

**EFFECT OF SOIL AMENDMENTS ON SOIL QUALITY AND
YIELD OF UPLAND RICE IN NORTHERN UGANDA**

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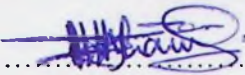
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**A DISSERTATION SUBMITTED TO THE FACULTY OF AGRICULTURE AND
ENVIRONMENT IN PARTIAL FULFILMENT OF THE REQUIREMENTS
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ENVIRONMENTAL SCIENCE AND NATURAL RESOURCES
MANAGEMENT OF GULU UNIVERSITY**

February, 2023

DECLARATION

I, Ogwal Lawrence hereby declare that this research dissertation is my original work, except where it has been acknowledged. I further affirm that this dissertation has never been presented to Gulu University or any other tertiary institution for award of a degree.

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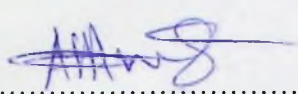
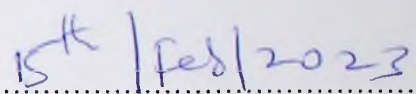
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APPROVAL

This dissertation entitled "*Effect of soil amendments on soil quality and yield of upland rice in northern Uganda*" was done under our guidance. It is ready for examination with our approval as University supervisors.

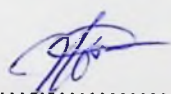
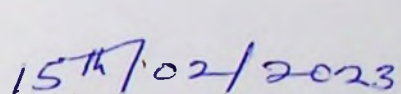
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DEDICATION

This dissertation is dedicated to members of my family, Ruth, Catherine, Sheila and Gabriel.

Also, to my late father Tom Edward Ojede and my prayerful mother, Ms. Lilly Awor.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AAS	Atomic Absorption Spectrophotometer
CEC	Cation Exchange Capacity
CGIAR	Consultative Group for International Agricultural Research
EDTA	Ethelenediamine tetraacetic acid
FAO	Food and Agriculture Organization of United Nations
FYM	Farmyard Manure
GPS	Geographical Positioning System
JICA	Japan International Corporation Agency
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
NARO	National Agricultural Research Organization
NERICA	New Rice for Africa
PRiDe	Promotion of Rice Development
SWC	Solid Waste Compost
USDA	United States Department of Agriculture
WHO	World Health Organization
UBOS	Uganda Bureau of Statistics
ZARDI	Zonal Agricultural Research and Development Institute

ABSTRACT

Soil health is an indispensable component of an environment that reflects the capacity of soil to provide ideal conditions for normal plant growth and support to ecosystem services. However, the potential of soils to sustainably support ecosystem service and optimize crop yields is threatened by land degradation. A field experiment was conducted at Ngetta ZARDI, Lira city with the aim of evaluating soil amendment techniques using organic and inorganic fertilizers for increased yield of upland rice in northern Uganda. Specifically, the study determined the effects of varying levels of solid waste compost, farm yard manure and NPK fertilizer on soil chemical properties and yield, and examined the effect of organic soil amendments on the concentration of heavy metals in soil and rice grains. The experiment was laid out in a Split-plot design with three replications. The treatments used included; solid waste compost (SWC) at 5, 10 and 15 tons/ha, farmyard manure (FYM) at 5, 10 and 15 tons/ha and NPK fertilizer (NPK) at 100, 200 and 300 kg/ha and control. Data on yield components, growth parameters, grains and soil samples were subjected one way-way ANOVA test to analyze differences between the means of dependent variables. The results indicated that the highest yield of 4.1 tons/ha was obtained from NPK fertilizer applied at 300 kg/ha, followed by SWC10 and FYM15 that gave the yields of 2.9 tons/ha and 2.8 tons/ha, respectively, compared to control at 1.5 tons/ha grain yield. The highest concentration of heavy metal (Cadmium) was obtained from treatments of SWC15 and FYM15 at 1.77 and 1.13 ppm, respectively, compared to control at 0.10 ppm. Therefore, the study established that application of fertilizer packages, significantly increased soil organic matter, nutrient contents and grain yields. The application of SWC and FYM increased concentration of Cd in soils and grains after soil organic amendments.

Key words: Soil health, land degradation, solid waste compost, farm yard manure, soil amendments, Heavy metals and rice yield.

