SOIL-INORGANIC NITROGEN CHANGES IN RICE FIELDS UNDER SELECTED CROP MANAGEMENT INTERVENTIONS AND HYDROLOGICAL CONDITIONS IN KILOMBERO FLOODPLAIN, TANZANIA

AUSTIANO BERNARD YOBELE

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ABSTRACT

A study was conducted at Ifakara Morogoro Region with a purpose of investigating the effect of selected crop management interventions and hydrological conditions on soil NH_4^+ and NO_3^- content. Study sites were located at Valley Middle and Fringe sites as distinct hydrological zones. An experiment, in a complete Randomized block design, with six treatments: Semi-natural vegetation (TR1), Farmers practice (TR2), bunding alone (TR3), bunding + 60 kgN/ha (TR4), bunding + 120 kgN/ha (TR5) and bunding+Lablab green manure (TR6) was laid down in three replicates. SARO 5 rice variety was used as a test-crop. The trials were set during the 2014/15 pre-season and 2015/16 main season. Data was collected from 0-10cm soil depth. A Two-way ANOVA and post hoc – Tukey HD test statistical analyses were performed using GenStat Programme. Pre-season NH_4^+ showed 3 patterns: initial increase to peak values within 3 and 6 weeks for the Fringe and Middle sites, a period of decline (7th to 9th week, Middle, and 4th to 6th Fringe) and a period of increase (from 7th, Fringe and 10th week, Middle). Highest peak NH_4^+ values were at the Middle site (TR6 - 0.007401, TR5 - 0.004776, and TR4 - 0.04525, g/kg soil and TR4 - 0.004524, TR5 - 0.004595 g/kg soil). Peak NH_4^+ values differed significantly among treatments, following the trend: TR6>TR5>TR3>TR4>TR1>TR2 and TR4>R6=TR5=TR3+TR2>TR1 at the Middle and Fringe sites, respectively. Nitrate content decreased within 1-2 weeks both sites to attain the least values between 4 and 7 weeks and rose steadily to 10. Rice cropping season NH_4^+ and NO_3^- variation showed a similar trend for both sites, apart for a sudden increase in the treatments with N input at week 8 and 10. Hydrological conditions did not significantly influence the NH_4^+ and NO_3^- ($P = 0.05$) content. The study recommends repeating the work under controlled conditions.

DECLARATION

I, Austiano Bernard Yobele, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted to any other institution.

Austiano Bernard Yobele	Date
(MSc. Candidate)	

The above declaration is confirmed by;

Prof. M. Kilasara	Date
(Supervisor)	

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LIST OF ABBREVIATIONS AND SYMBOLS

BD	Bulk Density
C: N	Carbon-to-Nitrogen ratio
CRBD	Completely Randomized Block Design
CV	Coefficient of Variation
eh	Redox Potential
FRAM	Ferroelectric Non-volatile Random Access Memory
IRRI	International Rice Research Institute
M	Molar
MNRT	Ministry of Natural Resources in Tanzania
Mv	Mil volts
NH_4^+	Ammonium
Nm	Nanometer
NO_3^-	Nitrate
NTCHS	National Technical Committee for Hydric Soils
OD	Oven dried
PD	Particle Density
r.p.m	Revolutionary per minute
TR	Treatment
WFP	Water Filled Pore
WHC	Water-Holding Capacity
WKAP	Weeks After Transplanting Rice
WKT	Weeks before Transplanting Rice

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Wetlands are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6 meters (Ramsar, 1971). Wetlands consist primarily of hydric soils, which support ecosystem services (Bedford, 1996; MAHSC, 2004). The characteristics of wetland soils differ considerably with changes in hydrological conditions (Keeney and Sahrawat, 1986; Reddy and DeLaune, 2008). There are three distinct hydrological conditions (Keeney and Sahrawat, 1986; Reddy and DeLaune, 2008). These are: i) Center zone that, has a flooded soil and a water table that ranges from 50-70mm above the surface. ii) Middle zone that, contains saturated soils, but without excess floodwater (thickness of about few mm to 10mm blow the soil surface), and iii) Fringe zone that, has water table beneath the surface. Soils that occur in zones (i) and (ii) above are known as hydric soils while those in (iii) are considered as upland soils (Reddy and DeLaune, 2008).

The global wetland area is estimated to be around 7 to 9 million km^2 covering about 4 – 6% of the Earth’s surface (Inglett *et al.*, 2005; Mitsch and Gosselink, 2007). Wetlands are among the world's most biologically productive ecosystems and are rich in ecological species diversity (Munishi and Kilungu, 2004). Wetlands support the livelihood for more than three billion of people in the world and millions of people in Africa (Mitsch and Gosselink, 2007). In East Africa, wetlands cover about 4% of total land (Gichuki and Macharia, 2006) while in Tanzania about 10% of the terrestrial land is occupied with wetlands (Mombo *et al.*, 2011). They include large lake systems, river floodplains, and deltaic mangroves (Kamukara, 1990). Tanzania is endowed with potential wetlands that support the livelihood of a large community (Mombo *et al*., 2011). In view of the importance of wetland and evidence of their degradation (Kamukala, 1990), Tanzania ratified the Ramsar Conversion that hinges on wetland wise use concept with a purpose of ensuring wetlands sustainability (MNRT, 2004a). Accordingly, Tanzania designated four wetlands as Ramsar sites: Rufiji-Mafia Kilwa, Lake Natron basin, Malagarasi-Muyovozi and Kilombero flood plain (Ramsar, 2008). That notwithstanding, the sustainability of these and other wetlands in Tanzania is threatened by numerous socio-economic activities, particularly agriculture, that are taking place in these and other wetlands (Munishi *et al*., 2003; Madoffe and Munishi, 2005; Kashaigili, 2006; Chuwa, 2010; Kalisa *et al*., 2013).

Kilombero Flood plain is the fourth designated wetland of international importance under the Ramsar Treaty on Wetlands in Tanzania (Byers *et al*., 2012). The valley is of great economic, ecological and biological significance (Mombo *et al*., 2011). The major economic activities in the valley include fishing, pastoralism and agriculture (Mombo *et al*., 2011). Intensive agricultural production is the leading economic activity with sugar cane and paddy being the most important crops (Issa, 2004; Kato, 2007). In recent years, there has been an influx of investors who are interested to carry out large-scale farming in the floodplain (MNRT, 2004b).

One of the commonest inputs in agriculture is mineral N fertilizer (Cassman *et al*., 1998; Kimetu *et al*., 2006; Mgonzo, 2012). Mineral N is a requirement for the vegetative species in wetlands but if used inappropriately, it can lead to poisoning of some wetland species and a source of greenhouse gas emission (Wall, 2013; Audet *et al*., 2014). Wetlands, nevertheless, respond differently to the application of mineral N fertilizer depending on the existing local conditions; in particular the type of soil, vegetation, water flow rates and amount of applied fertilizer (Schmied, 2001; Reddy and De Laune, 2008; Smith, 2010).

1.2 Problem Statement and Justification

Rice is a commercial crop with an increasing productivity in the Kilombero valley (Kato, 2007). Mineral nitrogen fertilizer is becoming an essential input for the production of the crop, notably in irrigated systems (Nascente *et al.*, 2009). Mineral N in the soil is very dynamic (Becker *et al.*, 2007; Reddy and De Laune, 2008). The processes that determine the dynamic nature of mineral N depend on a number of soil conditions, the most important ones being the soil hydrological conditions (Reddy and De Laune, 2008), soil pH (Vitosh and Johnson, 1995; Brady and Weil, 1999), N input (Reddy and De Laune, 2008; Yeasmin *et al.*, 2012) and crop husbandry (Lou *et al.*, 2011). Both the type of N and the level of application determine its usefulness for crop production under wetland conditions (Ngwene *et al.*, 2013).

In wetland soils, it is common to overcome mineral N deficiency by increasing the organic or inorganic soil mineral N pool (endogenous and exogenous N sources) thus contributing to increase yields (Yeasmin *et al.*, 2012). Most plants take up nitrogen in the form of NO_3^- (Buresh *et al.*, 2008). Rice is exceptional to other plants by having the ability to take up N in the NH_4^+ form (Wang *et al.*, 1993). In addition, both NH_4^+ and NO_3^- are very dynamic depending on the wetland hydrology in particular presence of free water and redox potential (Pezeshki and Delaune, 2012). As a result, the status of both NH_4^+ and NO_3^- in wetlands and the dynamics of the two are of great importance for N management and for paddy production (Buresh *et al.*, 2008). Depending on existing conditions, in paddy rice production systems, N can be lost via number pathways that are associated with leaching (Kimetu *et al.*, 2006), volatilization (Loomis and Connor, 1992; Jones *et al.*, 2007), denitrification (Brady and Weil, 1999) and nitrification (Sahrawat, 2010). Apart from causing net N loss, these pathways are responsible for causing negative environmental effects and climate change (Reddy and DeLaune, 2008). For instance, NH_4^+ N is known to be toxic to aquatic life even at low concentration in water (Reddy and DeLaune, 2010; Wall, 2013). On the other hand, NH_4^+volatilization increase the risk of climate change effects (Audet *et al.*, 2014). NH_4^+, a production of mineralization, is easily oxidized to NO_3^- under aerobic conditions. The latter moves from the oxidized zone downward into the anaerobic zone where it is reduced to NO_2^- and eventually to N_2O and N_2 (Smil, 2000).

The two have direct contribution to global warming as they do adversely affect the ozone layer (Audet *et al.*, 2014). Likewise, NO_3^-N increases the risk of ground water pollution when leached from flooded soils (Yeasmin *et al.*, 2012). For economic reasons, environmental upkeep for the well-being of wetland biodiversity and minimization of the contribution of the added N fertilizers to greenhouse gas emission, it is necessary to monitor the inorganic N status in wetland rice production. A number of factors influence the dynamics of mineral or inorganic N dynamics in wetlands. These include temperature (Schmied, 2001; Wang *et al.*, 2004), redox potential (Pezeshki and Delaune, 2012), moisture regime (Wang *et al.*, 2004; Reddy and DeLaune, 2008), pH (Corstanje and Reddy, 2004), C:N ratio (Smith, 2010), microbial activity and microbial biomass, (Reddy and DeLaune, 2008) availability of electron acceptors (Sahrawat and Narteh, 2001, 2002, 2003; Sahrawat, 2004), cation exchange capacity (Cassman *et al.*, 1998), amount and nature of clay (Sugihara *et al.*, 2010a), nature and amount of salts (Bu *et al.*, 2015), inputs and nature of organic materials (Sugihara, 2010; Sugihara *et al.*, 2010a, b). The demand of N by paddy varies with crop growth or development (Muhammad *et al.*, 2010). Knowledge about the quantity of mineral N needed at each stage is necessary in order to reduce N losses and increase the N use efficiency. Due to the variation of the factors that influence mineral N dynamics in wetlands, it is imperative to understand is behavior during the cropping season in order to develop basis for appropriate N. This calls for the need to evaluate the effect of mineral N application rate and management interventions in terms of their contribution to labile N in the root zone. Fertilization and other anthropogenic factors in combination with mineralization processes make it hard for farmers to optimize the mineral N supply to the crops and lessen the mineral N pool which results in increased mineral N loss. When the concentration of NH_4^+ and NO_3^- is unknown, the available blanket fertilizer recommendations for rice farmers may lead to too low or too high concentration of available mineral N, the latter increases the risk for pollution.

It is important to know how much mineral N is present throughout the growing season under selected farming practices that are common to small-scale farmers in floodplains, notably in Kilombero valley, and currently, no studies has been conducted pertaining the mineral N dynamics in wetlands soil with due respect on hydrological condition. Studies Geoge *et al.* (1993); Cassman *et al.* (1998); Corstanje and Reddy (2004) do indicate that the soil drying that follows inundation during paddy production increases mineral N in the soil. The level of this nutrient is variable hence, its consequences to both water quality and greenhouse gas emission of the following flooding period (Yeasmin *et al.*, 2012). It is important to establish the content of mineral N prior to the onset of the rain season or at the beginning of the following rice crop in wetland. A thorough knowledge of the issues raised above would enable economic and sustainable rice production in the Kilombero flood plain where information hitherto is scanty.

1.3 Objectives of the Study

1.3.1 Overall objective

To investigate the effect of selected crop management interventions and soil hydrological conditions on the variation of soil NH_4^+ and NO_3^- content during 2015/16 rainy season.

1.3.2 Specific objectives

The specific objectives of the study were:

1. To assess the effects of selected crop management interventions on the variation of NH_4^+ and NO_3^- content during pre and after transplanting rice.
2. To find out the effect of hydrological conditions on NH_4^+ and NO_3^- status under paddy growing season.

1.4 Null Hypothesis

1. There is no difference in soil NH_4^+ and NO_3^- content due to imposed crop management during the rice production season.
2. The soil NH_4^+ and NO_3^- content does not vary with hydrological conditions irrespective of the imposed crop management and time since transplantation.

CHAPTER TWO

2.0 LITERETURE RIVIEW

2.1 Wetland Soils and Hydrological Conditions

Wetlands consist primarily of hydric soils, which support ecosystem services (Bedford, 1996; MAHSC, 2004). The characteristics of wetland soils differ considerably with changes in hydrological conditions (Keeney and Sahrawat, 1986; Reddy and DeLaune, 2008).There are three distinct hydrological conditions (Keeney and Sahrawat, 1986; Reddy and DeLaune, 2008). These are: i) Center zone that, has a flooded soil and a water table that ranges from 50-70mm above the surface. ii) Middle zone that, contains saturated soils, but without excess floodwater (thickness of about few mm to 10mm blow the soil surface), and iii) Fringe zone that, has water table beneath the surface. Soils that occur in zones (i) and (ii) above are known as hydric soils while those in (iii) are considered as upland soils (Reddy and DeLaune, 2008).

Hydric soils are defined as soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (Federal Register, 1994). Hydric soils are associated with reducing conditions. According to Inglett *et al*. (2005), they are characterized by a redox potential of < +300 mV. Most of the processes that occur in wetland soils are conditioned by redox potential. These include the processes that determine the N status in the wetland such as nitrification, denitrification and ammonia diffusion (Reddy and DeLaune, 2008).

