubber bung and the suspension mixed by inverting the cylinder carefully ten (10) times. 2 - 3 drops of amyl alcohol was added to the soil suspension in order to remove froth and after 20 seconds the hydrometer was placed gently into the column.

At 40 seconds, a hydrometer reading was taken and the temperature of the suspension measured. Step 6 was repeated (mixing of the soil suspension 10 times) and the cylinder allowed standing undisturbed for 2 hours. After two hours, both hydrometer and temperature readings were taken. Necessary temperature corrections were made since temperature affects the hydrometer readings. Once the sand, silt and clay distribution was measured, the soil was assigned to a textural class (Okalebo *et al.,* 2002).

3.2.1.7 Soil moisture determination

Soil moisture data was recorded after every 2 weeks to ensure that the water table was below 50cm and that the soil was not flooded while carrying out the experiment.

3.2.2 Leaf Area Index measurements

Leaf Area Index (LAI) was determined directly by taking a set sample (based on previous research data) of foliage from a plant canopy, measuring the leaf area per sample plot and dividing it by the plot land surface area. Indirect methods measure canopy geometry or light extinction and relate it to LAI. In this study both direct (non destructive) and indirect (destructive) methods were applied.

3.2.2.1 Sunscan method (Non destructive sampling)

The non destructive leaf area index measurements were carried out using the SunScan canopy analysis system (Delta-T Devices, Cambridge, UK). The Sunscan probe has an array of 64 PAR sensors embedded in a 1 meter long probe, and is connected via cable to a handheld PDA (Figure 3). As a reading is taken, all the sensors are scanned and the measurements are transmitted to the Personal Digital Assistant (PDA). The average light level along the probe is calculated, and all of the individual sensor readings are available if required for detailed PAR mapping. An operating button on the probe handle enables successive readings to be taken quickly and simply on demand. Readings are in units of PAR quantum flux (mol m^{-2} s^{-1}) and units of LAI ($m^2.m^{-2}$) . In brief, the PDA which is used to store data is first switched on. The probe is placed under the canopy where 3 readings are taken from every point (6 points per plot) which amounts to 18 readings from every plot. When taking measurements, the rod is held at the same angle and in the same direction from the beginning to the end of sampling to minimize variations. The Sunscan readings are taken when the sky is clear to avoid interference of the clouds. Sunscan LAI determination coefficient extraction mode is as follows:

$$K(X, \theta) = \sqrt{(X^2+\tan(\theta)^2)} / X+1.702(X+1.12)^{-0.708} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Eqn 2.}$$

θ –Zenith angle of the direct beam

X – ELADP (Ellipsoidal Leaf Angle Distribution Parameter)

Figure 3: Delta-T Sunscan equipment showing various components for measurements of LAI. Source (Author) 2016

3.2.2.2 Procedure for determining Leaf Area Index using copy method (Destructive method)

The selected leaves from the plant in the field were stripped and stored in a cool box (to avoid shrinkage). Leaves were then photocopied using a normal photocopy machine. The copied leaf images from the paper were cut and weighed and a plain paper of the same size as the paper leaves was also weighed to assist in calculating the leaf area. The paper leaves were then air-dried and leaf area calculated as follows:

LAI = weight of leaf paper (g) / (weight of paper/Area of paper)................*Eqn 3.*

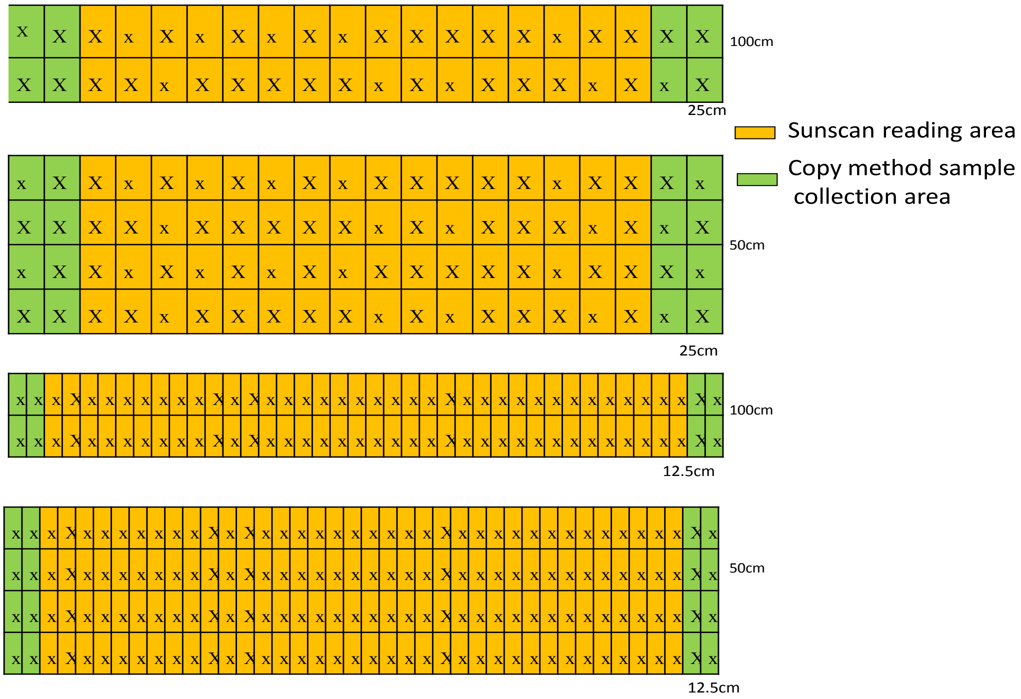


Figure 4: A schematic drawing of maize spacing in the field and the positions where the sunscan probe was positioned while taking the readings for the Leaf Area Index.

3.2.3 Maize grain and dry matter yield Determination

Maize was harvested at harvest maturity and sub sampling done per plot excluding the guard rows to avoid effects of the neighboring plots. The procedure entailed counting the standing plants, cutting them down, counting the number of cobs and obtaining the total weights and subsample weights of both the dry matter and cobs. The cobs and the dry matters subsamples were then left to dry in the greenhouse for two weeks after which they were oven dried overnight at 70^0C to ensure constant dry weight. The cobs were then threshed and the grain weight recorded. A small sample was taken from the grains for determination of N, P and K content in the laboratory as described by Okalebo *et al.,* (2002).

Maize yield was calculated as follows:

Yield/plot= Total Fresh Weight* sample Dry weight/ Sample fresh weight. …….. ***Eqn 4***

Yield (T/ha) =Yield per plot* 1000/ Harvested area. ………….. ***Eqn 5***

3.3 Data analysis

Statistical analysis was done using the following model, as applicable to the RCBD design.

$Y_{ij} = \mu + \alpha_i + \beta_j + \sum_{ij}$

Where,

Y_{ij} =Plot Observation

μ= Mean of observations

α= Effect due to treatment application

β_j = Effect due to blocking

$\sum_{ij}$ = Experimental error.

Data was managed using Microsoft Excel and subjected to Analysis of Variance (ANOVA) using Genstat statistical software version 12. Means were separated using Standard Error of the Difference (SED).

CHAPTER FOUR

RESULTS

4.1: Effects of nitrogen fertilizer application and plant density on soil properties of reclaimed wetlands.