CHAPTER ONE: INTRODUCTION

1.1 Background

Soil health is an indispensable component of an environment that directly or indirectly provides an ideal condition for the existence of ecosystems (Lehmann et al., 2020 and Fierer et al., 2021). In recent years, the potential of soils to support plant nutrition and growth has been threatened by land degradation (Bhowmik et al., 2019). It is estimated that about 33% of the total global earth's surface is degraded and more than 3 billion hectares affected by some forms of land degradation globally (Bai et al., 2008 and Eswaran et al., 2019). However, the demand for a healthy soil is rising steadily because the world needs to feed 9.5 billion people by 2050, with less impact on environment (Haney et al., 2018 and Timsina, 2018). According to Dijk et al. (2021), the global population increase is alarming and has exerted pressure on land resource use. This has attracted reasonable attention because of the looming food insecurity and ecological risk posed by human activities (Fungo et al., 2011). In Sub-Saharan Africa, the extent and severity of land degradation arising from anthropogenic activities cannot be under scored (Vanlauwe et al., 2014). Zingore et al. (2015) compiled considerable evidence that land degradation is alarming in East Africa, and takes different forms like soil erosion, deforestation, bush burning and environmental pollution. In support, Olsson et al. (2019) reported that, about 15% of degraded land is caused by poor farming methods, illegal dumping of waste, excessive use of fertilizers and pesticides among others. This has contributed to increased loss of biodiversity, ecological imbalance, declining soil fertility and low crop yields.

In Uganda, about 41% of the total land area is degraded (Vlek et al., 2017), whereas in northern region districts with fairly flat terrain, over 30% of agricultural land is subjected to some forms of land degradation (Mubiru et al., 2017; Nseka, (2022); Atube et al., 2021). This makes northern

Uganda a hot spot for land degradation, and its impacts can be heavily felt among the poor rural communities. There is need for strategic interventions on soil health improvement within the confines of organic amendments to restore degraded soils (Raghunathan et al., 2021). In fact, land restoration strategies, would influence the productive potential of soils to sustainably improve soil fertility and restore ecological imbalances. Over the years, several efforts have been made to improve soil fertility through organic and inorganic amendments (Kaizzi et al., 2014; Kaizzi et al., 2018; Komakech et al., 2015). A study by Tsuboi et al. (2018) found that inorganic fertilizer increased rice yield by 30% when applied at active tillering and panicle initiation stages. In a related study, Jjagwe et al. (2020) reported that organic fertilizers are alternative sources of plant nutrient that can restore soil ecosystems and improve soil health. Similarly, Mubiru et al. (2017) reaffirmed that, soil amendment methods have been developed to address the problem of poor soil health in degraded soils using external inputs such as compost and farmyard manure, but these have not been widely used in northern Uganda due to a number of challenges that include; limited knowledge on the use of organic manure, inadequate information on the amount of fertilizer applied in the soil, and unknown available nutrient content in the manure. In addition, the presence of heavy metals in solid waste compost and farm yard manure is worrisome due to their non-biodegradability in soil and movement in food chain which poses risk in human health (Karami et al., 2010; Karim et al., 2013). Therefore, there was need to investigate the efficacy of solid waste compost, farm yard manure and NPK fertilizer in soil chemical properties, soil-plant heavy metal concentration and yield of upland rice in northern Uganda.

1.2 Problem statement

Soil is an important natural resource that provides nutrients, water and support to plants. Its ability to sustain plants and ecosystems make soil an integral part of the environment and land use practices. In Uganda, farmers depend solely on agricultural soil as source of livelihood for food production. However, the ability of soil to sustainably support crop productivity is seriously affected by soil degradation and declining soil fertility (Nakato, 2022). For long, smallholder farmers in northern Uganda use inorganic fertilizers, compost and practice crop rotation to improve soil quality and increase crop yield (Onaga et al., 2012; Oonyu et al., 2011), but with limited success and low adoption due to numerous constraints such as high cost of inorganic fertilizers, limited knowledge on fertilizer use, increased environment pollution and nutrient depletion through crop removal (Okello et al., 2019). Besides, the declining soil fertility has resulted into low crop yield and loss of vegetative cover hence accelerated soil nutrient loss through land degradation. The declining crop yield is associated with inadequate knowledge on soil amendments, fertilizer application rates and limited alternative sources of plant nutrients. According to Babasola et al. (2018); Abebe and Debebe (2019), organic fertilizer such as solid waste compost and farmyard manure provide an alternative source of plant nutrients and has potential to improve soil quality. Similarly, Genchi et al. (2020) reported that solid waste compost and farmyard manure have been used to improve soil fertility; however, they may contain heavy metals, and can be transferred to food chain posing great risk to human health. Therefore, this study was conducted to address the problem of poor soil quality in degraded land and as such, the effect of soil amendments on soil-plant heavy metal concentration and yield of upland rice in northern Uganda was evaluated.