2.2 Forms of Nitrogen in Wetland Soils

There are two major sources of N in the soil, namely organic and inorganic N sources. Organic forms of N are present in compounds such as amino acids, proteins, and more resistant N compounds (Reddy and DeLaune, 2008). In bio-solids, the majority of N added to the soil is in organic form (Reddy and DeLaune, 2008). Simple organic compounds are easily degraded by microorganisms to form amino acids and eventually mineral N (Buresh *et al.*, 2008). However, the organic compounds that contain N within the soil and their associated ecosystem are extensively different. Inorganic forms include NH_3, NH_4^+, NO_3^- and NO_2^- (Reddy and DeLaune, 2008). NH_4^+ and NO_3^- are readily available to plants and microorganisms (Muhammad *et al.*, 2010). NH_4^+ is the stable form of mineral N, which accumulates in the soil under reduced conditions (Buresh *et al.*, 2008).

NH_4^+ is oxidized to NO_3^- under aerobic conditions (Kimetu *et al.*, 2006; Reddy and DeLaune, 2008). Accumulated NO_3^- can be rapidly lost by denitrification up on flooding or paddling (Buresh and De data, 1991; Sigh *et al.*, 1999) or through water saturation by heavy rains even before dry-sown rice takes place (Sharma *et al.*, 2005). This happens when the percentage water filled pore space (WFP) exceed 60% (Linn and Doran, 1984). From the respiration point of view, this correspond to redox potential of $< +$ 300mV (Ingllet *et al.*, 2005; Pezeshki and Delaune, 2012). The NO_3^- that forms at the aerated zone migrates quickly into deeper anaerobic zone where denitrifying microorganisms convert it into gasous N, in particular N_2O (Smil, 2000; Aulakh *et al.*, 2001; Cai *et al.*, 2001).

2.3 Source of Nitrogen in Wetland Soils

Organically bound mineral N exists in wetland soils including seasonally added sediments (Reddy *et al.*, 2010). In cultivated wetlands, organic based N can be added as farmyard manure, green manure, compost, crop residues, and azolla (Patnaik and Rao, 1979; Issa, 2004). These furnish wetland soils with mineral N upon decomposition. The relative rate and turnover time of mineral N depends on the quantity and quality of the substrate (Kalumuna, 2005; Kimetu *et al.*, 2006; Lou *et al.*, 2011). Similarly, mineral N content in compost manure varies depending on the chemical composition of the material and quality of preparation (Issa, 2004). Inorganic or mineral N sources in wetland soils include industrial fertilizers and atmospheric mineral N deposition (Brady and Weil, 1999). In paddy production, a commonly used industrial fertilizer includes UREA, CAN and NPK (Mgonzo, 2012).

2.4 Nitrogen Dynamics in Wetland Soils

In wetland soils, N is bound to undergo a number of processes depending on the environmental conditions. These include mineralization of organic N into mineral N (NH_4^+ - N), ammonia volatilization, nitrification, denitrification and losses of N from site through leaching, runoff and seepage (Reddy and DeLaune, 2008; Yeasmin *et al.*, 2012). NO_3^- is the dominant form of inorganic mineral N in drained aerated soils while NH_4^+ is the dominant and stable forms of inorganic N that accumulates in submerged or reduced soils (Buresh *et al.*, 2008).

2.4.1 Mineralization

Mineral N mineralization is referred to the decomposition or oxidation of the chemical compounds inorganic matter into plant-accessible forms (Robert, 2005). It is one of the significant factors for plant nutrition and soil fertility, also it has been approximated to about 95% of the total mineral N in most surface soils are organically combined (Abdelmagid, 1980). In wetland soils, there are various environmental factors affecting mineral N mineralization, these are temperature (Powers, 1980), moisture regime (Palm *et al.*,1989), C:N ratio (Smith, 2010), redox potential (Pezeshki and Delaune, 2012), microbial activity and microbial biomass (Sugihara, 2010; Sugihara *et al.*, 2010a, b), availability of electron acceptors (Sahrawat and Narteh, 2001, 2002, 2003; Sahrawat, 2004), amount and nature of clay (Sugihara *et al.*, 2010a), nature and amount of salts, soil organic matter content and quality (Bu *et al.*, 2015) and the supply of nutrients such as phosphorus (P) are among the important determinants of ammonium production in submerged rice soils (Inamura *et al.*, 2009). These factors differ from flooded conditions to non-flooded conditions hence influencing the mineral N mineralization. Even in the same type of soils in wetland soils, mineral N mineralization may also be influenced by different type and cultural practices as well as vegetation to a particular zone (Vitousek *et al.*, 1982). Among the factors, temperature and moisture are reported to be more influential to mineral N mineralization (Wang *et al.*, 2004). Ponnamperuma (1972) reported that the increase of temperature even up 50°C contributed to the increase of mineral N mineralization in soils under flooded condition. The amount of mineral N mineralized between 25 and 30°C was larger than 20 and 25°C (Ando *et al.*, 1992). The mineralization rate at the wet soils is different from the soil at a transition from wet to dry, and eventually to the dry soil (Ando *et al.*, 1992).

Mineralization of organically bound N leads to the formation of ammonium (Kundu and Ladha, 1997; Gao *et al.*, 2016). Under anaerobic conditions, the only main end-product of mineralization is NH_4^+- N (Ready and Delaune, 2008; Gao *et al.*, 2016). Mineralization under reduced soil conditions is characteristically lower because of the low metabolic requirements of anaerobic microorganism (Zaman *et al.*, 1999; Sahrawat, 2010). This is associated with a slower breakdown of organic matter and plant residues (Villegas-Pagga *et al.*, 2000). Hence lower gross N mineralization compared with when it occurs under aerobic soil conditions (Sahrawat, 2010). Anaerobic soil conditions therefore are associated with lower mineralization and lower immobilization (Wang *et al.*, 2001) leading to higher rates of inorganic release compared to aerobic soil conditions (Tusuneem and Patrick, 1971). The rate of mineralization by the anaerobic micro-organism is low (Buresh *et al.*, 2008). This leads to higher net N mineralization in submerged (reduced soil condition) compared with oxidized soil conditions (Tusneem and Patrick, 1971). However, Wang *et al.* (2001) while studying inorganic mineral N release from 20 different soils found that net mineral N mineralization was not always higher under submerged conditions. The net buildup of inorganic mineral N in submerged (reduced) soils is reportedly higher in presence than absence of rice plants (Glosh and Kashyap, 2003). This phenomenon involves more processes than merely a reduction of mineral N (Kundu and Ladha, 1997). Prolonged soil submergence or anaerobic conditions can promote a buildup of less-decomposed substances of the soil organic matter with relatively high phenolic content, humic acid and calcium humate content (Olk *et al.*, 1996). Their content represents about 20-25% of the total soil organic matter in intensively cultivated tropical rice soils (Bao *et al.*, 2004). These constituencies have the potential to abiotically immobilize hence reducing the rate of nitrogen N mineralization (Olk *et al.*, 1996). Abiotically fixed mineral N is believed to contribute to the indigenous mineral N supply and could therefore explain the lack of decline in rice crop yield in long-term continuous cropping plots receiving 0 N supply in an experiment conducted in the Philippines (Padilla, 2001).

Due to the low mineral N requirements for anaerobic metabolism, the net release of inorganic mineral N from decomposing plants residues would be expected to occur at a higher C: N ratio in submerged rather than aerobic soil (Buresh *et al.*, 2008).

2.4.2 Nitrification and denitrification

Nitrification and denitrification are two processes that are interlinked (Reddy and DeLaune, 2008). Both processes depend heavily on the oxygen (O_2) status of the floodwater. On the other hand, nitrification as the process of oxidizing NH_4^+- N to NO_3^- demands availability of free oxygen (Abdelmagid, 1980; Patrick and Reddy, 1986;

Sahrawat, 2010). The level of O_2 in the flood water depends on the photosynthetic O_2 production by algae and possibly higher plants, density or activity of O_2 consuming microorganisms, and extent of mixing of water by wind or convention currents (Vitosh and Johnson, 1995). Availability of O_2 in surface flooded soils is affected by the net O_2 consumption rate and its renewable rate from the floodwater. Two zones, an aerobic surface and anaerobic subsurface zones exist in flooded soils (Broodbent, 1978).

There are number of factors that affect the thickness of the aerobic zone. These include; the concentration of oxygen, content of easily decomposable fraction of the soil organic matter, degree of microbial activity, content of iron (Fe_2^+), manganese (Mn_2^+), sulfur (S_2^-) and NH_4^+ (Patrick and Reddy, 1986). Diffusion of Fe_2^+ (Reddy and Patrick, 1980), Mn_2^+ and S_2^- from lower anaerobic zone diminishes the thickness of the aerobic layer while increase in the concentration of NH_4^+ led to its increase (Reddy and Patrick, 1984). Increase in the aerobic surface layer with increase in NH_4^+ concentration has been partly attributed to the accumulation of NO_3^- in the surface layer resulting from nitrification of NH_4^+ (Reddy and DeLaune, 2008).

Denitrification takes place deeper in the anaerobic subsurface zone under O_2 free conditions (Babbar and Zak, 1996). This is accomplished by some microorganisms (bacteria belonging to the genera *Pseudomonas, Bacillus, Micrococcus, Thiobacillus, Xanthomonas,* and *Spirillum*) that are capable of converting carbohydrate substrate to CO_2 and H_2O using nitrate as an electron receptor instead of O_2 (Vitosh and Johnson, 1995). $5(CHO) + 4\ NO_3 + 4H^+\ 5CO_2 + 7H_2O$. Once NH_4^+ is oxidized to NO_3^- the latter moves downward into the anaerobic zone (eh <+300mV) where it is transformed into NO_2^- and eventually gaseous N_2O and N_2 (Smil, 2000). Rice and other marsh and swamp plants have a unique capability of absorbing atmospheric O_2 into the root system through the stem (Amstrong, 1967) which lead to existence of aerobic micro-zone around the roots hence predominance of aerobic microflora (IRRI, 1964) that enhance nitrification-denitrification process. Other factors that affect denitrification rate include the presence of easily available carbon (Stanford *et al*., 1975b), temperature (Stanford *et al*., 1975a), pH, soil moisture content, soil texture, presence of denitrifying bacteria, and presence of overlying floodwater (Vitosh and Johnson, 1995; Brady and Weil, 1999).

NH_4^+ content in the floodwater and the underlying anaerobic soil profile is derived from various sources including decomposition of soil organic matter in the water column and mineralization of organic N in the aerobic soil layer and floodwater and mass movement of NH_4^+ by diffusion from the anaerobic soil layer to the aerobic soil layer and flood water (Cassman *et al*., 1998). Movement of NH_4^+ from the anaerobic to aerobic part in the soil occurs by diffusion (Rosenfeld, 1977). Reddy and Patrick (1984) reported NH_3 diffusion coefficient ranging from 0.03 to 0.85cm^2/day. Berner (1979) calculated that 70% of the NH_4^+ liberated from below the 10cm depth was through diffusion and mixing. Similar NH_4^+ diffusion values were reported by Rosenfeld (1977).

The factors which influence NH_4^+ diffusion rate include NH_4^+ concentration gradient which is a function of the NH_4^+ consumption in the aerobic zone during nitrification and NH_3 volatilization, the NH_4^+ generation rate in the anaerobic zone, the NH_4^+ concentration in the pore water, content of other cations in the exchange complex, cation exchange capacity of the soil and relative pore space which is a function of bulk density (Reddy and Patrick, 1984; Cassman *et al*., 1998).

2.4.3 Ammonia volatilization

Ammonium volatilization is an important process in mineral N dynamics of wetland soils. This process is mostly predominantly under the alkalinity environment (Palm *et al*., 1989).

Rates from applied fertilizer can reach up to about 20-22% loss at pH of 9-10 but diminishes considerably at low pH (Singh and Vaje, 1998). According to Simpson (1968) and Vlek *et al.* (1981) the process of NH_3 loss can be presented as follows:

Absorbed NH_4^+ $\rightleftarrows$ NH_4^+ (in solution) $\rightleftarrows$ NH_3 (in solution) $\leftrightarrows$ NH_3 (in soil). The equilibrium is the key factor that determines the direction of the process. The factors that affect NH_3 volatilization include pH of the water, floodwater urease activity, NH_4^+ content, the N source (Ventura and Yoshida, 1977), and rate, time, and method of application (Mikkelsen *et al*., 1978; Pedrazzini and Tarsitano, 1998). It has been reported that at pH 5.0 and below, approximately 0.004% of the N is present as free NH_3 and the fraction increases to about 10-fold with each unit increase in pH (Loomis and Connor, 1992).

NH_4^+ from fertilizers broadcast into a high pH water are highly susceptible to direct NH_3 volatilization losses. Mineral N losses from fertilizer broadcast into floodwater also varied with the N source, rate, time, and method of application (Mikkelsen *et al*., 1978). An acidic or neutral pH favors ionized NH_3 whereas an alkaline pH favors the existence of unionized NH_3, the critical pH being 7.5 (Reddy and Delaune, 2008). Deep application of mineral N fertilizers reduces NH_3 volatilization (Jones *et al*., 2007). The pick concentration of ammonical mineral N in floodwater of tropical rice fields due to hydrolyzed urea typically occurs 1-5 days after urea application (Buresh *et al*., 2008). The process is favored by high concentration of ammonical mineral N, high floodwater pH and temperature (Cai, 1997). The magnitude of NH_3 loss from submerged soils is directly related to the content of aqueous or partial pressure in water at the interface with the atmosphere (Buresh *et al*., 2008) of the aqueous NH_3 varies with the pH of the water. It is negligible at pH 7.5 but increases rapidly to attain over 40% at pH 9.2 (Loomis and

Connor, 1992). Ammonium loss through volatilization in high pH soils can be reduced through flooding as flooding lower the pH levels (Motomura, 1962).

2.4.4 Leaching

Other losses of mineral N in flooded wetlands include leaching, runoff and seepage. These vary depending on the local conditions. Due to negative charge of soils, NO_3^- is loosely detained in the soil and can readily be leached down the soil profile (Kimetu *et al.*, 2006). Intensification of agricultural production, in particular the use of mineral N fertilizers contributes to higher rate of mineral N loss (Addiscott, 1996). The raised concern of water contamination worldwide has been associated with high rate of NO_3^- leaching. This has been accelerated by the increased of both fertilizer and pesticide application (Spalding and Exner, 1993). Di and Cameron (2002) reported that an increased use of organic fertilizers also contributed to enhanced mineral N loss.