4.1.1: Soil pH

Results on the effect of treatments on the soil pH are presented in Figure 5 below. Figure 5 shows the initial soil pH before treatment application and effects of nitrogen fertilizer and plant density on soil pH across seasons. The pH of the soil was low, ranging from 4.5 to 4.7 at the start of season (Figure 6) which is considered as strongly acidic. At the end of the second season, pH values for 100 cm * 12.5 cm (-N) increased from 4.0 to 4.6 while that of treatment 50 cm* 12.5 cm (-N) decreased from 4.6 to 4.0.

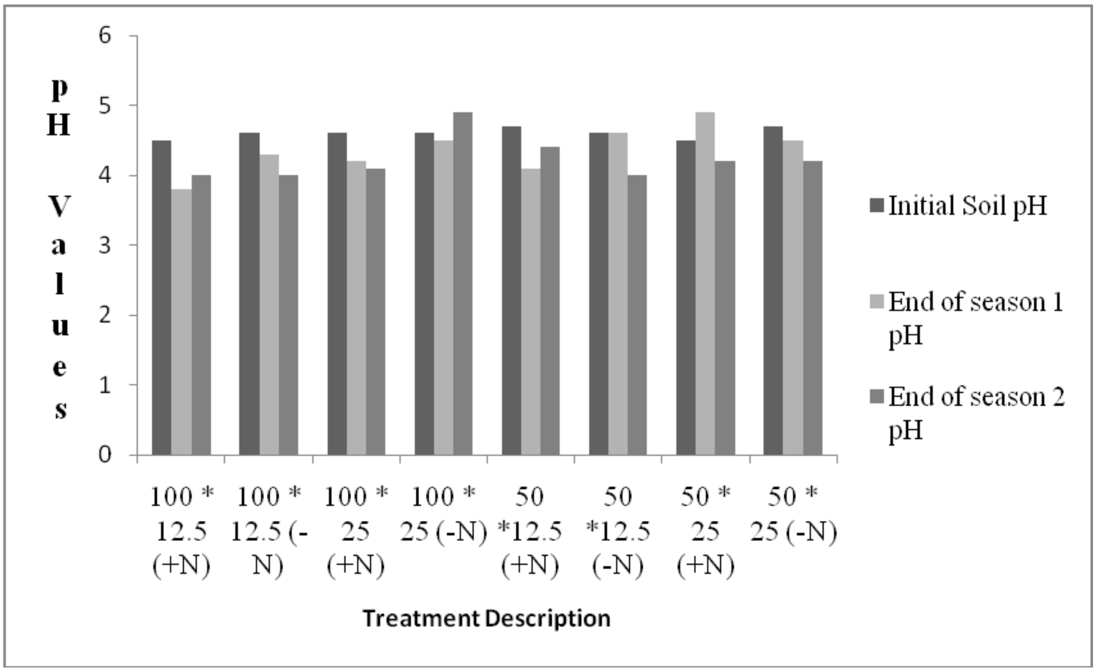


Figure 5: Trends in soil pH at the beginning and end of each season.

4.1.2 Soil Phosphorus

Results on the effect of treatments on the soil Phosphorus are presented in Figure 6 below. In reference to figure 6 below the soil phosphorus ranged between 101.9 to 137.2 ppm P during the start of the experiment. There was a general decrease in P content by the end of season 2 except for treatments 100*12.5(+N), 100*25(-N), 100*25(+N), and 50*12.5(+N) which experienced an increase in soil P at the end of season 2, though the differences were not significant.

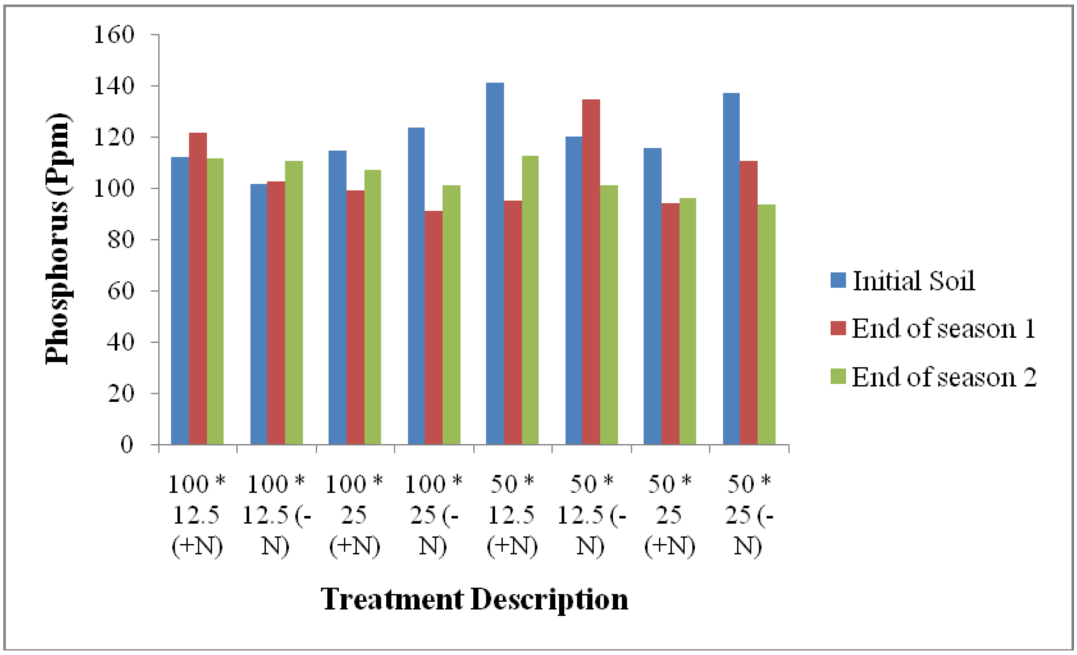


Figure 6: Phosphorus values (ppm) in the soil across seasons.

4.1.3: Total nitrogen

Results on the effect of treatments on the soil Nitrogen are presented in Figure 7 below. The results for total soil N and C before and after the cropping seasons are shown in the figure 7 below. Initial N values were above 0.25% before planting maize ranging from 0.44 - 0.48% while at the end of season 1 the range was 0.36 - 0.37% and thus considered high. The values of soil N did not differ so much during the planting seasons but were lower compared to the level of nitrogen before the start of the seasons. It was also not highly affected by the spacing since the range did not vary so much from one treatment to the other. Differences were not significant.

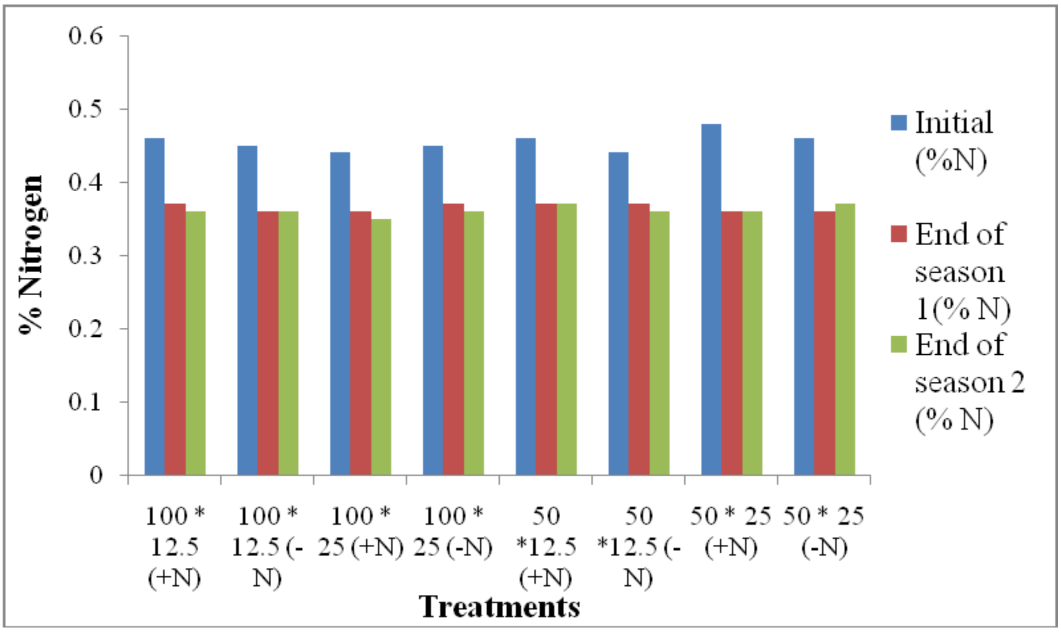


Figure 7: Trends in Total Soil N during the growing seasons.