1.3 Objectives

1.3.1 Main objective

The main objective is to assess the impact of soil amendments for improvement of soil quality and upland rice yield.

1.3.2 Specific objectives

1. To determine the effects of solid waste compost, farmyard manure and NPK fertilizer on soil chemical fertility attributes.
2. To determine the effects of varying levels of NPK fertilizer, solid waste compost and farmyard manure on yield of upland rice.
3. To examine the effects of organic soil amendments on the concentration of heavy metals in soil and rice grains.

1.4 Hypotheses of the study

- a) Increasing doses of NPK fertilizer, solid waste compost and farmyard manure will produce similar increasing effect on soil chemical fertility indicators such as soil pH, OM, N, P, K, Ca and Mg of soil.
- b) The yield of rice will increase linearly to increasing doses of NPK fertilizer, solid waste compost and farmyard manure will follow an increasing linear.
- c) Increasing application of organic soil amendments will increase the concentration of heavy metals in soil and grains of rice.

1.5 Significance

Soil health improvement is an important aspect of crop production for sustainable crop yield. The knowledge of soil nutrient balance and the amount of fertilizer required to support plant growth is needed to address the problems of soil degradation and declining soil fertility (Kijima et al., 2010; Tsuboi et al., 2018). One of the factors that contribute to poor soil health in northern Uganda is land degradation (Okello et al., 2019; Musebe et al., 2013). This is caused by poor agricultural practices, soil erosion and improper disposal of solid waste among others. The problem is worsened by limited knowledge and information on fertilizer use and the high cost of inorganic fertilizers (Kaizzi et al., 2018). These would be addressed using external inputs like solid waste compost and farmyard manure which are cheap, affordable and has long term effect in improving soil physical and chemical properties. Intrinsically, the study on the effects of soil amendments on soil-plant heavy metals concentration and yield of upland rice would provide an alternative source of plant nutrients, and reverse the trend of soil degradation in northern Uganda. Furthermore, the study would provide baseline information to students and other researchers of Gulu University or other universities for further studies in the field of soil science and solid waste management.

CHAPTER TWO: LITERATURE REVIEW

2.2.1 Global rice production

Rice (*Oryza sativa*) is the second largest cultivated cereal crop in the world after wheat. It is one of the leading food crops and reported to feed two third of the world's population (CGIAR, 2016). Asia is the world's largest producer and consumer of rice and accounts for over 90% of the total rice production in the world (Bandumula, 2018). According to smith and Dilday (2003), no grain crop is more important than rice because of its nutritional and socio-economic roles in improving the livelihood of the world population. In Africa, rice has increasingly become a staple food, source of income and provides about 70% of the human calorie intake compared to other cereals like sorghum, millet and maize (Sohl, 2005; Chauvin et al., 2012). In Sub-Saharan Africa, rice is ranked the fourth most important cereal crop, and supports livelihood of more than 900 million people (Dibba et al., 2012).

2.2.2 Rice production in Uganda

Rice production trend in Uganda has increased greatly since the introduction of upland rice varieties "New Rice for Africa" (NERICA) in 2002, from about 95,000 metric tons to the current estimated 750,000 metric tons of rice (Hong et al., 2021). Several improved varieties of rice are grown by farmers, which include upland varieties for purposes of food and income generation (MAAIF, 2019). Despite the socio-economic importance of rice in Uganda, its productivity remains low both nationally and at household level (Akongo et al., 2016). According to Musebe et al. (2013), the low rice yield continues to affect farmer's income and food security. Similarly, Kaizzi et al. (2014) reported that low yield of rice is attributed to declining soil fertility and poor soil health, and remains a big threat to sustainable rice production. In a related study, Okello et

al. (2019) reported that an average yield of upland rice in northern Uganda without fertilizer is 1.04 tons/ha, which is attributed to poor agricultural practices and limited use of fertilizers to improve soil quality.