According to Peoples *et al.* (1995) leaching, runoff, seepages and crop harvesting have been reported to be the principal ways of mineral N loss accounting to about 89% of the mineral N applied in the soil. However, about 20–50% of the N applied is capable of being recovered by most of the annual crops (Paroda *et al.*, 1994). NO_3^- leaching may be managed by better timing of ploughing, improved stock management and precision farming, reducing N application rates, synchronizing N supply to plant demand, use of cover crops and pasture leys (Di and Cameron, 2002).

2.5 Green Manure and other Organic Sources of N in Rice ecosystem

Understanding the mineral N mineralization patterns of green manure legume residues is crucial in the synchronization of N release from plant residue and uptake by subsequent crops. Green Manure decomposition and subsequent N release depend largely on residue quality and quantity, soil moisture and temperature and specific soil factors such as texture, mineralogy and acidity, biological activity and the presence of other nutrients (Myers *et al.*, 1994). It has been demonstrated that nutrient release to biochemical properties of the substrate, in particular lignin, polyphenols and N content (Palm *et al.*, 2001; Wang *et al.*, 2004; Nziguheba *et al.*, 2005). As a result, even for the same legume, different rates of N mineralization have been observed. Working on the decomposition of 3 legumes, Odhiambo (2010) established mineralization rate constant of 0.004 to 0.008 week^{-1} for lablab treated soils while for sun hemp treated soils, the mineralization rate constant varied from 0.005 to 0.012 N week^{-1}. Chilagane (2013) reported that Sun hemp tends to release N at a constant rate of 0.012 N week^{-1}, Lablab (0.008 N week^{-1}) and velvet beans (0.004 N week^{-1}). These sources are excellent providers of mineral N to subsequent rice crop thus reducing the need for the application of industrial mineral N fertilizers (Yadvinder-Singh *et al.*, 1991). The application of green manure with urea can reduce NH_3 loss. Losses of mineral N from applied green manure are often lower than from urea. Becker *et al.* (1995) noted an average loss of mineral N from green manure of 14% of the applied N as compared with 35% mineral N loss from urea. Loss of mineral N from organic sources can be reduced by synchronizing the crop need with the with the mineral N release pattern or by mixing the leguminous green manure with rice straw that has a high C:N ratio as means of retarding mineral N release. Watanabe *et al.* (1998) measured mineral N recovery rate of up to 62.9% of the applied mineral N from Azolla.

2.6 Effect of Soil Moisture on Nitrogen Status in Wetlands

Previous soil aeration studies have demonstrated the importance of the soil air/water balance upon aerobic and anaerobic microbial activities (Yadvinder-Singh *et al.*, 1991; George *et al.*, 1993). Aerobic microbial activity increases with soil water content until a point is leached where water displaces air and restricts the diffusion and availability of oxygen. Soil moisture expressed in terms of percentage Water Filled Pores control the soil microbial activity and the related processes such as mineralization and denitrification. Linn and Doran (1984) showed that soil 60% water filled pore (%WFP) was the threshold for supported maximum aerobic microbial activity, below and above which a decrease was noted. According to the authors, non-tilled soils characteristically had higher %WFP than the ploughed soils, and correspondingly showed a huge difference in CO_2 and N_2O emission between the two.

Maximum rates of microbial respiration, nitrification, and mineralization occur at the highest water content (lowest tension) at which soil aeration remains non-limiting (Buresh *et al.*, 2008). When soil water contents approach or exceed field capacity, the percentage of soil pore space filled with air or water are better indicators of aerobic versus anaerobic microbial activity than either water content or water potential (Gilmour *et al.*, 1977; Linn and Doran, 1984). A number of studies have shown that a soil water content equivalent to 60% of a soils water-holding capacity (WHC) delineates the point of maximum aerobic microbial activity showed that soil 60% water filled pore (WFP) was the threshold for supported maximum aerobic microbial activity, below and above which a decrease was noted (Pal and Broadbent, 1975; Gilmour *et al.*, 1977; Linn and Doran, 1984).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location and Characteristics of the Study Sites

3.1.1 Location of the study sites

This study was conducted in the Kilombero Valley Floodplain wetland, located in Kilombero district at Morogoro region (Fig. 1). It covers an area of 7967 km^2 (Samora *et al.*, 2013). The Valley area is characterized by sub-humid tropical climate with relative humidity varying between 70 and 80% and an annual rainfall of about 1200–1400 mm (MNRT, 2004a). The valley is also characterized by two rainy seasons: a short rainy period also known as Vuli that last from December to February and a long rainy season also known as Masika that extends from March to May/June. The atmospheric temperature varies between 20 °C and 30 °C (MNRT, 2004b).

The flood plain is characterized by fertile swelling shrinking type of soils, which are mainly flooded during the long rainy season but develops cracks during the dry season particularly between July and October (Samora *et al.*, 2013). The major activities in the area are agriculture, livestock keeping, fishing and business (Kato, 2007).

3.1.2 Site description of the study sites

Three experimental sites were set up in three villages selected based on their soil hydrological differences. These were Kantindiuka, Kiyongwire and Kivukoni village, whose position with regard to river flooding were Fringe, Middle and Central zone, respectively (Fig. 1). These represent the three distinct hydrological conditions on which the study was based.

The corresponding characteristics of the sites are thus explained. (i) The Center zone refers to the central part of the main wetland water flow. It is characterized by prolonged water saturated conditions with a peak water flood height of 1m and a flooding period of around 2-3 months when water covers the ground surface (ii) The Middle zone is an intermediate position between the prolonged flooded center zone and the least flooded part of the floodplain (Fringe). It is characterized by flooding period less than a month during when flowing water completely cover the land surface but in which the root zone is moist throughout the cropping season and being underlain by a soil layer that is saturated with water throughout the cropping season. (iii) The Fringe zone is saturated with water to the land surface for a period less than 2 months. It enjoys a much longer period of surface water saturation than the Middle zone because it receives seepage water from the hills after rain which last longer than the main river flooding at the former. The site in the center, middle and Fringe part of the Kilombero River flood plain will be referred as Centre, Middle and Fringe zone or site in the rest of the document.

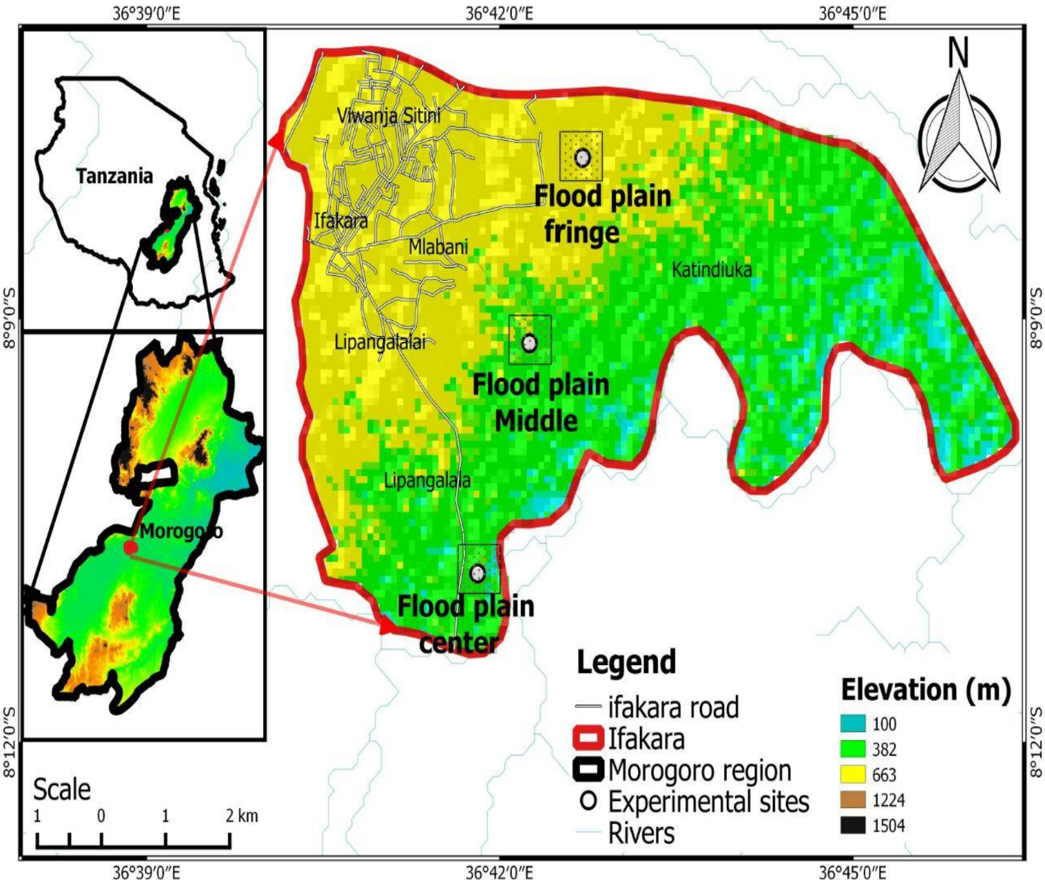


Figure 1: Location map of the experimental sites

3.1.3 Rainfall of the studied research sites

The distribution of rainfall for the 2015/16 cropping season is shown in Fig. 2.

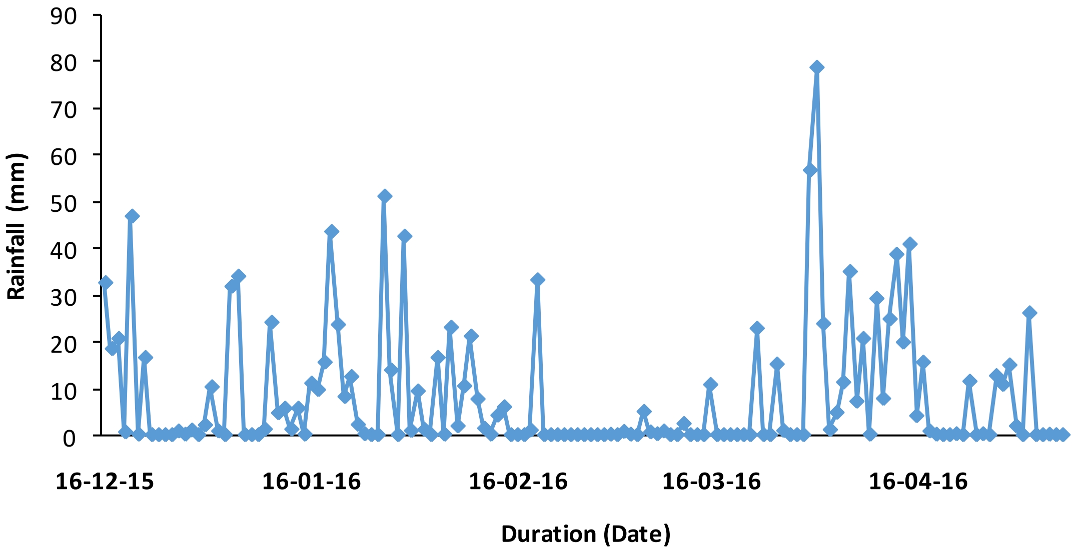


Figure 2: The rainfall during the 2015/16 rainy season

3.2 Field Experiment and Data Collection

3.2.1 Experimental design

An experiment with six treatments replicated three times in completely randomized block design (CRBD) was laid down at three sites with distinct hydrological conditions during the 2014/5 and July 2015/6 rain season. The treatments were: (i) a semi-natural vegetation that was initially tilled but left with no crop (TR1) (ii) Farmers practices - Rice crop with no added mineral N and without bunds (TR2). (iii) Rice crop + bunds but with no applied mineral N (TR3). (iv) Rice crop +Bunds + 60kg/ha urea (TR4). (v) Rice crop +Bunds + 120kg/ha urea (TR5). (vi) Rice + bunds+ lablab green manure with no mineral N (TR6). In the lablab treatment, the former was incorporated into the soil 45 after germination. The quantity incorporated in the soil contained an equivalent of 50 kg N/ha.

Paddy (*Oryza sativa)* variety TXD 306 also known as *S*ARO 5" was used as a test crop in this study. The experiment was laid on 5 x 6 m^2 plots with a plant spacing of 20 x 20 cm^2 as recommended by Kanyeka *et al.* (2007). Standard agronomic crop management was maintained throughout the cropping season.

Plate 1: Fringe experimental site four weeks after paddy rice transplantation

3.2.2 Data collection

3.2.2.1 Determination of hydrological-based characteristics

3.2.2.1.1 Rainfall of the studied sites

The rainfall of the studied sited was collected using an automatic weather station. Measurements were recorded hourly and stored in a data logger.

3.2.2.1.2 Soil moisture measurements

Soil moisture data were recorded using Virrib sensors. From each experimental site, a Virrib sensor was installed horizontally at a depth of 10 cm with an automatic measurements logged every 15 minutes (Walker *et al*., 2004).

3.2.2.1.3 Redox potential measurement

The redox values were determined at each site following the method developed by Vorenhout *et al*. (2004). Values were continuously recorded on a daily basis using an Ag/AgCl electrode. Configuration and data collection was performed using a mobile computer. Data were processed by a central PIC processor (PIC16F877) and stored in 256 Kbit ferroelectric non-volatile random access memory (FRAM) serial memory. Configuration of and data collection from the data logger were performed with the computer program Hypnos Data Collector Version 1.4, created using LabView (NIC, 1998).

3.2.2.2 Determination of the soil characteristics

Soil samples were collected from the experimental sites for laboratory characterization. From each experimental site, 18 soil samples were randomly collected from the 0-30 cm depth, mixed together to constitute a composite sample. Composite soil samples were packed transported to the laboratory, air-dried, ground and sieved through a 2-mm sieve ready analysis.

3.2.2.3 Soil NH_4^+ and NO_3^- content data collection

The following data were collected from the experimental plots: NH_4^+ and NO_3^- content. Prior to data determination, soil samples were collected from each individual and prepared as detailed below.

3.2.2.3.1 Soil sampling and sample preparation

Soil samples earmarked for NH_4^+ and NO_3^- measurement were collected from individual plots during the 2015/16 rain season. Samples were taken prior and during cropping season. The pre-paddy growing season (dry wet transition period) lasted from 16 December (that corresponded with the start of the 2015/16 short rainy season) to 4 March 2016 with sample collection being carried out at an interval of 1 week. The second season of data collection took place between 18 March and 8 July 2016. Soil samples were collected every two weeks. Soil samples from each plot were randomly collected using a soil auger at the depth from 0-10 cm. six soil samples were collected from each treatment and mixed thoroughly making one composite sample.