4.1.4 Total Carbon

Results on the effect of treatments on the soil carbon are presented in Figure 8 below. The soil carbon (figure 8) was found to be high with an average of 3.4% at the start of the planting season which is considered high (Okalebo *et al 2002).* After harvesting, it was observed that there was a decline in the carbon content. At the end of Season 2 trend in soil C was irregular with some treatments indicating increasing values in while other treatments showed decreasing trends in %C. For instance the treatment 50 cm*25 cm (-N) showed increasing levels of % C from 1.82 to 2.21%. Treatment 100 cm*25 cm (+N) had carbon decrease from 2.21 to 1.89%.

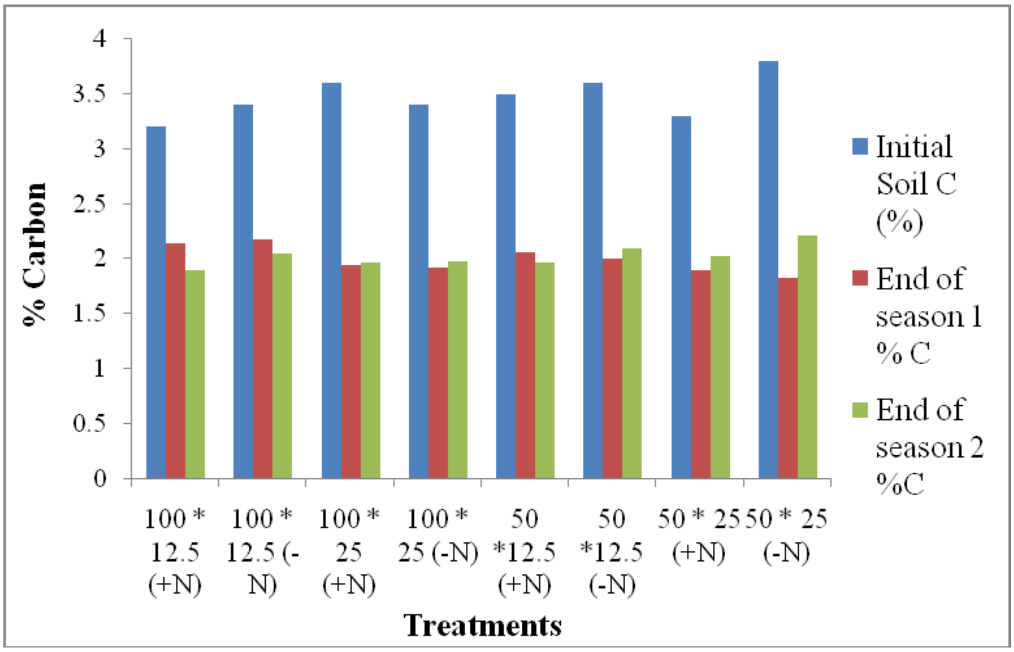
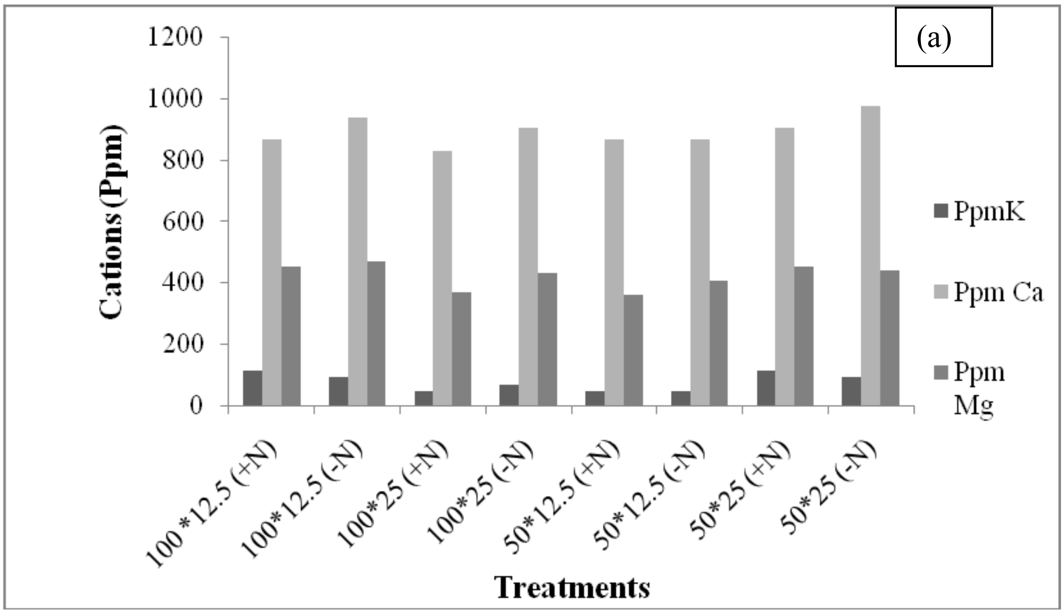


Figure 8: Trends in Total Soil C during the growing seasons.

4.1.5 Exchangeable Cation

Results on the effect of treatments on the soil Cations are presented in Figure 9 below The exchangeable cations results indicated that the initial soil was found to have low quantities of Potassium between 45 and 113ppm K, high Magnesium ranging from 210 – 470 ppm Mg while the amount of calcium was moderately low ranging between 408 -865 ppm Ca (figure 9).