2.2.3 Yield of upland rice

Rice crop is ranked second after maize in terms of adoption, its yield potential and ability to support livelihood through food security and economic returns (Akongo et al., 2016). In Uganda, an average yield of rice at household level with fertilizer amendment stands at 1.7tons/ha, and the national average yield of rice is between 2.5 and 3.0 tons/ha (Alibu et al., 2022). The low yield at both household and national levels is attributed to limited knowledge on fertilizer use and continuous nutrient depletion from the soil without replenishment. Therefore, soil fertility management and plant nutrition are integral components of rice production if sustainable yield is to be achieved. A study conducted by Aktar et al. (2019), reported that application of solid waste compost and farm yard manure improved soil physical and chemical properties, and increased rice yield by 20% compared to control plot. Similarly, Jiang et al. (2018) found that organic amendments increased crop yield by supplying adequate plant nutrients in the soil. According to Majbar et al. (2018), compost manure improved soil health and increased crop yield due to availability of essential plant nutrients like nitrogen, phosphorus and potassium. In a related study, Bodruzzaman et al. (2010); Wang et al. (2020) reported that organic amendments had great influence on soil nutrient status and increased grain yield.

2.3 Nutrient distribution, concentration and movement in rice plant

2.3.1 Nutrient distribution in rice plant

Nutrient distribution in rice plant takes different forms. Some nutrients are abundant in leaves, stems and the grains (calcium, zinc and calcium, and magnesium), while others like nitrogen, phosphorous and potassium are evenly distributed in grains and roots (Oladele et al., 2019). The distribution of nutrients among the vegetative parts of rice is significantly influenced by temperature (Liu et al., 2021), thus, as temperature increases, the distribution of nutrients like nitrogen, phosphorous and potassium also change, and hence reduction in dry matter content, that is, the proportion of nutrient distribution in leaves increase from 20% to over 50% at the expense of roots and the phytomer. According to Kim et al. (2020), extreme temperature and water stress affect soil nutrient uptake by the rice plant, and the distribution of nutrients within the rice plant is equally affected, hence poor dry matter production.

2.3.2 Nutrient concentration in plant tissues

The concentration of nutrients within the rice plant varies between different organs. For example, the concentration of nitrogen in the dry matter of very young leaf tissue is about 3.3%, but this may only be 0.5% in the roots (Bo et al., 2021). While phosphorous concentration is five times more in roots and stems than in grains. For potassium, the concentration in stems and sheath may reach 20% compare to 1% in grains (Mazlouzi et al., 2020). Given the variability in the fertility status of different soils, it is expected that the plant tissue nutrient concentration may change from location to location. According to Wang et al. (2018), the pattern of nutrient concentration in plant organs should be similar, but these findings are not in agreement with a study by Bashir et al. (2021), who reported that nutrient concentration in plant organs vary considerably, especially in the leaf tissue, which is the most frequently used diagnostic sampling part.

Similarly, Shrestha et al. (2020) reported that the concentration of any nutrient within the rice tissue depends highly on the age and the nutrient supply from the soil. This is in agreement with Wang et al. (2016), found that changes in nutrient levels in rice plant are associated with growth stages and the ages of the plant organs such as leaves, stems and roots. As a result, the nutrient concentration in rice plant may increase or decrease, for example, Phosphorous will decrease in the roots, while nitrogen will decrease in leaves and stems as rice plant approaches maturity (Wang et al., 2016). This happens at critical growth stages, after panicle initiation stage, mobile nutrients can be redistributed within the plant and nutrients can move from the leaf system to the developing grains. This normally causes a decrease in the nutrient concentration in the leaf lamina between early heading and full maturity stage (Guo et al., 2022). These findings therefore affirmed that, the concentration of nutrients within the rice plant tissues at any one time is dependent on the nutrient concentration within the soil and organs, and the age of the plant.