Individual samples were then wrapped into labeled plastic bags, kept in a cooling box with ice and immediately taken to the laboratory for analysis. In the laboratory, the samples were immediately frozen prior to extraction and eventually determination of NH_4^+ and NO_3^- of the three study sites, sampling at the Valley Centre site was stopped shortly after the start of the short rain season due to flooding.

3.3 Data Analysis

3.3.1 Soil characterization

The collected soil samples were analyzed for particle size distribution, bulk density, porosity, particle density, pH, total N, total carbon, and plant available phosphorus. Particle size analysis was analyzed by the hydrometer method on soil samples dispersed in a 5% sodium hexametaphosphate solution (Gee and Bauder, 1986). Bulk Density was estimated following the procedure after Blake and Hartage (1986). Particle was determined by pycnometer method after the method developed by Blake and Hartage (1986). Porosity was calculated using the corresponding particle and back density values using the formula (1-BD/PD), where BD = Bulk density and Particle density).

Organic carbon was determined following the Walkey-Black wet combustion method (Nelson and Sommers, 1982). Total N was analyzed by using the micro-Kjeldahl method after the protocol developed by Bremner and Mulvaney (1982). Available phosphorus was determined following the procedure developed by Olsen and Sommers (1982). pH was measured using a soil: water suspension (1:2:5) in accordance with the protocol after Mc Lean (1982).

3.3.2 Determination of NH_4^+ and NO_3^-

The frozen samples were defrosted before the NH_4^+ and NO_3^- extraction. A separate soil sample was used to determine the moisture content of each studied plot. These samples were defrosted, weighed prior and after oven-drying to constant weight at 105^0C. The measurements of dry weight were done using weighting an analytical balance. Approximately 20 to 25g of soil samples were weighed after defrosting and immediately taken to the oven. The moisture content was express as a fraction of the oven-dry weight of the sample in question. This value was used to convert the field obtained weight into the equivalent oven dry weight.

15g equivalent of wet soil were OD weight of the defrosted soil sample were shaken with 90 ml of 0.01M $CaCl_2$ for 60 minutes at 189 rpm (Houbal *et al.*, 1986), filtered, treated with one drop of 0.01 M sulfuric acid to prevent any microbial growth and kept for measuring the concentration of $NH_4^+$and NO_3^- (Nascente *et al.*, 2009). The method developed by Reardon *et al.* (1966) was adopted to determine the NH_4^+ concentration in the soil extract. 20 ml volume of the extract was adjusted to pH 7 using 0.01M NaOH (Kunamneni, 2003). An aliquot of 0.1 ml of the neutral (pH 7) extract was pipetted into a 16mm cells and reacted for 20 minutes with vario ammonia Salicylate and Cyanurate F5 powder. The NH_4^+ content was calorimetrically determined using photoflex photometer at a wavelength of 690nm. NO_3^- was determined following the methodology developed by Swinehart and Warren (1953). 1ml of the soil extract prepared as described on section 3.4.3 was pipetted into a 16 mm cuvette cells and reacted with vario nitrate Chromotropic powder for 10 minutes. The NO_3^- in the extract was spectrophotometry determined at a wave length of 436nm. Both NH_4^+ and NO_3^- were expressed in terms of g/kg soil.

3.4 Statistical Analysis

Post hoc –Tukey HD test and Two-way ANOVA analyses were performed by using GenStat Computer Software (Payne, 2009). The post hoc –Tukey HD test was used to separate the mean values of NH_4^+ and NO_3^- contents among the treatments. Two way ANOVA was used to test the effect of the hydrological zone between the Middle and Fringe sites with respect to NH_4^+ and NO_3^- content.

CHAPTER FOUR

4.0 RESULTS

4.1 Characteristics of the Studied Soils

The physical and chemical characteristics of the studied soils are presented on Table 1 and 2. The studied soils vary in soil texture. Clay content decreased with increase in distance from the river cause. The Centre site has about 60% clay while the Fringe site had the lowest clay content (30%). The silt content in was high in all sites ranging from 26% in the Centre and Middle sites to 39% in the Fringe site. The soil porosity was 54%, 48% and 54% for Center, Middle and Fringe, respectively. The C/N ratio at the center was 11.8, Middle 12.4 and Fringe16.5. The ratio had an increase depending with the hydrological condition from Center to Fringe.

Table 1: Soils physical characteristics of the of the studied sites

Site name	**Physical properties**					
	Sand (%)	**Silt (%)**	**Clay (%)**	**BD (Mg m^{-3})**	**PD (Mg m^{-3})**	**Porosity (%)**
Fringe	29.61	39.61	30.78	1.22	2.66	54
Middle	40.34	26.87	32.44	1.34	2.66	49
Center	12.00	26.54	61.47	1.21	2.66	54

Table 2: Soils chemical characteristics of the of the studied sites

Site name	**Chemical properties**				
	Organic C (%)	Total N (%)	C/N	Extractable P (mg kg^{-1})	pH
Fringe	1.82	0.11	16.5	49.98	6.1
Middle	0.87	0.07	12.4	16.52	5.8
Center	1.88	0.16	11.8	5.51	4.9

Centre was the most acidic one with pH of 4.9. Soil pH gradually increased from the Centre to the Fringe site with values of 5.8 and 6.1 in the Middle and Fringe sites, respectively. The content of organic carbon was rather low in all sites. It was about 1.8% at both Centre and Fringe sites but only 0.8% at the Middle site. Total N content was comparable between the Centre and Fringe sites (0.16 and 0.11%) but rather low (0.07%) at the Middle site. The corresponding C: N ratio at the Centre, Middle and Fringe was 11.7, 12.4 and 16.5, respectively.

4.2 Variation of Soil Moisture in the Root Zone of the Studied Soils During the Pre-paddy Growing Season

The soil moisture content within 0-10 cm varied over the season as shown on Table 3. At the Middle site, it ranged between 12.3 and 31.6% while at the Fringe it varied from 16.2 to 46.4%. The pattern of moisture content variation differed between the two sites. The Middle zone was rather drier than the Fringe zone during the first 4 weeks with moisture content ranging between 12 and 22% compared with 41 and 46%. It was interesting to note that immediately after the first rains early in December, the Fringe zone became wetter duo to surface water flow from the neighboring mountain slopes. This phenomenon did not occur at the Middle site. In view of the fact that the data were not suitable for assessing the contribution to the extent of soil aeration, a phenomenon that is associated with redox processes in the soil (Lin and Doran, 1984), the same was converted into percentage of water filled pore spaces so that they could be used to interpret their relation with redox related characteristics of the studied soils.

Table 3: Variation of soil moisture content in the root zone (0-10cm) in the studied soils during the pre-paddy growing season

Site	Soil moisture content (%)										
	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Middle	15.1	12.3	13.1	22.7	26.4	24.2	17.5	17.7	19.5	14.4	31.6
Fringe	43.4	46.4	43.1	41.3	16.2	14.9	16.8	14.7	22.7	29.7	30.6

Table 4 shows that the percentage WFP varied widely within and between the two sites. At the Middle site, it ranged between 22.7 and 53.9% during the 9 out of 10 weeks of the study period, and rose to 64.3% at week 20. At the Fringe site, it varied between the soils during the first 4 weeks with percentage WFP ranging from 76. 5 to 86.0%. Thereafter, in particular between week 4 and week 7, the percentage WFP ranged between 27.4 and 31.1%. This was the dried period at this site. From week 9 to week 10 the percentage WFP started to rise again (55.0 to 56.8%). These are discussed later on in conjunction with the variation of NH_4^+ and NO_3^- at these sites.

Table 4: Water filled pore space at the Middle and Fringe sites during the pre-paddy growing season

Site	Percentage water filled pore space (%WFP)										
	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Middle	30.8	25.1	26.7	46.4	53.9	49.4	35.7	36.2	39.9	29.5	64.6
Fringe	80.5	86.0	79.8	76.5	30.0	27.7	31.1	27.4	42.1	55.05	56.8

4.3 Variation of the Redox Potential in the Root Zone of the Studied Soils

4.3.1 Variation of redox potential at the Middle and Fringe site during the pre-paddy cropping season

The values of the Redox potential at the Middle site varied narrowly during the transition period. They ranged from +341.5 to +394.7 mV.

At the Fringe site, a comparable situation existed between week 0 and week 7. High Eh values (over +600 mV) were noted from week 7 to 10. The values of the redox potential within the root zone for the main cropping season for both Middle and Fringe sites are shown on Table 5. Wide variations existed between the two sites. At the Middle site, Eh ranged from +121.6 to +394.2 mV.

Table 5: Variation of Redox potential (eh) at the Middle and Fringe sites during the pre-paddy cropping season

Site	Redox potential (mV)										
	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Middle	392	383.7	341.3	344.5	349.3	350.9	361.9	365.6	363.6	371.8	394.7
Fringe	358.7	349.6	345.3	351.1	348.1	341.6	346.2	350.3	672.7	676.7	688.9

4.3.2 Variation of redox potential at the Middle and Fringe sites during the paddy cropping season

The lowest values were recorded during the first 3 (121.6 to 237.0 mV) while from week 6-16, readings varied between 348.1 and 478.0 mV). A similar trend, though with some variations, was noted at the Fringe site. In general, the studied soils at the Middle and Fringe sites tended to have higher redox values towards the late stage of the cropping season (Table 6). For instance, at the Middle site, this started at week 6, while it was from week 12 onwards at the Fringe site.

Table 6: Variation of redox potential at the Middle and Fringe site during the paddy-cropping season

Site	Redox potential (mV)								
	Week 0	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
Middle	237.0	204.8	121.6	348.3	394.2	347.3	478.0	349.0	349.4
Fringe	195.3	209.2	352.3	242.9	403.7	295.5	408.3	350.2	357.5

4.4 Effect of Crop Management Interventions on the Variation of NH_4^+ Content

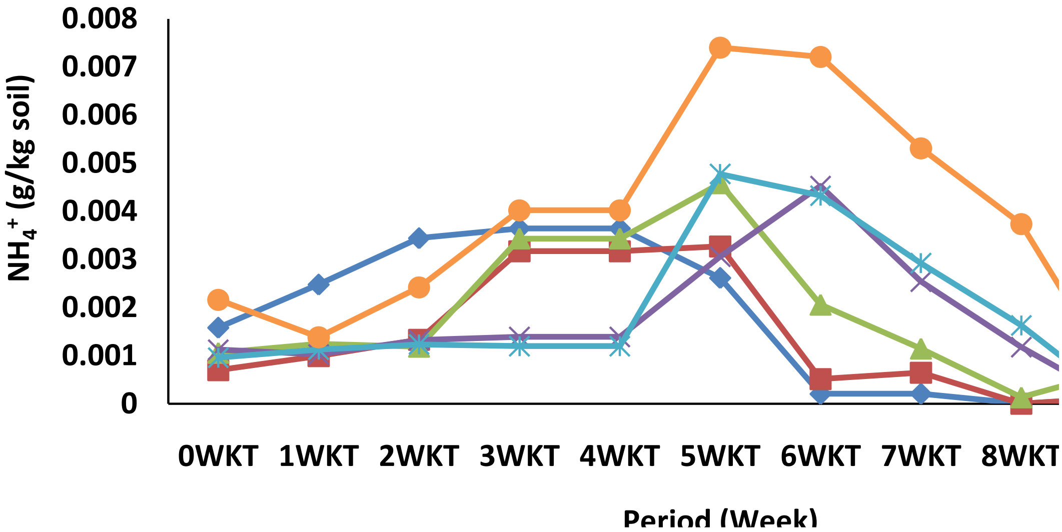
The data that shows the variation of NH_4^+ content in the studied soils is separated into two seasons: the dry-wet transitional (pre-paddy growing season) and the paddy cropping seasons, respectively.

4.4.1 NH_4^+ variability during the pre-paddy growing season

The data presented below consists of 2 sites: The Middle and the Fringe sites, respectively.

4.4.1.1 NH_4^+ content at the Middle site

The NH_4^+ content varied in results and involves 4 stages. The initial NH_4^+ content at the start of the rainy season, increase in NH_4^+ to attain a peak value, decrease from the peak NH_4^+ content to 0 g/kg soil, and lastly increase in NH_4^+ content (Fig. 3). At week 0, the NH_4^+ content at the Middle site was highest in TR6 (0.00215 g/kg soil) and lowest in TR2 and TR5 (0.000698 and 0.000958 g/kg soil), respectively. These values were significantly different at ($P = 0.05$) (Table 7). The remaining treatments had intermediate values.



WKT: Week before Transplanting Rice (Dry –wet transition weeks)

Figure 3: Pre-rice growing season NH_4^+ variation at the Middle site

NH_4^+ increased modestly with increase in time from week 0 to reach a peak value at between week 4 and 6 (Fig. 4). The corresponding NH_4^+ peak values were as follows: TR6>TR5>TR3>TR4>TR1>TR2. Between week 4 and 6, depending on the treatment in question, there occurred a gradual decline in NH_4^+ to attain lowest values at week 9 before the gradual increase at week 10 (Fig. 4). This increase attained significantly difference values at week 10 (Table 7) with TR3 attaining the highest value.