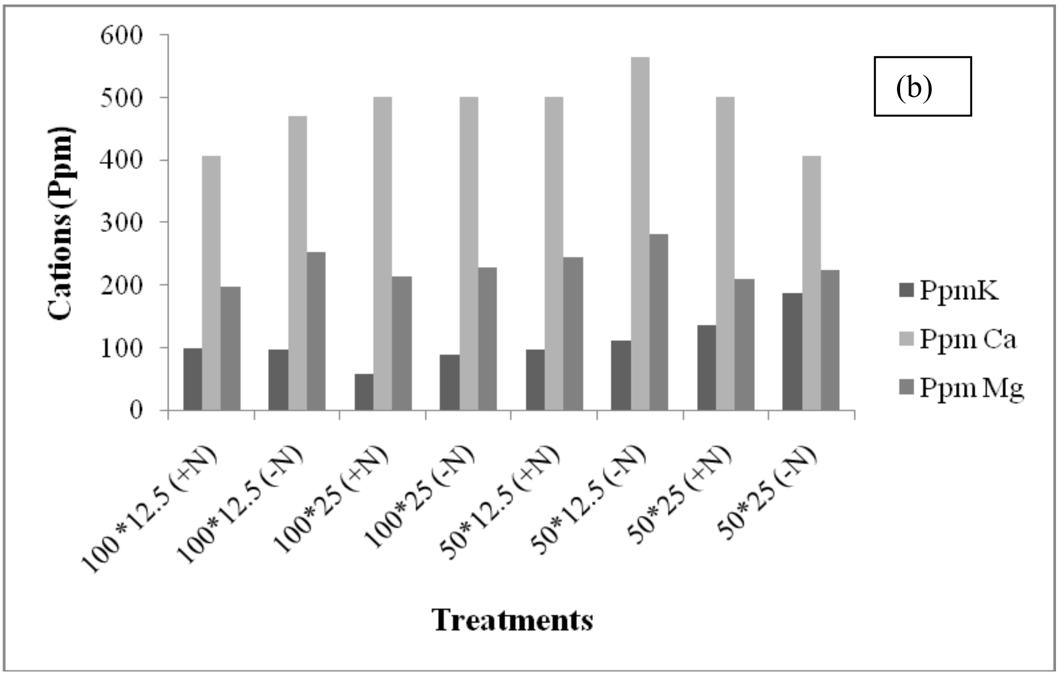


Figure 9: Levels of K, Ca and Mg cations in the soil across seasons.

4.2: Effect of nitrogen fertilizer application and plant density on the leaf area index.

Results on the effect of nitrogen fertilizer application and plant density on the leaf area index. are presented in Figure 10 below. Figure 10 shows a trend of the leaf area index of maize between beginning of season or 21 days after emergence of maize up to physiological maturity. The treatment 100 * 12.5 (+N) had the highest mean value for LAI but was not significantly different from the mean of LAI on the treatment 50 * 12.5 (+N) at 99% level of probability. LAI was highest ($p \leq 0.01$) on DOY 19 which was taken when the maize was at physiological maturity (occurs shortly after the kernel milk line disappears and just before the kernel black layer forms at the tip of the kernels).

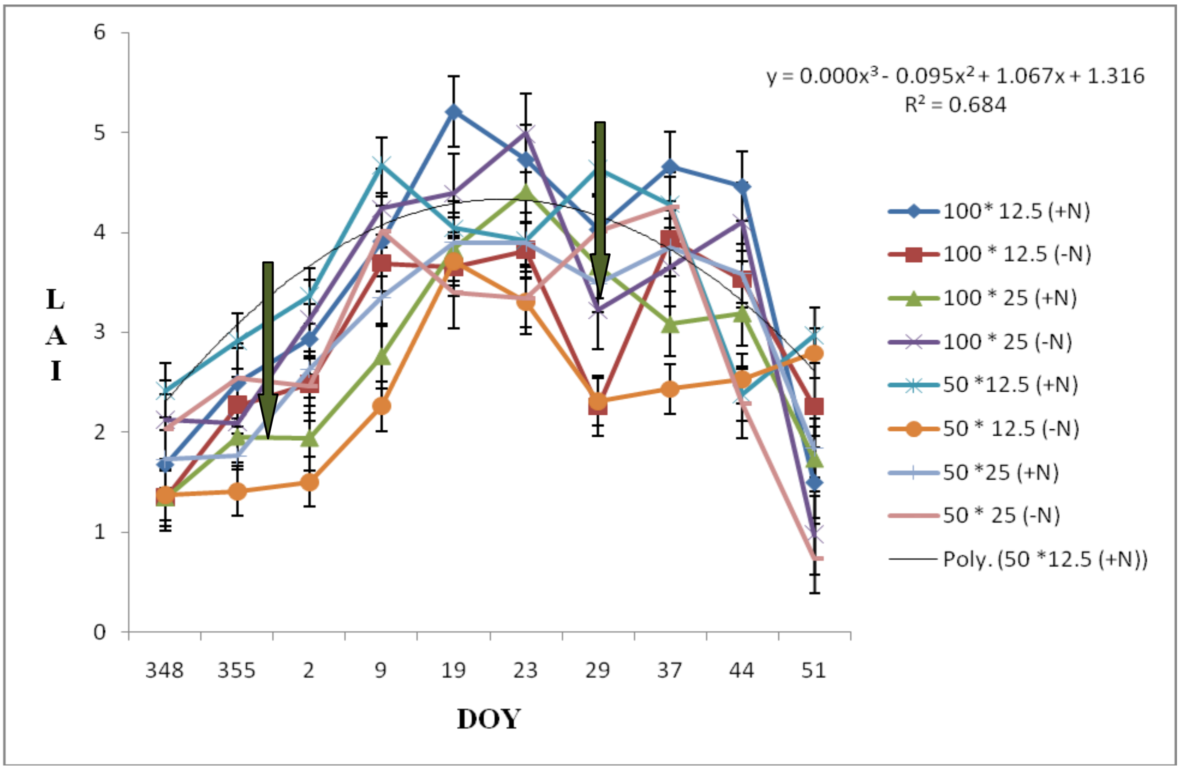


Figure 10: Changes in mean LAI with time (Days Of the Year) in the different treatment

4.3 Effect of nitrogen fertilizer application and plant density on maize grain and dry matter yield and plant tissue nutrient concentration.

4.3.1 Maize grain and dry matter yield

The effect of spacing and soil nitrogen on the maize yield during the two seasons is shown in Figures 12 and 13. In season 1 the average grain yield ranged between 1.6 to 4.2 t/ha. The treatment 50 cm*12.5 cm (-N) had a high yield of 4.2t/ha ($p \leq 0.05$) followed by 100 cm * 12.5 cm (+N) (3.6t/ha). Low yields were however recorded in the 100 cm * 25 cm (-N) and 100 cm * 25 cm (+N) treatments with 1.7t/ha. The average dry matter yield ranged between 2.0 to 9.1 t/ha. The treatment 50 * 12.5 (-N) had the highest yield of 9.1t/ha followed by 50 * 12.5 (+N) (7.1t/ha). Low yields of 2.0 t/ha were however recorded in the 100 cm* 25 cm (+N) treatments.

During the second season there was a general decline in grain yield in all treatment under study. Grain yield ranged between 1.6 to 2.5 t/ha with the highest yields recorded in the 50 * 12.5 (-N) and 100 * 25 (-N) treatments. The average dry matter yield ranged between 2.0 and 4.6 t/ha.

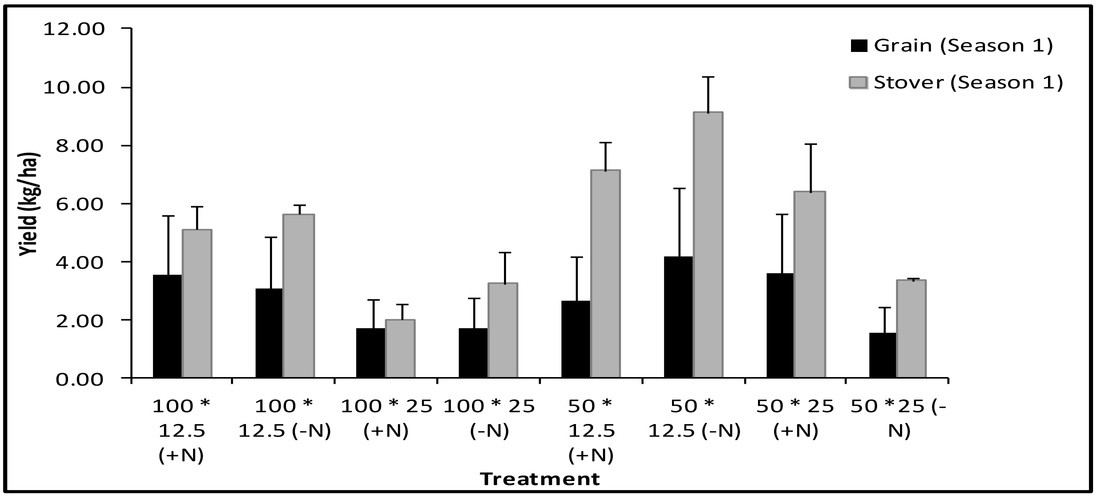


Figure 11: A graph of maize grain and dry matter yield during the first growing season. Error bars stand for SED.