2.3.3 Nutrient movement in rice plant

The rice plant grows in such a way that tillers of different sizes and length are present in one hill at the same time, and the relationship is thought to be important in the nutrition of the rice crop. According to Wang et al. (2016), nitrogen moves readily between the leaves, stems and grains over a wide range of plant development period. The quantitative loss of nutrients from the leaves, stems and roots at full maturity was estimated at 68% (Guo et al., 2022). In addition, the movement of nutrients from the soil to the different parts of the rice plant at different growth stages is affected by the crop removal at harvest. This loss is estimated at 150- 200 ton/ha per year of dry matter which requires replenishment using organic or inorganic fertilizers (Singh, (1978); Mandal et al., 2020). This suggests that, the soil nutrient supply should be large enough to support the growth of rice from establishment up-to harvest. However, some nutrients that remain in soil after crop harvest constitute the nutrient base for subsequent seasons (Abuye et al.,

2021). Therefore, the knowledge of nutrient imbalances in the soil are important in regards to the frequency and amount of fertilizer application in the soil.

2.4 Fertilizer use, implication and method of application

2.4.1 Fertilizer use and implication

For greater nitrogen use efficiency, it is recommended that upland rice requires fertilizer application rates of 50 kg/ha of DAP (basal) and 50 kg/ha of Urea (top dressing) to produce grain yield of 4.5 tons/ha. Generally, fertilizers are applied in the soil to produce the desired yield while maintaining sufficient nutrient levels in the soil. In this case, the amount and type of fertilizer used is important especially at active tillering and panicle initiation stages, when nutrient demand is high (Kijima et al., 2011). These growth stages are critical, because tillering and grain filling depends largely on the nutrients supplied to the soil from active tillering to early maturity stages (Fageria et al., 2011). This justifies the importance of essential nutrients such as nitrogen, phosphorus and potassium during critical growth stages of rice. According to Sims and place (1968), total nutrient uptake (NPK) in rice was proven to be between 7-10 folds higher at vegetative and reproductive stages than after flowering. This was true for nitrogen and phosphorous, but potassium uptake was uniform before and after flowering. In a related study by Awio et al. (2022), delayed fertilizer application by two months after planting, significantly retarded rice growth and leaf production in rice. After three months of delayed fertilizer application, recovery from the fertilizer stress became difficult and progressively impossible as the rice crop advance to maturity. Therefore, for rice plant to benefit more from the fertilizer applied in the soil, then fertilizer should be applied at early stages of growth.

2.4.2 Method of fertilizer application

Rice fields are ploughed every season to achieve a desired seed bed, which makes fertilizer application convenient before, at planting and at later stages of growth (Nasution et al., 2021). This maximizes the use of plant nutrients by the rice plants. According to Satyanarayana et al. (2002), incorporating compost or manure into the soil before planting helps rice plants to easily take up the organic minerals at early stages of growth. Thus, placement of fertilizers in close proximity to rice roots, and applying manure one month before planting is the most efficient way to ensure that rice plant benefits from the nutrients applied in the soil. In addition, the nutrients applied are not easily lost through immobilization under very dry soil conditions.

2.5 Yield response to fertilizer application

The yield of a crop is an indicator of soil nutrient levels other conditions being constant. Soil with good nutrient balance is expected to give a very good yield unless crop performance is interfered with by drought, pest, disease or genetic potential of the crop variety. Most smallholder farmers experience low rice yield partially because of the declining soil fertility in degraded soils (Okello et al., 2019). Application of fertilizers have tremendous effect on rice yield, but variation in yields may be due to the type of fertilizer used, time and amount of fertilizer applied (Kijima et al., 2011). According to Kaizzi et al. (2018), application of inorganic fertilizers (DAP and Urea) increased grain yield of rice by 20% over control. In a related study by Komakech et al. (2015), farmyard manure applied in maize field increased grain yield by 16% compared to control.

2.6 Amendment of soil using organic manure

The use of plant and animal residues as fertilizers is one way of replenishing soil nutrients. For organic materials to provide plant nutrients, they must undergo a process of decomposition to form organic matter and then applied in the soil. According to Stevenson (1986), there are three interrelated organic matter fractions that occur in the soil, which must be taken into account when using organic fertilizers to improve soil health; 1) Plant and animal residues; when fully decomposed are capable of providing nitrogen, phosphorous, calcium and sulphur for plant growth; 2) Microbial biomass, which provide temporary storage part for soil nutrients, and 3) The resistant humus fraction. Notably, the level of soil organic matter content is a very good indicator of a fertile and productive soil, but this depends on the quality and quantity of organic manure used (Christensen, 1992). Parr and Colacicco, (1987) reported that organic manure provides a good source of plant nutrients, and plays an important role in maintaining soil structure and stable soil aggregates. Therefore, the knowledge about nature and soil organic matter turnover is a prerequisite for understanding the chemical reactivity, structure and fertility of soil, and to predict the fate of animal manure, compost and mineral fertilizer added to soil.