Table 7: Effect of crop management interventions on the NH_4^+ content during the pre-paddy growing season at the Middle site

Treatment	**NH_4^+ content (g/kg soil)**			
	Week 0	**Week 1**	**Week 6**	**Week 10**
TR1	0.00158ab	0.002476a	0.000204a	0.002154ab
TR2	0.000698a	0.000992a	0.000514a	0.002836ab
TR3	0.001058ab	0.001242a	0.002058ab	0.004212bc
TR4	0.001121ab	0.00102a	0.004525b	0.001955ab
TR5	0.000958a	0.001121a	0.004325b	0.005478d
TR6	0.002158b	0.001383a	0.007207c	0.00361abc
Mean	0.001262	0.001135	0.00314	0.00337
F statistics	0.019	0.1	0.001	0.002
L.S.D	0.0007662	0.000663	0.001666	0.00141
CV(%)	5.3	14.4	5.3	24.7

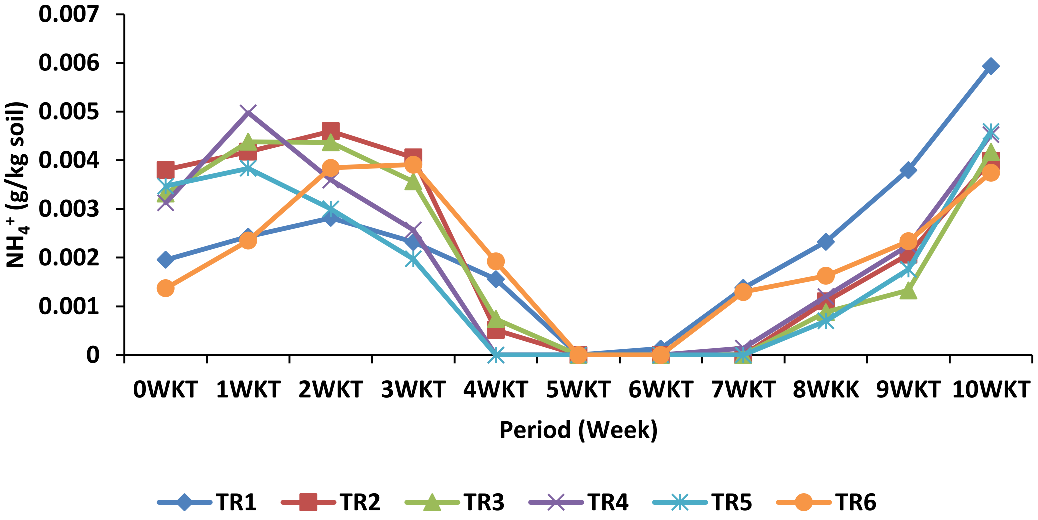
*Means in the same column followed by the same letter(s) are not significantly different according to Tukey test (P = 0.05).

At week 6, there were large differences in NH_4^+ content among the treatments which can be grouped into 4 categories: TR6 stood alone with the highest NH_4^+ content (0.00720 g/kg soil) followed by TR4 and TR5 category (0.004525 and 0.004325 g/kg soil), respectively and TR3 (0.002058 g/kg soil) while the last category which also had the lowest NH_4^+ content consisted of TR2 and TR1 (0.000514 and 0.00020 g/kg soil), respectively. These categories were statistically significantly different (Table 7). From week 9 to week 10 there was a large increase in NH_4^+ in almost all treatments. The highest and lowest NH_4^+ content at week 10, occurred in TR 5 and TR3 (0.005478 and 0.004212 g/kg soil), respectively.

4.4.1.2 NH_4^+ content at the Fringe site

NH_4^+ variation at the Fringe site varied with time as shown in Fig. 4. The NH_4^+ content on the first day, immediately after the first rain episode, varied widely among treatments.

Treatments TR2, TR3, TR4 and TR5 had significantly (P = 0.05) higher NH_4^+ (over 0.003 g/kg soil) content than TR1 and TR6 (0.001 and 0.002 g/kg soil), respectively (Table 8). Generally, the NH_4^+ content varied over the pre-paddy growing season in all treatments. The content of NH_4^+ characteristically varied showing three distinctive periods irrespective of the imposed management intervention. These were: initial period which corresponds with the on start of the rains during when the NH_4^+ content was relatively high and showed a tendency of increase to reach a peak value, followed by a second period during when the NH_4^+ content decreased with time to attain 0 value and lastly a period of NH_4^+ increase with time (Fig. 4).



WKT: Week before transplanting rice (dry –wet transition weeks)

Figure 4: NH_4^+ content during the pre-paddy growing season at the Fringe site

During the first phase of increase in NH_4^+, differences existed both in the peak value and the period required to attain it. For instance, in TR4 (60 kg N + bunds) NH_4^+ almost doubled (0.003 to 0.005 g/kg soil) over a week. A similar trend was observed in TR6 (Green manure + bunds) with an increase from 0.01 (in week 0) to 0.004 g/kg soil (in week 3) (Table 8). The remaining treatments showed a less pronounced increase in

NH_4^+ and differed in the period to reach peak NH_4^+ content. TR3, TR4 and TR5 reached peak $NH_4{}^-$ values at week 1, and TR1 and TR2 attained it at week 2 while that of TR6 was at week 3.

Table 8: Effect of crop management interventions on the NH_4^+ content at selected periods during the pre-paddy growing season at the Fringe site

Treatment	**NH_4^+ content (g/kg soil)**			
	Week 0	**Week 1**	**Week 6**	**Week 10**
TR1	0.001955ab	0.002431a	0.00013286a	0.005934b
TR2	0.003805c	0.004176a	0a	0.003988a
TR3	0.003314c	0.004379a	0a	0.004174a
TR4	0.003126bc	0.004973a	0a	0.004524a
TR5	0.003471c	0.003836a	0a	0.004595a
TR6	0.001371a	0.002349a	0a	0.003742a
Mean	0.00284	0.00369	0.000022	0.00449
F statistic	0.9	0.097	0.465	0.158
L.S.D	0.000871	0.002115	0.000171	0.001713
CV (%)	0.9	8.4	21	4.4

*Means in the same column followed by the same letter(s) are not significantly different according to Tukey test (P = 0.05).

There was a different pattern of decrease in NH_4^+, from the peak value to the lowest among the treatments as shown on Fig. 4. The start of the decrease was as follows: week 1 for TR2, TR3, TR4 and TR5; week 2 for TR2 and week 3 for TR6. Lowest or absolute 0 values were reached at different periods: week 4 for TR4 and TR5; and week 5 for the rest of the treatments.

The period during when there was no NH_4^+ also varied with treatments: 4 weeks (week 4-7) for TR4 and TR5; 3 weeks (week 5 to week 7) for TR2 and TR3 (week 5 to week 7); 2 weeks (week 5 to week 6) for TR1 and TR6, respectively.

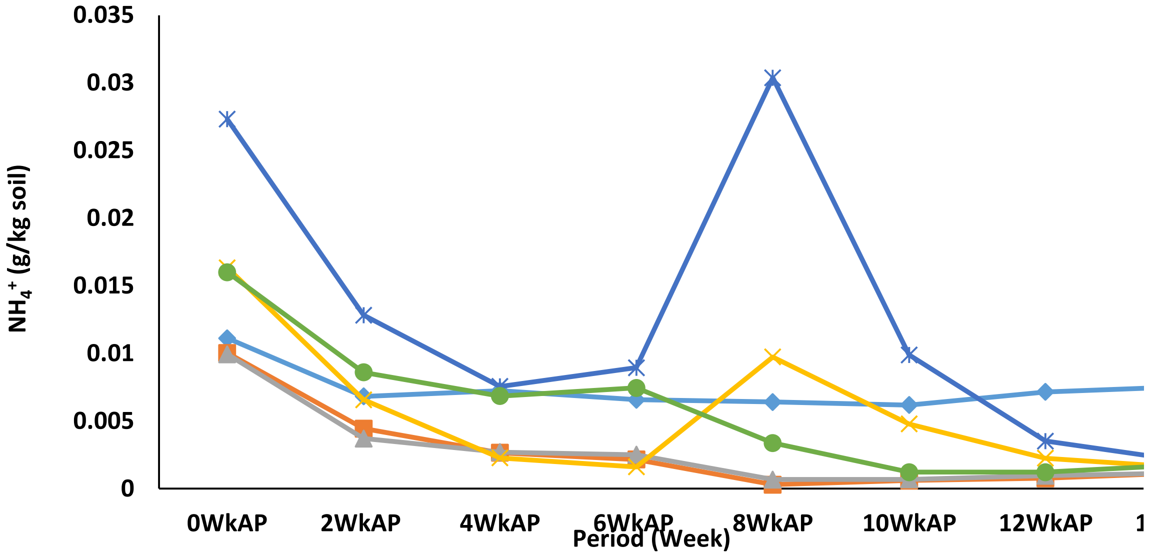
The increase in NH_4^+ during the last phase also varied among treatments. The largest increase at week 10 was observed in TR1 (0.006 g/kg soil) while the lowest (0.003 g/kg soil) was recorded on TR6. The difference among treatments was statistically significant (P = 0.05) at week 10 (Table 8).

The period of mineralization to attain peak NH_4^+ followed the trend: RT4>TR6=TR5=TR3=TR2>TR1. These results indicate that the lablab green manure treatment led in the turnover of peak NH_4^+ followed by the urea-treated treatments (TR4 and TR5) ones and eventually the control. The treatment with bunds behaving like the ones which received mineral N. Difference in the amount of added urea was not reflected in the peak NH_4^+ content.

4.4.2 NH_4^+ variability during the paddy cropping season

4.4.2.1 Content of NH_4^+ in valley Middle

NH_4^+ variation at Middle site over the rice-cropping season is indicated in Fig. 5. The NH_4^+ content at week 0 (just after planting of the rice) varied slightly among treatments.



WKAP: Week after transplanting rice

Figure 5: NH_4^+ content during the paddy-cropping season at the Middle site

It was highest in TR5 (0.02731 g/kg soil) and lowest in TR2 (0. 0.00993 g/kg soil). The values for TR4, TR5 and TR6 at week 0 were higher (P = 0. 05) than that of the rest of the treatments (Table 9). It is also important to note that significant differences in NH_4^+ occurred among the treatments even at subsequent periods during the rice-cropping season.

Table 9: Effect of crop management interventions on the NH_4^+ content during the paddy-cropping season at the Middle site

Treatment	**NH_4^+ content (g/kg soil)**		
	Week 0	**Week 8**	**Week 16**
TR1	0.01112a	0.0064bc	0.008739b
TR2	0.01003a	0.000289a	0.001486a
TR3	0.00993a	0.000669a	0.001465a
TR4	0.01633b	0.009733c	0.002018a
TR5	0.02731c	0.030381d	0.002914a
TR6	0.016b	0.003369ab	0.002564a
Mean	0.01512	0.00847	0.0032
F statistic	0.001	0.001	0.001
L.S.D	0.001891	0.002127	0.001252
CV (%)	3	1.5	1.9

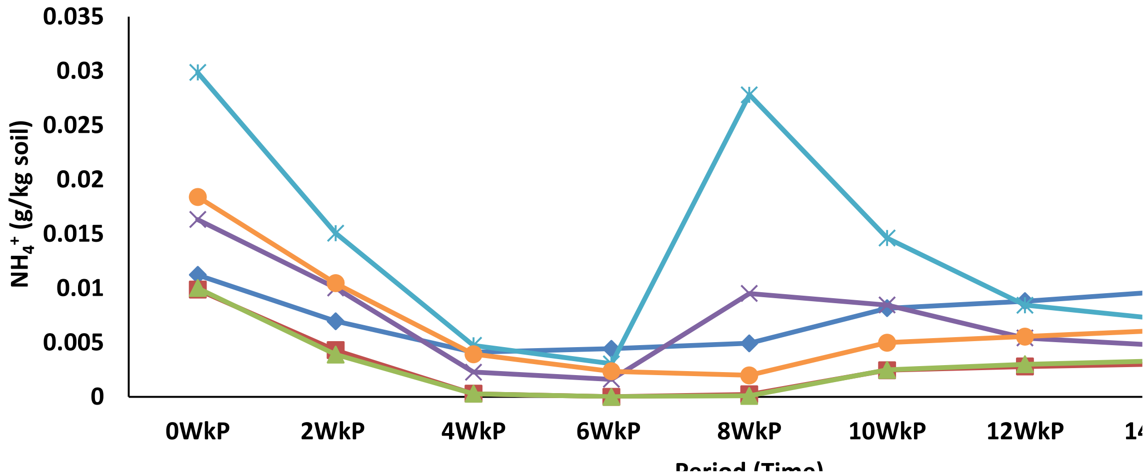
*Means in the same column followed by the same letter(s) are not significantly different according to Tukey test (P = 0.05).

In general, there was a decrease in NH_4^+ content with time in most of the treatments over the 16-week period. TR4 and TR5 behaved differently by showing a sharp rise in NH_4^+ at week 8 (0.009733 and 0.03038 g/kg soil) but thereafter, both showed a similar trend of decline in NH_4^+ content with time up to week 16. The highest decrease within the 16 weeks in NH_4^+ content was noted in TR5 (0.024746 g/kg soil) while the least was recorded in TR3 (0.007912 g/kg soil).

Whereas, TR1, TR2 and TR3 had significantly lower NH_4^+ during the early stages of the rice-cropping season, toward the crop maturity TR1 had significantly higher NH_4^+ content compared with the rest of the treatments at week 16 (Table 9).

4.4.2.2 Content of NH_4^+ in valley Fringe zone

In Fig. 6, shows the variation of NH_4^+ at the Fringe site. At week 0, the NH_4^+ content was highest in TR5 (0.02987 g/kg soil) followed by TR6 (0.01841 g/kg soil). On the other hand, TR1, TR2 and TR3 had the lowest values. These differences were significantly different ($P = 0.05$) from the rest (Table 10).



WKP: Week after transplanting rice

Figure 6: NH_4^+ content during the paddy-cropping season at the Fringe site

TR2, TR3 and TR5 maintained the same trend even at later stages of the cropping season as exemplified at week 8 and 16 (Table 10). However, just like in the case of the Middle site, TR1 maintained significantly higher NH_4^+ values during the same period.

Table 10: Effect of crop management interventions on the NH_4^+ content during the paddy-cropping season at the Fringe site

Treatment	**NH_4^+ content (g/kg soil)**		
	Week 0	**Week 8**	**Week 16**
TR1	0.01123a	0.00492b	0.010551d
TR2	0.00987a	0.000213a	0.003653a
TR3	0.01002a	0.000083a	0.003627a
TR4	0.01633b	0.009513c	0.005379ab
TR5	0.02987c	0.027823d	0.008084c
TR6	0.01841b	0.001975ab	0.007236bc
Mean	0.01595	0.00742	0.00642
F statistic	0.001	0.001	0.001
L.S.D	0.001966	0.001805	0.001361
CV (%)	2.2	1.9	4.6

*Means in the same column followed by the same letter(s) are not significantly different according to Tukey test (P = 0.05).

The NH_4^+ content rose sharply at week 8 in TR4 and TR5 (0.009513 g/kg soil from 0.003032 g/kg soil and 0.027823 g/kg soil from 0.003032 g/kg soil at week 6 for TR4 and TR5, respectively) (Fig. 6). These peak values were statistically significant (P = 0.05). Apart from the special phenomenon for TR4 and 5 at week 8, the general trend for the rest of the treatments was a decline in NH_4^+ content from week 0 to week 6 or 8 depending on the treatment in question, a slight increase of the same at week 10 and stagnation for the rest of the cropping season to week 16.