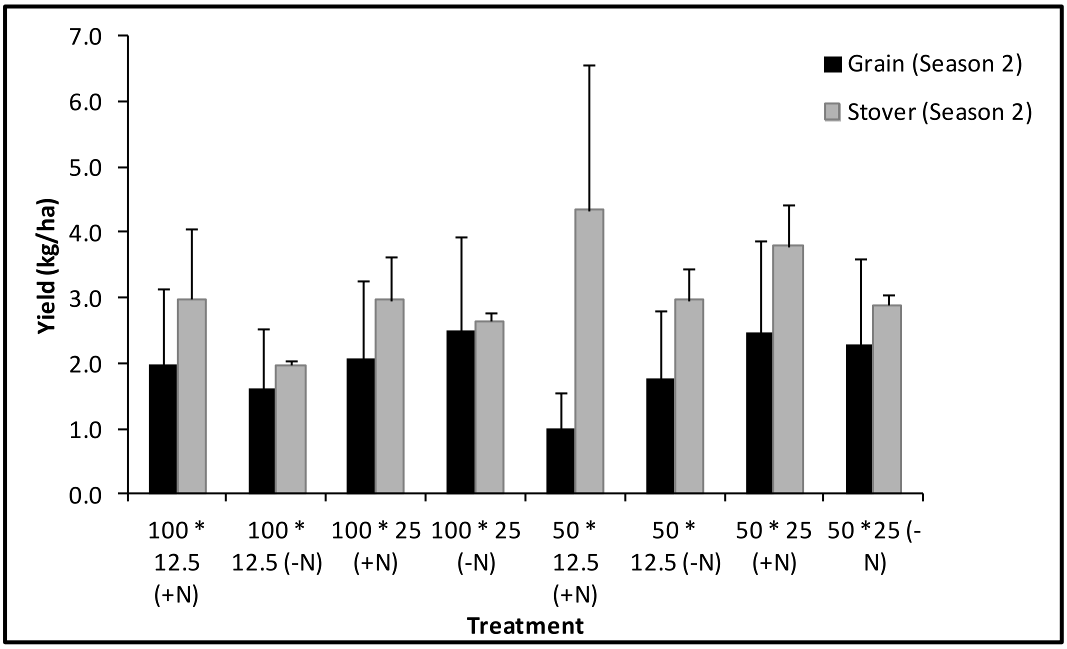


Figure 12: A graph of maize grain and dry matter yield during the Second growing season.

4.4 Trends in relationship between grain yield and LAI

Correlation analysis showed a positive relationship between LAI and maize grain yield (r = 0.509). Increase in the maize grain yield corresponds to increased LAI recorded using both sunscan and copy methods. Treatment 50*12.5(-N) had the highest value of LAI at 4.9 as well as high grain yield 4.2 t/ha. Treatment 100*25 (+N) had the lowest LAI 2.4 with a corresponding low yield 1.6 t/ha (Figure 14).

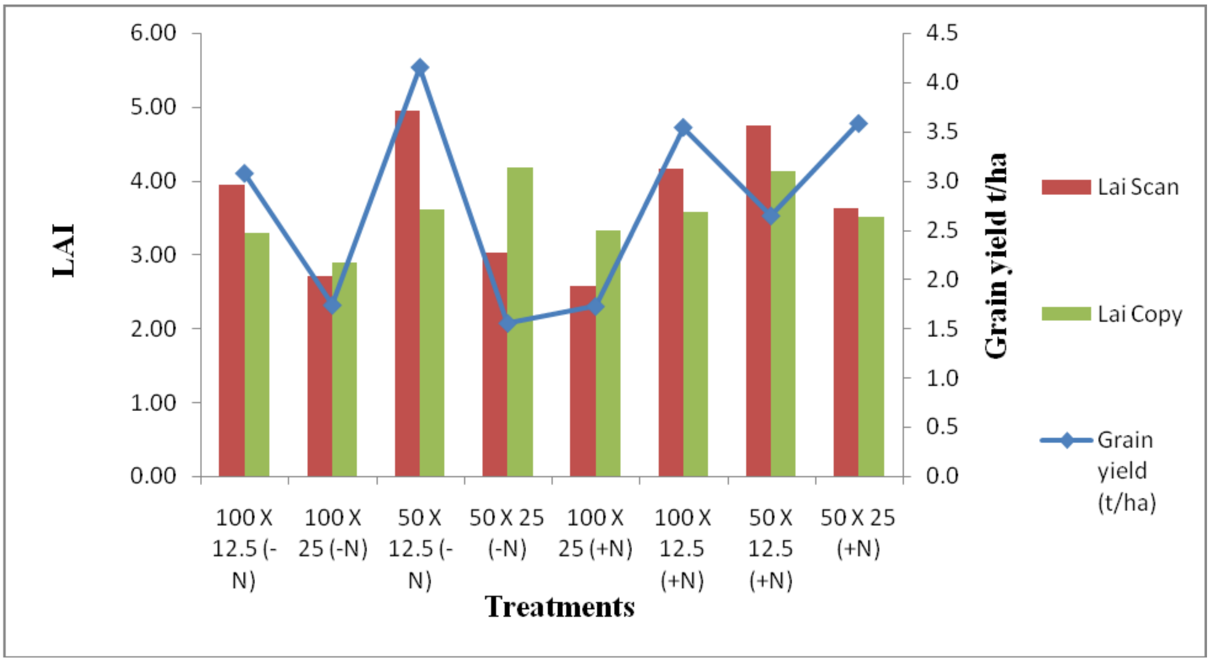


Figure 13: Relationship trends between Grain yield and LAI.

4.3.1.1 Plant tissue analysis for N, P, K in grains and dry matters

The plant tissue analysis ($p \leq 0.05$) indicated that treatments with the highest value of %N concentration in the grain and dry matter were observed in the treatment with 50 cm *25 cm (-N) at 1.89% and 1.31% respectively which is considered deficient. The treatment 100 cm*12.5 cm (+N) had the highest grain P%, and K concentration values of 0.52% (high) and 0.37% which is considered low, respectively as shown in the Figure 16 and 17 below. The treatment 50 cm*12.5 cm (+N) had the lowest values of % N, P, K in the grains as well as the lowest K value in the dry matters. From Figure 15, 16 and 17 below, it is evident that the Nitrogen concentration was low since most of the values were below 2.45% (Okalebo et al., 2002)

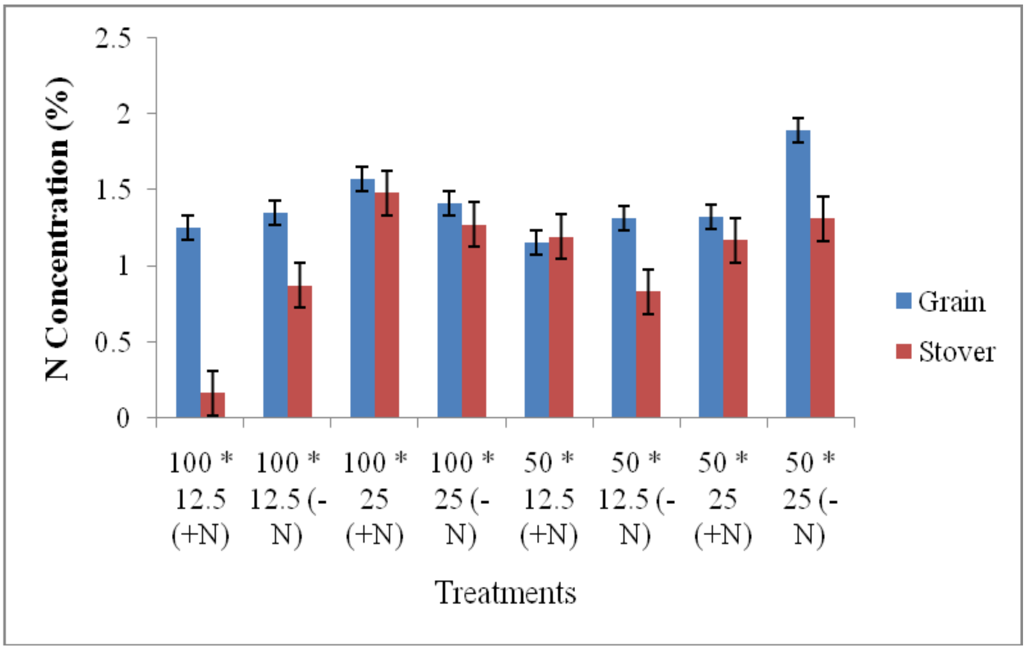


Figure 14: Results showing N concentration in Grains and Dry matter

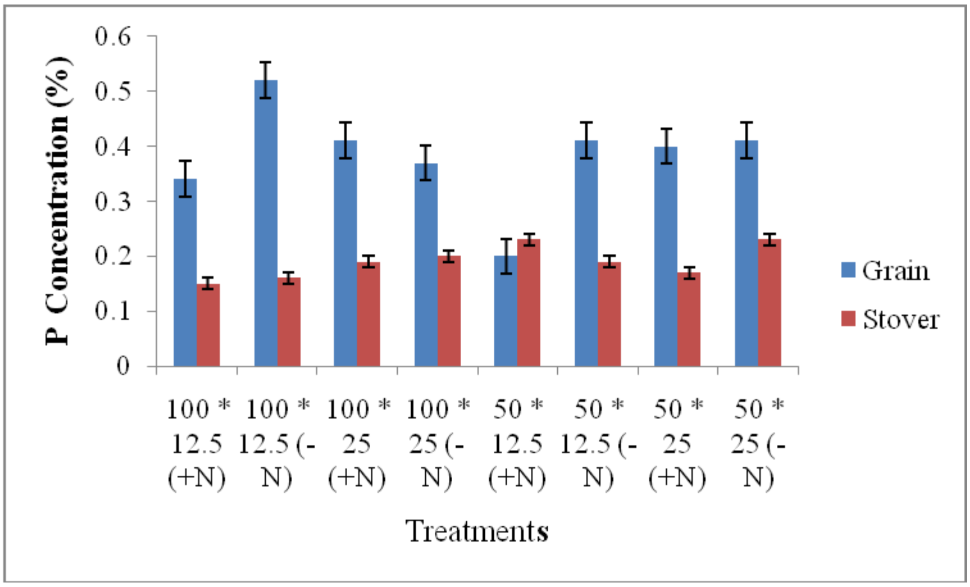


Figure 15: Results showing P concentration in Grains and Dry matter

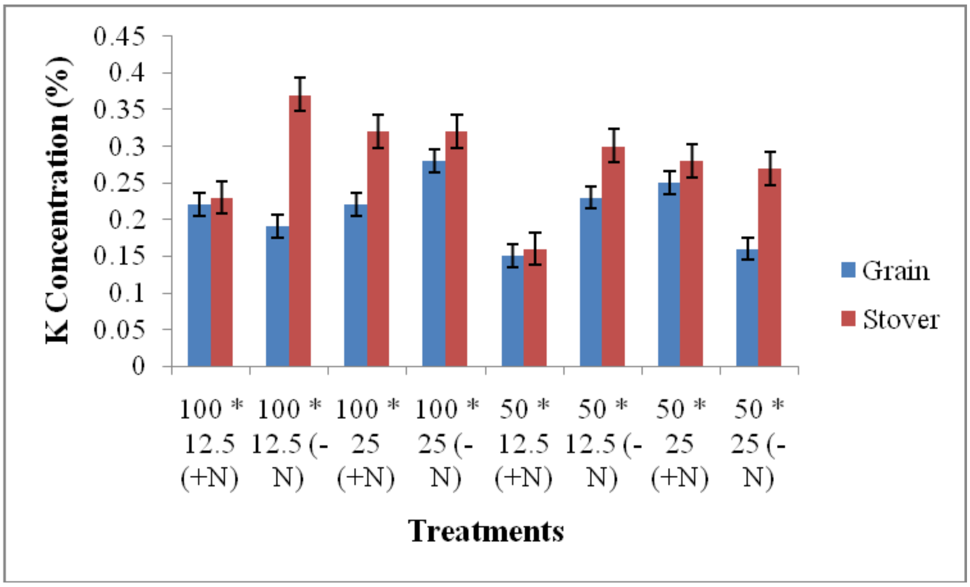


Figure 16: Results showing K concentration in Grain and Dry matter

CHAPTER FIVE

DISCUSSION

5.1: Effects of nitrogen fertilizer application and plant density on soil properties of reclaimed wetlands.

5.1.1 Soil pH changes during the growing season

The low soil pH as observed on this site could be associated with the nature of soils eroded from the uplands which are mainly nitisols (Jaetzold *et al.,* 2006). It could also be due to the continued use of mineral fertilizers without proper soil management leading to increased acidity (Jaetzold *et al.,* 2006). This mainly occurs during the denitirification process whereby in anaerobic conditions, the ammonium from urea is reduced into hydrogen ions which when released into the soil solution causes a further reduction in the soil pH (Odendo *et al.,* 2006) which is also possible for this site especially during the rainy seasons. In addition, the nature of the parent material is a major factor which may have contributed to the continuosly experienced low pH. The soils here which are mainly fluvisols have been formed as a result of deposition from the Nitisols in the highland areas (Kamiri *et al.,* 2013) and are known to be high in iron with reticulate segregation of Mn hydroxides in the ped surfaces in the lower parts of the nitic horizon. In anaerobic conditions, microbes reduce Ferric iron to ferrous iron and sulfates to sulfides which consequently forms sulfuric acid. Organic matter is also decomposed in these conditions forming a potentially acid compound (pyrite) and alkaline compounds (bicarbonates) and the presence of pyrites in fluvisols leads to formation of acidic soil conditions and consequent low soil pH (Lukombo *et al.,* 2014). With reference to the treatments applied, treatments with addition of Nitrogen in form of urea could also have contributed to the decrease in pH through the denitrification process.