4.5 Effect of Crop Management Interventions on the Variation of NO_3^- Content

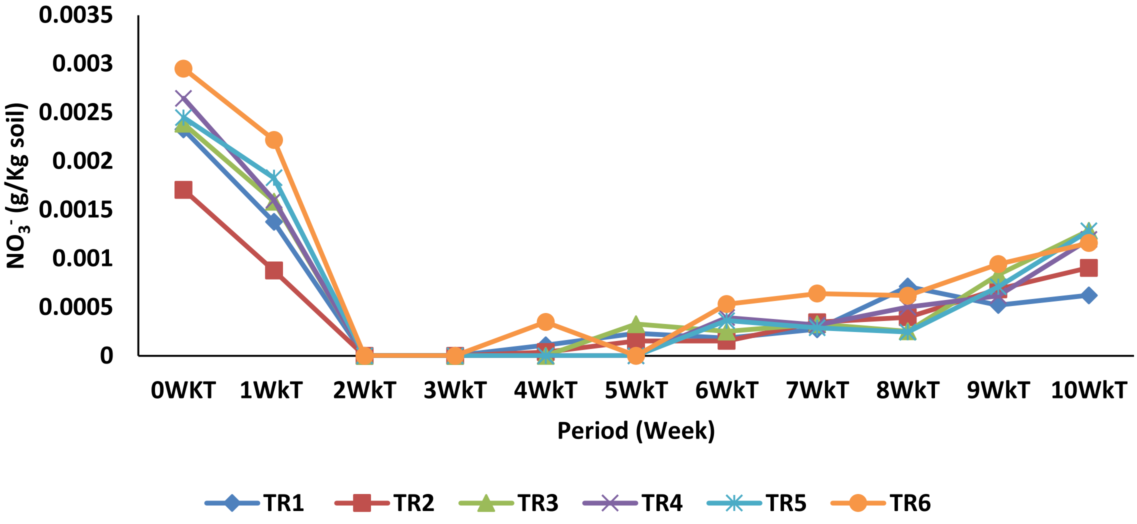
The data that shows the variation of NO_3^- content in the studied soils is separated into two periods: the pre-paddy growing season and the and the paddy cropping period, respectively.

4.5.1 NO_3^- content during the pre-rice croping period

The results which are presented here include those of the NO_3- content both at the Middle and Fringe sites.

4.5.1.1 NO_3^- content at the Middle site

The NO_3^- content at the start of the rain season varied slightly among the treatments with TR6 and TR2 having the highest and lowest (0.002951 and 0.002324 g/kg soil) values, respectively (Fig. 7).



WKT: Week before transplanting rice (dry –wet transition weeks)

Figure 7: NO_3^- content during the pre-paddy growing season at the Middle site

The NO_3^- content decreased to attain 0 g/kg soil in all treatments within two weeks. From week 3 to week 5 week, depending on individual treatment, there was positive change in NO_3^- content.

Table 11: Effect of crop management interventions on the NO_3^- content during the pre-paddy growing season at the Middle site

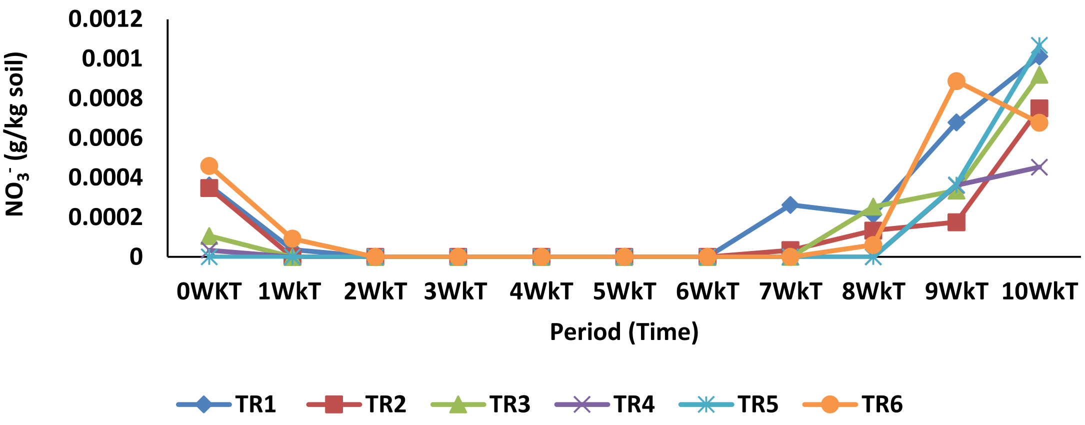
Treatment	NO_3^- content (g/kg soil)		
	Week 0	**Week 6**	**Week 10**
TR1	0.002324a	0.0001821a	0.000621a
TR2	0.001706a	0.000153a	0.000903ab
TR3	0.002383a	0.0002505a	0.001285b
TR4	0.002645a	0.0003933a	0.001195ab
TR5	0.002448a	0.0003612a	0.001283ab
TR6	0.002951a	0.0005301a	0.001159ab
Mean	0.00241	0.000312	0.001075
F statistics	0.101	0.08	0.023
L.S.D	0.000822	0.000271	0.000396
CV (%)	9.2	10.3	5.3

*Means in the same column followed by the same letter(s) are not significantly different according to Tukey test ($P = 0.05$).

This increase was noted all the way through from week 0 to week 10 though the pattern varied among treatments. These increases in NO_3^- were, nevertheless, not statistically significant ($P = 0.05$) except at week 10, where the NO_3^- value in TR1 (0.000621 g/kg soil) was statistically significantly lower than that measured in the rest of the treatments (Table 11).

4.5.1.2 NO_3^- content at the Fringe site

The content of NO_3^- at the Fringe site during the pre-paddy growing season is shown on Fig. 8. At week 0 TR6 had the highest value (0.002104 g/kg soil). There was virtually no NO_3^- in the rest of the treatments.



WKT: Week before transplanting rice (dry –wet transition weeks)

Figure 8: NO_3^- content during the pre-paddy growing season at the Fringe site

Table 12: Effect of crop management interventions on the NO_3^- content during the pre-paddy growing season at the Fringe site

Treatment	NO_3^- content (g/kg soil)		
	Week 0	**Week 6**	**Week 10**
TR1	0.0003604a	0a	0.0010126a
TR2	0.0003482a	0a	0.0007507a
TR3	0.0001057a	0a	0.0009195a
TR4	0.0000337a	0a	0.000453a
TR5	0a	0a	0.0010683a
TR6	0.00004594a	0a	0.0006769a
Mean	0.000492	0	0.000814
F statistic	0.001	0	0.155
L.S.D	0.0003849	0	0.000509
CV (%)	30.3	0	17.3

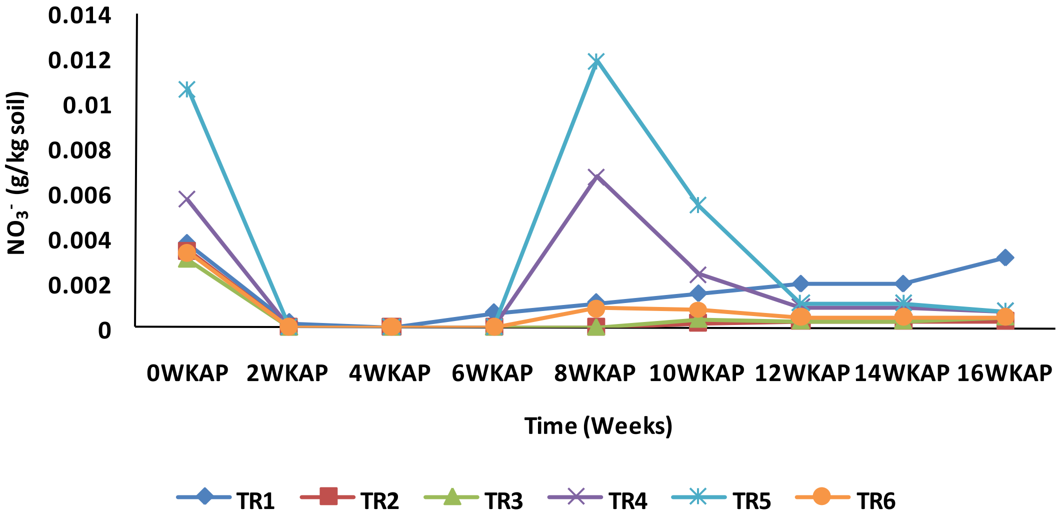
*Means in the same column followed by the same letter(s) are not significantly different according to Tukey test (P = 0.05).

Between week 1 and 7, with an exception of TR6, there was virtually no NO_3^- in the root zone for most of the imposed treatments. Increase in NO_3^- took place differently among treatments between week 7 and 10. However, the noted differences were not statistically significant (P = 0.05) (Table 12). At week 10 therefore, the root zone NO_3^- ranged from 0.000453 (TR 4) to 0.0010683 (TR5) g/kg soil, respectively.

4.5.2 NO_3^- content during the paddy cropping season

4.5.2.1 NO_3^- content at Middle zone

These results show the following characteristics: Initial relatively high NO_3^- values that varies among treatment separating the latter into 3 categories and which are statistically significantly different (P = 0.05) (Table 13), decline of NO_3^- to attain absolute or close to 0 g/kg soil from week (except for TR4 and TR5) that showed a unique rise in NO_3^- at week 8) to the rest of the cropping season (Fig. 9).



WKAP: Weeks after transplanting rice

Figure 9: NO_3^- content the rice paddy-cropping season at the Middle site

At week, 0 the NO_3^- content was highest in TR5 (0.010681 g/kg soil) followed by TR4 (0.005722 g/kg soil). The two were significantly different (P = 0.05) from the rest of the treatments (Table 13). There was an abrupt rise in the NO_3^- content at week 8 in TR5 to attain 0.011948 kg/kg from soil 0 g/kg soil at week 6. A similar trend occurred in TR4 (0.00675 g/kg soil at week 8 compared with 0 g/kg soil at week 6).

Table 13: Effect of crop management interventions on the NO_3^- content during the rice-cropping season at the Middle site

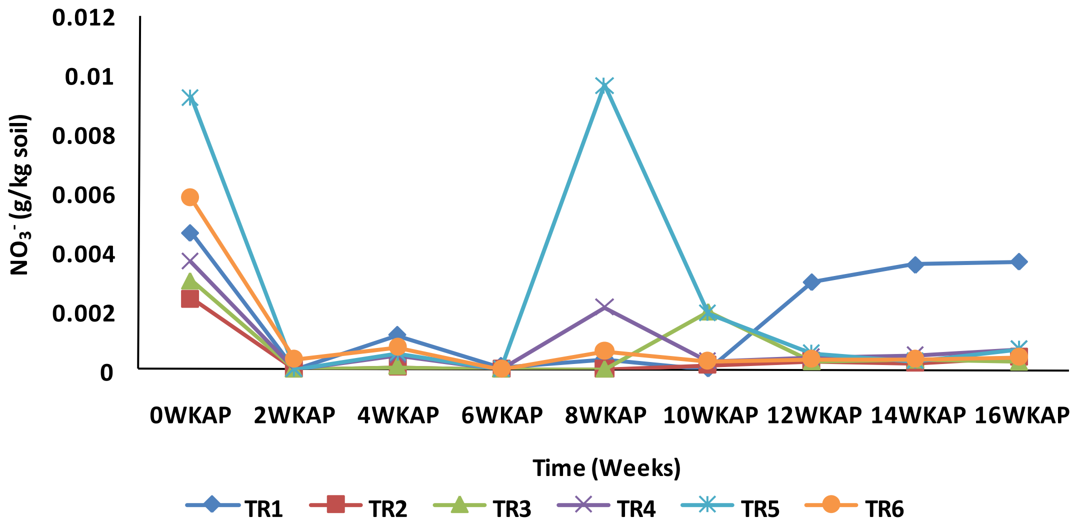
Treatment	NO_3^- content (g/kg soil)		
	Week 0	**Week 8**	**Week 16**
TR1	0.00378a	0.001113a	0.0031145b
TR2	0.003474a	0a	0.0002873a
TR3	0.003075a	0a	0.000463a
TR4	0.005722b	0.00675b	0.0007468a
TR5	0.010681c	0.011948c	0.0007007a
TR6	0.00336a	0.000852a	0.00047a
Mean	0.00502	0.00344	0.00096
F-Statistic	0.001	0.001	0.001
L.S.D.	0.000997	0.001291	0.000985
CV (%)	2.2	3.8	14.9

*Means in the same column followed by the same letter(s) are not significantly different according to Tukey test (P = 0.05).

In both cases, the NO_3^- thereafter declined to attain close to 0 g/kg soil at week 12 and remained almost constant to week 16. TR1 had a minor but insignificant increase of NO_3^- from week 6 to week 16.

4.5.2.2 NO_3^- content at the Fringe site

The NO_3^- variation during the rice cropping season resembled that of the Middle site with two exceptions: significantly high (P = 0.05) TR1 value than the rest of the treatments at week16 and an abrupt rise in NO_3^- content in TR3 at week 10 (Fig. 10).



WKAP: Week after transplanting rice

Figure 10: NO_3^- content the rice paddy-cropping season at the Fringe site

Table 14: Effect of crop management interventions on the NO_3^- content during the rice paddy-cropping season at the Fringe site

Treatment	**NO_3^- content (g/kg soil)**		
	Week 0	**Week 8**	**Week 16**
TR1	0.004646a	0.000354a	0.003662b
TR2	0.00242a	0a	0.000408a
TR3	0.003047a	0a	0.000238a
TR4	0.003686a	0.002085a	0.000663a
TR5	0.009302b	0.009691b	0.000691a
TR6	0.005841ab	0.000643a	0.000402a
Mean	0.00482	0.00213	0.00101
F statistic	0.001	0.001	0.001
L.S.D	0.002291	0.001988	0.001029
CV (%)	13.4	20.6	22.9

*Means in the same column followed by the same letter(s) are not significantly different according to Tukey test (P = 0.05).

At week 0, TR5 had the highest NO_3^- (0.009302 g/kg soil) followed by TR6 (0.005841 g/kg soil) while the lowest NO_3^- value was recorded in TR 2 (0.00242 g/kg soil) (Table 14).