5.1.2 Changes in soil Phosphorus as observed during the growing season

At the end of the second season, the P levels obtained were considered high according to Okalebo *et al.,* (2002) but lower than what is expected in wetland soils since the wetlands are known to have high P of up to 140 to 150 ppm P, but was within the lower range of the recorded P (80-90 ppm P) as observed by Kamiri, *et al.,* (2013). Increase in P was observed in some of the treatments and this could be attributed to the additional P added as a blanket application. However, this field had been cropped for many years and phosphorus depletion is possible. The soil pH was also recorded as strongly acidic which could have resulted to P fixation. As soils become more acid, particularly when the pH drops below 4.5, it becomes increasingly difficult to produce food crops. As soil pH declines, the supply of most plant nutrients decreases while aluminum and a few micronutrients become more soluble and toxic to plants. These problems are particularly acute in humid tropical regions that have been highly weathered as is the case in this site. Another problematic effect of soil acidification is the tendency for phosphorus to be rendered unavailable for plant uptake. As aluminum and iron are released during the acidification/weathering process, they become more accessible on cation exchange sites, in solution, or simply on exposed surfaces. Both ions react readily with phosphate, forming relatively insoluble compounds through a process known as phosphate fixation. Phosphorus availability for wetland crops is largely controlled by chemical equilibrium soil (Mfundisi *et al*., 2014), and particularly in the soil pH range of 4-6 when the drainage of these soils decreases due to the high redox potential of these soils which could be the case in this site. Excessive soil moisture as experienced with the wetland soils reduces soil oxygen supply due to reduced aeration as experienced in the site during high rainfall seasons thus limiting phosphorus absorption (Brady and Weil, 2002). This is however contrary to what was observed in this site since the quantity of P in the grain was high and this could mean that the plant could have re-translocated P from older leaves to complete the photosynthesis process and this explains the low yield despite the high P content in the grain and dry matter (Mfundisi *et al*., 2014).

5.1.3 Effect of treatment on soil Nitrogen during the growing season

From the results, it is observed that there was a decline in the soil N at the end of season 1. This may have been due to loss of N as a result of leaching and denitrification known to be common in wetland soils which involves conversion of ammonium Nitrogen to nitrogen gas and Hydrogen ions (Patrick and Mickelson 1968). In treatments where Nitrogen fertilizer was added, there was also no significant increase in Nitrogen.

At the end of Season 2, the values of soil N were similar to the values at the end of Season 1 indicating that the rate at which the crops used soil N in both seasons was constant. This is contrary to what was expected since the soil was expected to have low values of Nitrogen due to uptake by the plants.

It has been observed that spacing and soil nitrogen are not likely to be the only major causes of reduced yields in the wetland soils (Loomis *et al.,*1965). This is because even in the treatments where nitrogen fertilizer was added the yield was not significantly different compared to those without. This could therefore mean that the fertilizer applied (Urea 120kgN/ha in split application) was not effectively utilized by the plant as shown by the tissue analysis results. Therefore, other underlying factors could have contributed to low crop yields and therefore the fact that crops in these soils could be requiring more than just nitrogen for increased yields cannot be underestimated as reported by (Sanchez and Logan, 1992). The adequate N concentration did not translate to high yields. Interaction between nitrogen and other nutrients like K occurs at the interface between the plant (rhizoplane) and soil (rhizosphere) and therefore the absence of other nutrients at the interface may also lead to reduced uptake of the nitrogen by the plant due to the antagonistic effects of the nutrients (Brady and Weil, 2002). In addition, the low soil pH observed in this site together with other underlying factors could have contributed to unavailability of nitrogen due to fixation of nutrients because of redox reactions which have an antagonistic effect on various nutrients (Patrick and Mickelson 1968). Evidence of redox reactions could be observed on the soil clods evidenced by red colouration of iron (personal observation) as well as the water flowing in the streams near the site. Nitrogen is highly mobile but is highly affected by soil pH which causes retardation of the nitrification process. Nitrogen and P cycling maybe especially dynamic at the boundary between the uplands and the wetlands where the site lies and this is due to episodic inundation which results to alternating cycles of oxidation and reduction which may convert N limitation on the uplands to P limitation on the wetlands or co-limitation on the wetland soils (Darke and Walbridge, 2000).

5.1.4 Effect of treatment on soil Carbon during the growing season

After harvesting, it was observed that there was a decline in the carbon content and this could be attributed to decomposition and mineralization of organic matter arising from soil disturbance during tillage and cultivation (Van Ittersumma *et al.,*2013). At the end of Season 2 there were no specific trend in soil C with some treatments indicating increasing values in while other treatments showed decreasing trends in %C which could be attributed to the dynamic nature of this soil. For example, the treatment 50 cm*25 cm (-N) showed increasing levels of % C while plant density, which contributed to more residue, also contributed to the high carbon content.

Treatment 100 cm*25 cm (+N) had carbon decrease from 2.21 to 1.89%. This shows that the amount of plant residue from the crop in season 1 could have led to the increase in the organic carbon in the soil after the second season in some of the treatments. C: N ratio of the maize is also low (ranging from 5.3 to 5.6) thus the residue is highly decomposable leading to increase in carbon (Okalebo *et al.,*2002). Application of nitrogen did not result to high carbon values since the amount of carbon either decreased or increased in all treatments regardless of nitrogen application.

5.1.5 Changes in soil Cations as observed during the growing season

The exchangeable cations determined in the initial soil were found to have low quantities of Potassium while the amount of calcium was moderate. The low levels of exchangeable cations can be attributed to the acidic soil conditions which are explained by the fact that flooding causes acidic soils to become more acidic and alkaline soils more alkaline (Sanchez and Logan. 1992). However, the amount of Magnesium and Calcium were observed to decline during the seasons (Figure 8). The amounts of K are found to be different from those observed by Patrick *et al.,* (1968) who stated that most soils which have undergone flooding contain high contents of K. They also observed that Ca and Mg deficiencies are infrequent in wetland soils and similar observations can be seen from the results in Figure 8 and this is due to the fact that very little removals occur for this nutrients whether in grain or dry matter thus minimal reductions are observed and the low levels of K in the soil is also a contributing factor.

5.2 Effect of nitrogen fertilizer application and plant density on the leaf area index

The LAI and the total maize yield indicate a positive trend as shown in Figure 13. It is evident that the total yield (grain, dry matter) was related to the LAI and where there was an increase in the leaf area index there was also an increase in the yield for maize. This therefore means that the LAI can be used to predict crop productivity in this case the maize yield which can be a very effective tool in agriculture (Asner et al., 2002).In this case, treatment with plant spacing of 50 cm*12.5 cm with or without N was sufficient for radiation interception and plant dry matter production (Figure 13). If plant density is low as is the case with treatment 100 cm*25cm, LAI values are correspondingly much smaller. Solar radiation was not optimally used at low planting density, and potential yield (dry mass produced per unit area) was never realised as reported by Carberry *et al.,* (1993).

The trend of LAI with time (fig 13) shows that decline in LAI started after comb formation, and this is attributed to leaf senescence as also observed by Lukombo *et al.,* (2014). The treatment 100 * 12.5 (+N) had the highest mean value for but was not significantly different from the mean of LAI on the treatment 50 * 12.5 (+N) at 99% level of probability. LAI was highest ($P \leq 0.01$) at sampling time 5 which was taken when the maize was at physiological maturity. The CV was high and this can be explained by the various factors that affected the crop while in the field for instance the hailstones which affected the leaves of maize during flowering stage as well as during tasseling. Correlation between the two methods used in determining the LAI showed that the two methods had a weak positive correlation, and this means that either of them could be used in determination of LAI considering availability of resources and simplicity of the method but one cannot be used in the place of the other since each method is affected differently by external factors such as the weather.