4.6 Effect of Hydrological Conditions on the NH_4^+ and NO_3^- Variation During the Paddy Growing Season

This section deals with the results of the NH_4^+ and NO_3^- content as affected by both the imposed treatments and the hydrologic conditions. These are pooled results of the studied hydrological conditions (Middle and Fringe sites). Due to the existence similarity in magnitude and trends in the content of both NH_4^+ and NO_3^- values in the treatments between the pooled values (Middle and Fringe combined) and those from the individual sites (Middle or Fringe) as presented in section 4.4.2 (for NH_4^+) and 4.5.2 (for NO_3^-), in this section, the focus will be put on the results showing the effect of hydrological conditions on NH_4^+ and NO_3^- content.

4.6.1 Effect of hydrological conditions on the content of NH_4^+

The values of NH_4^+ for a given week at both the Middle and Fringe sites are presented in Fig. 11. Statistical comparisons of the NH_4^+ content between the two sites are shown on Table 15 and 16.

Table 15: Two-way ANOVA for NH_4^+ content comparison between the Middle and Fringe sites at week 0.

Variate: NH_4^+

SOURCE OF VARIATION	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Treatment	5	2.991E-03	5.983E-04	81.13	<.001
Block (site)	1	4.382E-06	4.382E-06	0.59	0.448
Treatment.Block	5	1.641E-04	3.283E-05	4.45	0.005
Residual	24	1.770E-04	7.374E-06		
Total	**35**	**3.337E-03**			

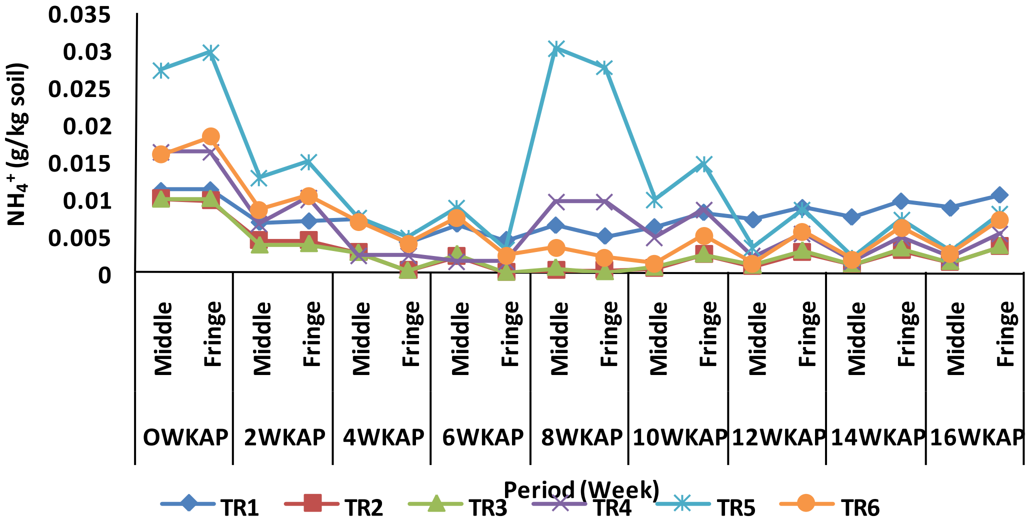


Figure 11: NH_4^+ content in the different treatments at the Middle and Fringe sites during the paddy-growing season

There was no significant difference between the sites with different hydrological conditions throughout the entire study period of 16 week. This is exemplified on Table 15, 16.

Table 16: Two-way ANOVA for NH_4^+ content comparison between the Middle and Fringe sites at week 6.

Variate: NH_4^+

Source of variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Replicate stratum	2	2.166E-05	1.083E-05	2.04	
Treatment	5	2.050E-04	4.100E-05	7.71	<.001
Block	1	1.538E-10	1.538E-10	0.00	0.996
Treatment.Block	5	7.124E-06	1.425E-06	0.27	0.926
Residual	22	1.170E-04	5.317E-06		
Total	**35**	**3.507E-04**			

These results therefore indicate that irrespective of the treatment in consideration, there was no significant difference in NH_4^+ content between the Middle and the Fringe site throughout the rice-growing season. Therefore, these results indicate that the site hydrology did not have a significant influence over the NH_4^+ status.

4.6.2 Effect of hydrological zone on the root zone NO_3^- content

The variation of the NO_3^- content at the Middle and the Fringe sites for the 16 weeks of the study is shown in Fig. 12. There was no significant difference in NO_3^- content for the entire period of the study. This is shown as an example on Table 17.

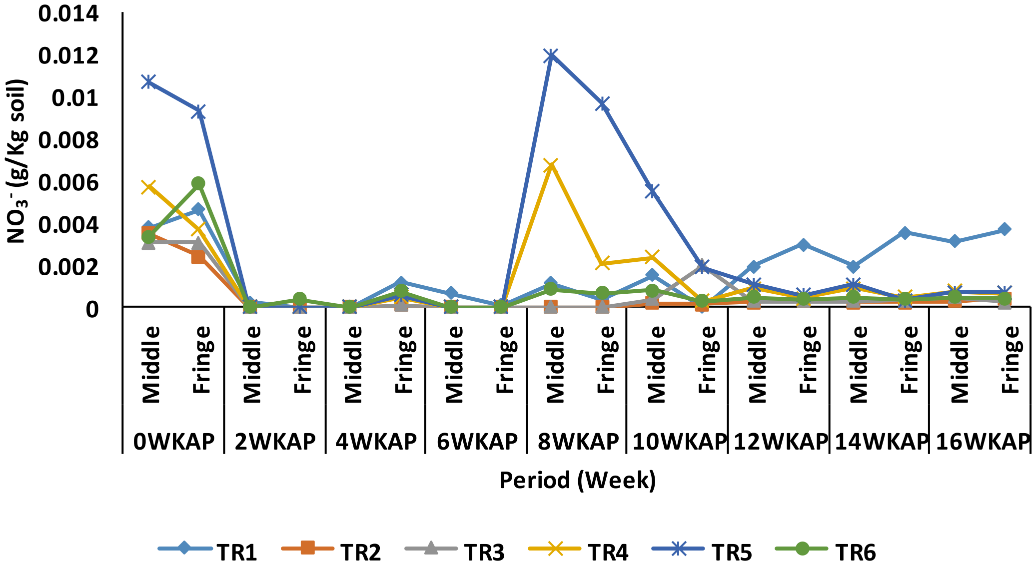


Figure 12: NO_3^- content in the different treatments at the Middle and Fringe sites during the paddy-growing season

Table 17: Two-way ANOVA for NO_3^- content comparison between the Middle and Fringe sites at week 0

Variate: NO_3^-

Source of variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Replicate stratum	2	2.465E-06	1.233E-06	1.26	
Treatment	5	2.023E-04	4.046E-05	41.24	<.001
Blocks	1	3.309E-07	3.309E-07	0.34	0.567
Treatment. Blocks	5	2.077E-05	4.154E-06	4.23	0.008
Residual	22	2.158E-05	9.810E-07		
Total	**35**	**2.474E-04**			

Results for statistical analysis on NO_3^- in the later periods (Week 0 to week 16) were no pronounced differences between the Middle and the Fringe. The interaction between blocks and treatments were statistically difference in some weeks. These results therefore indicate that the site hydrology did not have a significant influence over the NO_3^- status.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of Crop Management Interventions on the Variation of NH_4^+ Content

This discussion is separated into two sections pre-rice cropping season and the rice-cropping season.

5.1.1 Variation of NH_4^+ during the pre-rice growing season (Dry-wet transition period) at both sites; Middle and Fringe site

These results are discussed separately at each of the studied sites and thereafter by comparing the two together. Also, a reflection is given on the seasonal variation between the pre rice growing season (wet-dry transitional period) that corresponds to the short rain season and the long rain season which is also referred to as the paddy cropping season.

The main features of the NH_4^+ variation during the wet-dry transitional season were increase in NH_4^+ within the initial period following the first rainfall to reach a peak value; decrease of the same to attain 0 g/kg soil value of NH_4^+ content and an eventual rise towards the end of the season. This trend is characteristic of both sites during the wet-dry season.

The increase in NH_4^+ content following initial rains is attributed to mineralization, a phenomenon that has been widely associated with decomposition of organic matter to release nutrients in a mineral form including NH_4^+ (Yadvinder-Singh *et al.*, 1991; Nziguheba *et al.*, 2005; Sugihara *et al.*, 2010a, b). Differences in the peak value among treatments can be considered as a reflection of the content of mineralizable N in the substrate which is the soil organic matter (Wang *et al.*, 2004; Nziguheba *et al.*, 2005).

Mineralization will normally continue as long as the conditions allow, including presence of substrate. The factors which control mineralization include pH, C:N ratio, redox potential, microbial activity and microbial biomass, availability of electron acceptors, cation exchange capacity, amount and nature of clay, nature and amount of salts, inputs and nature of organic materials, soil organic matter content and quality and the supply of nutrients such as phosphorus (P) among others, are important for ammonium production in submerged rice soils (Deenik, 2006; Inamura *et al*., 2009). Most of these factors were similar if not exact among the treatments except the organic matter content and probably the C/N ratio. It is obvious that the treatments that were fertilized with N, organic or inorganic are expected to have developed more biomass than those without and hence have a much higher mineralizable N and a much longer period of attaining the peak NH_4^+ content (Palm *et al*., 2001; Kimetu *et al*., 2006). This appears to be the case for the Middle site in which TR6, TR5 and TR4 had among the highest peak NH_4^+ values compared with the rest of the treatments. It is important to point out that the mineralization equally occurred at the Fringe site with much less pronounced differences among the treatments compared with the same at the Middle site. The lack of consistence in the peak NH_4^+ content and the duration to attain it cannot be well explained. This may be partly attributed to the much higher percentage water filled pore space during the first 3 weeks. Also, differences among treatments were noted with regard to the rate of losing water through natural drainage after rain episode (Plate 1), a phenomenon that was not characterized. The soil at the Fringe site was wetter between week 0 and week 3, with percentage WFP values stood at 80.51% at week 0, 86.05% at week 1 and 79.85 and 76.55 % at week 2 and week 3, respectively. These conditions are sub-optimal for both decomposition of organic matter (Gilmour *et al*., 1977) ammonification (Pal and Broadbent, 1975). This could be the reason why the Middle site, whose percentage WFP values attained a maximum of 53. 89% during the period that led to peak mineralization. Linn and Doran (1984) showed the linear relationship between microbial activity and WFP values between 30 and 60% with the latter being typically the optimal moisture conditions for he microbiologically controlled processes including mineralization.

From these results, it is clear that the mineralization period for peak NH_4^+ production ranged between 3 and 6 weeks at the Middle site and between 1 and 3 weeks at the Fringe site. The difference is mostly likely linked with differences in soil moisture status, the latter being more humid and having a percentage water saturation of above the field capacity (>60%) during the first 4 weeks of the start of the rain season. In addition, mineralization tended to take longer period with relatively higher peak NH_4^+ in the treatments that had higher biomass incorporated in the soil in the previous season

The similarity in the trend of decline in NH_4^+ between the Middle and Fringe sites tends to suggest existence of similar influencing factors. The decline can be associated with many pathways including plant uptake, leaching (where conditions allow) (Kimetu *et al*., 2006), volatilization (Jones *et al*., 2007), nitrification (Reddy and DeLaune, 2008; Sahrawat, 2010), deamination (Reddy and DeLaune, 2008), decline in decomposable organic matter (George *et al*., 1993) and plant uptake (Begon *et al*., 1998; Marschner, 2008). In the first instance, the phenomenon is largely attributed to nitrification and plant uptake of both NH_4^+ and NO_3^-. The reason for associating the decline with nitrification is supported by the existing aerobic conditions during this period as evidenced by the high redox potential values (Table 5). A number of previous studies have related redox values of > + 300 mV with aerobic conditions (Inglett *et al*., 2005; Pezeshki and Delaune, 2012) which are conducive to nitrification (George *et al*., 1993; Reddy and DeLaune, 2008). The NH_4^+ decline period coincided with a considerable decrease in soil moisture content (Table 3). During this period, the percentage of water filled pore (%WFP) ranged from 35.7% (week

6) and 29.57% (Table 4). Under such low moisture content soil microbial-led, processes including organic matter decomposition and mineralization take place at a low level (Pal and Broadbent, 1975; Gilmour *et al.*, 1977; Linn and Doran, 1984). According to Linn and Doran (1984), at <30% WFP, microbial activity become severely reduced.

The rapid rise in NH_4^+ content in all treatments from week 9 to week 10 is attributed to the increase in soil moisture. The soil moisture status changed from 14.49% moisture content, equivalent of 29.57% WFP at week 9 to 34.67% (64.63% WFP) at week 10. According to Linn and Doran (1984) the %WFP value at week 10 can be considered to be close to optimal for microbial based processes such as mineralization. The NH_4^+ turnover at week 10 reflect the NH_4^+ supply capacity of the soil just prior to rice crop transplant. This is in concordance with previous observations that dry conditions are ideal for the soil microbial biomass that act as both nutrient sink and source of nutrients tropical ecosystems prior to the subsequent rain season (Tripathi and Sigh, 2007; Sugihara *et al*., 2010a). The soil's NH_4^+ supply capacity was highest in TR5 and TR3 in that decreasing order and outperformed the rest of the treatments at the Middle site, while at the Fringe site it is TR1 that recorded the highest value.

5.1.2 NH_4^+ variability during the paddy cropping season at both sites; Middle and Fringe site

In this study, NH_4^+ content generally decreased with time during the rice-cropping season except for the treatments that received urea at week 7 after the transplantation of the rice plants. The decrease in NH_4^+ with time resemble the finding by Carmona *et al.* (2012) who noted a decline of the same over a period of 91 days. The decline could be partly attributed to rice crop uptake (Ghosh and Bhat, 1998) and possibly leaching (Kimetu *et* *al*., 2006). Meng *et al.* (2014) noted considerable NH_4^+ losses through leaching beyond the 50cm soil depth in both conventional and organic based rice production systems.

The observed NH_4^+ decline from the first week onwards at both sites coincided with existence of reducing soil conditions as evidenced by the low (< + 300 mV) redox values. Under such a situation, NH_4^+ does accumulate in the soil environment (Kimetu *et al*., 2006: Reddy and Delaune, 2008) unless other factors which favors its removal such as NH_4^+ volatilization due to high pH (Loomis and Connor, 1992; Singh and Vaje, 1998) or leached or displacement by runoff (Garc´ıa-Garc´ıa *et al*., 2006; Eder *et al*., 2015) have an influence. However, the soils under the study had pH values (5.8 and 6.1 for the Middle and Fringe sites, respectively). This is outside such a range. The most probable cause for the observed low NH_4^+ values is low N mineralization rate and or leaching. It is well documented that low redox potential lowers mineralization by the fact that only anaerobic or facultative anaerobers can accomplish the respiration process (Inglett *et al*., 2005; Pezeshki and Delaune, 2012). This category of microorganisms has both a low carbon assimilation capacity and energy requirements (Pezeshki and Delaune, 2012). Redox values below + 300 mV is considered to be the limit for aerobic respiration (Mitsch, and Gosselink, 2007; Rostaminia *et al*., 2011; Pezeshki and Delaune, 2012). Consequently, the N mineralization rate is also low (Yan and Jing, 2003; Kimetu *et al*., 2006). This could explain the rather low values of NH_4^+ recorded in the first 4 - 6 weeks of the season at the Middle and Fringe site, respectively.

The sudden increase in NH_4^+ in TR4 and TR5 at week 8 was associated with ammonium fertilizer application that took place at week 7. In practice, urea will hydrolyze to release NH_4^+ in a period of 5-7 days (Dharmakeerthi and Thenabadu, 1996; Pattnaik *et al*., 1999). This could therefore explain the higher values of NH_4^+ recorder in TR4 and TR5 during week 8. Meng *et al.* (2014) observed fluxes of NH_4^+ as detected in leached N upon application of DAP (di-ammonium phosphate) and urea topdressing.

However, the content of NH_4^+ in the treatment with 120kg/ha of added urea (TR5) was not proportionately higher than that of the treatment with 60kg/ha of urea (TR4). The former was 3-fold higher indicating that there could be other factors which determined the NH_4^+ content during the period under discussion. However, these are not addressed in this study. In view of the fact that the redox potential in the soil (root zone) for a greater part of the rice cropping season was above the +300 mV at the Middle site, these conditions were favorable for oxidation of NH_4^+ into NO_3^- (Pezeshki and Delaune, 2012). This could not only explain the generally low levels of NH_4^+ observed in this study but also the sudden decline in NH_4^+ in TR4 and 5 immediately after week 8.

Although release of NH_4^+ in paddies during the late cropping season of paddy has been reported before by Meng *et al.* (2014), the rather significant accumulation of NH_4^+ in TR1 ought to be further investigated to find out the causative factors.

The input of organic 60 kg of inorganic N upon lablab green manure incorporation (TR6) in the soil appeared not to influence the NH_4^+ content. These results are contrary to many previous studies (Yadvinder-Singh *et al*., 1991; George *et al*., 1992; Becker *at al.,* 1995). Lablab decomposes to release NH_4^+ about 4 to 6 weeks after it has been incorporated into the soil under aerobic conditions (Pereira *et al*., 2016). Under anaerobic conditions, the ammonification of lablab would take much longer time with lower NH_4^+ yield (Buresh and De data, 1991; Becker *at al*., 1995). The lack of response in NH_4^+ could be related to the low redox potential that dominated during the early stage of the rice-cropping season as shown on Table 6. Under such a situation, the mineralization process becomes negative

(Casman *et al.*, 1998; Toure *et al.*, 2009). This could explain the poor response in NH_4^+ production throughout the rice-cropping season. One would have expected to see some differences between TR6 and the rest of the treatments notably those without any added N.

There was a considerable resemblance in the pattern of NH_4^+ variation at the Fringe site to that of the Middle site. This is exemplified by the general decrease in in the initial NH_4^+ content, the sudden rise in NH_4^+ content at week 8 for the treatments with added mineral N. These results can therefore be explained in a similar manner as those of the Middle site except for the significant increase in NH_4^+ content in TR5 and TR6 towards the late stage of the rice-cropping season (week 12-16) at the Fringe site. This difference cannot be explained with the available data; it needs further studies. This controversy need to be studied further.

The significantly high NH_4^+ values noted in the treatments with added urea can only be linked with N input. Previous studies have shown a higher ammonium production upon decomposition of crop residues from fields that have benefited from mineral N fertilizer (George *et al.*, 1992; Palm *et al.*, 1997; Villegas-Pangga *et al.*, 2000; Javier and Tabien, 2005; Kimetu *et al.*, 2006; Ngwene *et al.*, 2009). The lack of difference in NH_4^+ in the treatment, which received labalab green manure, contradicts previous studies (Buresh and De data, 1991; Yadvinder-Singh *et al.*, 1991; George, *et al.*, 1992; Becker *et al.*, 1995; Yadvinder-Singh *et al.*, 2005). The decline in NH_4^+ content in during the first 6 to 8 weeks of the rice-cropping season could be due to the consumption of mineral N with crop growth (Cassman *et al.*, 1998; Nascente *et al.*, 2009).

5.2 Effects of Crop Management Interventions on the Variation of NO_3^- Content

The effects of crop management interventions on NO_3^- variation have been discussed in both site under two seasons; i.e. Pre-rice cropping season (dry-wet transition period) and the rice-cropping season.

5.2.1 NO_3^- variability during the pre-rice cropping season at both sites; Middle and Fringe site

The variation of NO_3^- content over the study period followed a similar pattern at both sites reflecting some similarity in the conditions that controlled the soil NO_3^- status. The NO_3^- content declined sharply within 1 and 2 weeks at the Fringe and Middle sites, respectively to attain 0 g/kg soil. Surprisingly, this happened under categorically different moisture conditions. At the Middle site, soil moisture was rather stressed while at the Fringe site it was rather near saturation (Linn and Doran, 1984; George *et al.*, 1993). This trend does not reflect the relatively high ammonium produced during the 2-4 and 1-3 week periods at the Middle and Fringe site, respectively. There is a clear disparity between the two. It is assumed that the conditions, particularly at the Middle site were aerobic, as reflected by the redox potential values for the period under consideration, one would have expected a spontaneous oxidation of the existing ammonium and hence its reflection on the NO_3^- content. The same was expected for both the soil moisture and redox potential in particular at the Middle site. Cannot account for the difference between these two parameters. These results are contrary to the finding of Zaman *et al.* (1999) who noted highest nitrification rates in NH_4Cl-treated soil compared with other treatments with no added ammonium.

The extremely low or absence of NO_3^- between week 2 and 6 at the Fringe site and 2 to 5 at the Middle site cannot be well explained with available data. During this period, there was supply of ammonium in particular at the Middle site (Fig.3) and the moisture and redox potential were in a status that would favour nitrification. It would be beneficial to do a similar study in which the fate of N is fully characterized. The increases in NO_3^- content from week 4 (Middle) and week 6 (Fringe site) corresponded with nitrification process (Cassman *et al.*, 1998; Kimetu *et al.*, 2006). Differences among treatments were only noted in TR1 and TR3 at week 10 in which the NO_3^- content was higher than in the rest of the treatments.

5.2.2 NO_3^- variability during the paddy growing period at both sites; Middle and Fringe site

At both sites, NO_3^- tended to accumulate during the dry season. This is reflected by the rise in NO_3^- content towards the end of the pre-rice cropping period and the corresponding relatively high values of the same at the start (week 0) of the rice-cropping season. This could probably be attributed to NH_4^+ conversion to NO_3^- under aerobic condition (Cassman *et al.*, 1998; Wang *et al.*, 2001; Smith, 2010). Alternate wet and dry seasons have been shown to lead to formation of ammonium and its subsequent oxidation to NO_3^- (George *et al.*, 1993; Kleinhenz *et al.*, 1997; Pande, 2005).

Characteristically, the accumulated NO_3^- declined rapidly to attain 0 or close to 0 g/kg soil within 2 weeks, irrespective of the treatment and site. This drop in NO_3^- level could be attributed to denitrification caused by the low soil redox potential (Table 6). The redox potential changed from week 0 to week 2 as follows: 237.0 to 204.8 mV at the Middle site and from 195.3 to 209.2 mV at the Fringe site. These redox values fall under the range in which O_2 is limited and therefore favors denitrification (Patrick, 1960; Turner and Patrick, 1968; Reddy and Patrick, 1975; Buresh and Patrick, 1981).

The subsequent low nitrate content at the Middle site from week 2 and to week 10 in the treatment that were not supplied with mineral N (TR2, TR3 and TR6) would have negative consequence to the crop. At this stage, particularly the booting stage, which corresponded with week 8 and10, the demand for N is usually high (Cassman *et al.*, 1998; Kimetu *et al.,* 2006). The treatments which received 60 and 120 kg N/ha (TR4 and TR5) were the only ones in which there was significantly higher nitrate content at booting and grain filling stage. During the late cropping stage (week 12-16), all treatments with rice crop (TR2, TR3, TR4, TR5 and TR6) had virtually no NO_3^-. This could be partly explained by the low NH_4^+ content and possible crop uptake of any available NH_4^+ during the booting stage (George *et al.*, 1993; Olk *et al.*, 1996; Nascente *et al.*, 2009).

At the Fringe site, there was virtually no NO_3^- in all treatments at week 2. The same happened to all treatments with no added mineral N (TR1, TR2, TR3 and TR6) during the tillering and booting stage (week 2 to 8). As it was with the Middle site, a general decline in NO_3^- content to virtually 0 g/kg soil occurred for the treatments with rice crop (TR2, TR3, TR4, TR5) during the late cropping stage (week 12 to 16). This largely corresponded with the low NH_4^+ content in the soil particularly in the treatments that did not receive mineral N. This can be explained by the generally low content of NH_4^+ at the site that could have been converted to NO_3^- (Pande, 2005; Reddy and Delaune, 2008).

5.3 Contribution of Hydrological Conditions on the NH_4^+ and NO_3^- Variation

The choice of the two sites was based on assumption that the three major floodplain hydrological zones; Valley Central, Valley Middle and Valley Fringe differ in their hydrology (Keeney and Sahrawat, 1986; Inglett *et al.*, 2005; Reddy and DeLaune, 2008) as this has a profound effect on N status. The Valley Central zone was inundated throughout the duration of experimentation period, hence abandoned. The remaining two sites showed a lot of resemblance in their hydrological properties as evidenced by their redox potential.

During the rice-cropping period, both sites showed reducing conditions for 3 weeks at the Middle site and two weeks at the Fringe site followed by some fluctuations between moderately reduced and reduced soil conditions between week 6 and week10 as shown in Fig. 11 and 12**.** The soils of both sites returned to aerobic conditions between week 12 and week 16. This similar trend in redox potential is an important factor that explains the similarity that occurred in terms of root zone NH_4^+ and NO_3^- content between the two sites. Varied results from N dynamics studies in different time show the effect that differences in the hydrological condition can have on wetland N dynamics. NO_3^- removal have been measured in wetlands agricultural lands that showed high rate in NO_3^- dynamics under different hydrological zones in USA, Scotsman Valley in New Zealand and Rabis Bæk in Denmark (Cooper, 1990; Br¨usch and Nilsson, 1993). Devito *et al*. (1989) in a study of five wetlands on the Canadian wetland found that there was no significant net retention of N within the wetlands, but there was transformation of inorganic N to organic N that influence NH_4^+ and NO_3^- dynamics under different hydrological condition.

Also, Cai *et al*. (2002) reported that there was losses of NH_4^+ contents under different hydrological condition in lowland wetland soil. That notwithstanding, Asante (2015) reported that there were no significance relationship between NO_3^- status under different hydrological zone in wetland soil in Ghana inland valley. This is similar with the results of Yameogo (2017) who reported that NO_3^- level was not significantly different among the treatments under different hydrological condition in an inland valley of the West African savanna zone.

These results therefore indicate that the NH_4^+ and NO_3^- status at both the Valley Middle zone and the Valley Fringe zone did not differ significantly. It is implied therefore that the presumed difference in both NH_4^+ and NO_3^- status because of differences in hydrology between the two sites could not be verified. Accordingly, therefore the null hypothesis is therefore supported.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The pre-rice cropping season was marked with 3 phases of variation in NH_4^+ content. The 1st phase of increase in NH_4^+ content during the first to six weeks depending on the treatment in question followed with a period of NH_4^+ decline during the 5th to 9th week, and an increase in NH_4^+ level from the 10th to the 13th season.

Peak NH_4^+ in the 1st phase differed among treatments. Peak NH_4^+ production was significantly higher ($P = 0.05$) in treatments with external N input (TR4, TR5, and TR6) in both Middle Fringe sites. Significant differences ($P=0.05$) in NH_4^+ also occurred at the Middle site during the early period of decline (Week 6) in N where the trend was as follows: TR6>TR5=TR4>TR3=TR2=TR1.

The initial NH_4^+ content at the start of the rice-cropping season varied widely among treatments with higher values being mostly encountered in the treatments with external N input during the 2014/15 season. These were TR4 and TR5 at the Middle site and TR4, TR5, and TR6 the Fringe site.

NH_4^+ tended to decrease continuously from week 1 to attain lowest values at the start of the end of the cropping season (week 16) for almost treatments with no external mineral N at the Middle site. At the Fringe site, the decline in NH_4^+ followed a similar trend between week 4 and 8 then it either stabilized or increased slightly thereafter depending on the treatment under consideration.

The initial (starting) NO_3^- content during the pre-rice cropping season, ranged from 0.001706 (TR2) to 0.002951 (TR6) g/kg soil at the Middle site and from 0.0 to 0.0003604 g/kg soil. NO_3^- content decreased sharply (within 1-2 weeks) to attain the least values within 1-2 weeks at both sites.

NO_3^- content was nil or extremely low in all treatments between week 2 and week 3 (Middle) and between week 2 and Week 6 (Fringe).

End of the pre-season was characterized by increase in NO_3^- content (week 5-10 for the Middle site and week 7-10 for the Fringe site).

Addition of urea at week 6 led to a sharp and short-lived increase of NO_3^- at the beginning of the booting stage in the both sites.

6.2 Recommendations

Studies that concern N dynamics can be best understood if there is adequate characterization, in particular constant monitoring of the influxes, removal of N, transformations as well as changes in status in correspondence with changes in soil redox potential. It is recommended that future studies on mineral N status in wetland should focus on the N dynamics so as to understand how best to manage N resources for both economical and for environmental purposes.

Due to heterogeneity in field moisture conditions, a study like this one should be carried under controlled conditions in order to be able to correctly interpret the results.

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