5.3 Effect of nitrogen fertilizer application and plant density on maize grain and dry matter yield and plant tissue nutrient concentration.

The results also showed positive increase in grain yield as a result of both plant density and nitrogen application, suggesting that N shortage reduces leaf growth resulting in reduced percent of radiation intercepted, radiation use efficiency and dry matter partitioning to reproductive sink as reported by Asner et al., (2002). This could also be attributed to the positive correlation between leaf area index and grain yield. Grain yield showed positive and significant responses to increasing N availability hence increase in grain yield. Results of this study showed highly significant relationships between grai yield and its components. This is in harmony with the report of Cross (1991) who showed that grain yield is positively correlated with factors such as dry matter yield.

The content of N, P, K in the grain did not correspond to grain yield since the treatment with the highest value of grain yield (50 cm*12.5 cm (-N)) did not have the highest values of N, P, K in the grains. Mfundisi (2014) working in wetland soils reported similar results (0.57%) and this is explained as possible due to ability of the soil to respond to availability of the Phosphorus which is experienced in various wetland soils at under certain weather conditions. Phosphorus is however considered to be between critical and adequate levels which are required in the plant tissue and therefore uptake of phosphorus was efficient. Potassium is usually considered to be high in plant tissue but the results from the experiment indicate otherwise. The values of K in plant tissue are all below the critical value1.25%, an indication that uptake and concentration of K by the plant was poor as expected due to the low K concentration in the soil so other factors that affect the other soil properties did not affect uptake of K positively (Okalebo *et al.,* 2002). The results also indicated that the highest amounts of Nitrogen and phosphorus were taken up by the grains compared to Potassium which was highly concentrated in the dry matter, with treatment 100*25 (+N) being the best in uptake of the nutrients and can be recommended to a farmer planting maize specifically for fodder or grain of high nutrition due to its high N, P, and K concentrations in the grain and dry matter.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

1. Soil properties were affected in various ways by the application of Nitrogen as well as plant density. The pH values decreased in treatments receiving Nitrogen as well as in some which received no nitrogen and therefore the nitrogen source (urea) was not the only cause for the results observed. Plant density also affected the soil properties with nitrogen and phosphorus values reducing based on the plant density.
2. Leaf Area Index (LAI) was highly affected by density and Nitrogen. In treatments containing Nitrogen and with a high plant density, LAI was high; however, this was not the case in treatments with low plant densities.
3. The grain yield was highly dependent on the application of Nitrogen as well as plant density.

6.2 Recommendation

1. A plant spacing of 50 cm*12.5 cm with or without N is recommended for use in the wetland for highest grain yield based on the findings.

6.3 Further Studies

Further studies especially on Soil chemical and physical dynamics in reclaimed wetland soils and their effect on crop production need to be undertaken so as to determine the best solution to the soil problems in the area.

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APPENDICES

Appendix i : Analysis of variance for Grain yield

Variate: Grain_yield_t_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.6209	0.3105	1.33	
Rep.*Units* stratum					
Treatment_Description	7	19.8448	2.8350	12.19	<.001
Residual	14	3.2568	0.2326		
Total	23	23.7225			

Stratum standard errors and coefficients of variation during Dry Season

Variate: Grain_yield_t_ha

Stratum	d.f.	s.e.	cv%
Rep	2	0.1970	7.1
Rep.*Units*	14	0.4823	17.4

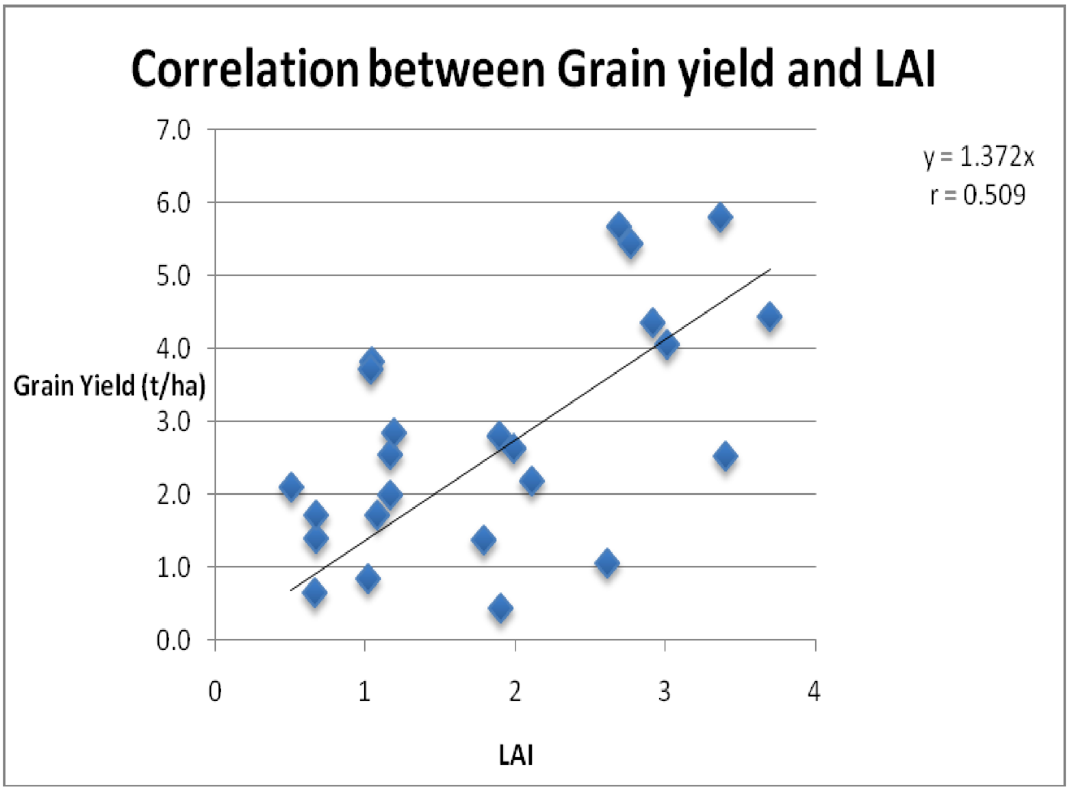
Least significant differences of means (5% level)

Table	Treatment_Description		
rep.	3		
d.f.	14	l.s.d.	0.8446

Appendix ii: Effects of Treatments on LAI, Grain and Dry matter yield

Treatments	LAI	Grain Yield	Dry matter Yield
25*100 –N	1.87a	1.739a	3.252ab
25*100 N	2.19b	1.727a	2.02a
25*50 –N	2.33b	1.556a	3.348abc
25*50 N	2.93c	3.614b	6.405bcd
12.5*100 –N	3.37d	3.077b	5.632abcd
12.5*100 N	3.41d	3.2b	5.112abc
12.5*50 –N	4.24e	3.822b	9.113d
12.5*50 N	4.54f	2.646ab	7.117cd
LSD	0.1607	1.3	3.769
F.Probability	<.001	0.009	0.022

Appendix iii : Correlation between Grain yield and LAI



Appendix iv: Evaluation of exchangeable cation levels in soils.

Rating	K	Mg	Ca
	----------------------------	mg kg^{-1}	-------------------------------
Very high	> 300	> 180	> 2400
High	175-300	80-180	1600-2400
Medium	50-175	40-80	1000-1600
Low	50-100	20-40	500-1000
Very low	< 50	< 20	< 500

Source: Okalebo et al., (2002)