2.7 Mineralization of soil organic nutrients

The mineralization of organically bound nutrients into inorganic forms involves a number of steps for the nutrients to be available for the plants. For example, the conversion of organic nitrogen involves the process of ammonification and nitrification, where ammonification is a major step in the mineralization process that provides readily available nitrogen for plant use (Semenov, 2019). Ammonium is the most preferred nitrogen supply for the plants as it is less readily lost from the soil than nitrates. Like other nutrient, phosphorous and potassium rate of

mineralization is affected by many factors including; rainfall, temperature, presence of soil microorganism and quality of organic inputs in the soil.

2.8 Solid waste compost and farm yard manure as sources of plant nutrients

2.8.1 Use of Solid waste compost to enhance soil nutrients

Solid waste compost is an organic fertilizer obtained from decomposed materials of solid wastes. In this material, solid wastes such as agricultural, animal, human, industrial and construction waste are processed into compost through “wind rowing”, a method commonly used in decomposing solid wastes (Ayilara et al., 2020). Basically, solid waste compost is a good source of organic matter and it is capable of supplying essential nutrients such as nitrogen, phosphorous, calcium, sulphur and other micro-nutrients in soil. According to Machadao et al. (2020), solid waste compost applied in the soil increased organic matter, pH values, cation exchange capacity (CEC) and levels of essential nutrients like nitrogen, phosphorus and potassium. Aktar et al. (2019); Majbar et al. (2018), reaffirmed that rice crop respond positively to application of solid waste compost and significantly increased grain yield and improved soil health. Similarly, Mekki et al. (2013) reported that solid waste compost increased organic matter content and pH of the soil. While findings by Jiang et al. (2018) indicated that organic amendment increased crop yield by supplying adequate plant nutrients in the soil and improved the resilience of soil structure in degraded soils. In a related study by Yuksel et al. (2015) showed that increasing doses of solid waste compost showed remarkable effect on organic matter content, pH value and cation exchange capacity of the soils.

2.8.2 Use of Farmyard manure to enhance soil nutrients

Farmyard manure provides an important source of plant nutrients, and has the potential to improve soil physical and chemical properties. According to Mubarak et al. (2009) farmyard manure provides an alternative source of plant nutrients that helped to improve soil fertility, hence increased crop yield. Similarly, Rasoulzadeh and yaghoubi (2010) reported positive response of farmyard manure in improving soil physical and chemical properties. Both studies revealed that farmyard manure provided adequate amounts of plant nutrients (N, P and K) to poor soils, increased crop yield and has longer term effects on improving soil physical and chemical properties.

2.9 Characterization, transition, phyto-toxicity and behavior of heavy metals in soils

2.9.1 Characterization and transition of heavy metals in soil

Heavy metals exist naturally in the earth's crust and ecosystem in different forms and amounts. They are defined on the basis of chemical properties, toxicity and atomic weights (Duffus, 2002). Soil is the major sink for heavy metal contaminants released into the environment through human-induced activities and natural processes like rock weathering (Wu et al., 2014). Some of the heavy metals that cause soil pollution include lead (Pb^{2+}), chromium (Cr^{3+}) and cadmium (Cd^{3+}). According to Zhang et al. (2018), soil may be contaminated with heavy metals through disposal of metal wastes, lead gasoline and paints, application of inorganic fertilizers, animal manure, compost, sewerage sludge, pesticides and irrigation water. Other means through which heavy metals find their ways into the soils include; corrosion of metals, soil erosion, leaching and atmospheric deposition. In a study by Wuana et al. (2011), the buildup of heavy metals in farmland causes soil contamination which has detrimental effects to the ecosystem or indirectly poses a big risk to human health through; polluted agricultural food chain, drinking contaminated

underground water, reduction in food quality and safety and direct ingestion or contact with contaminated soils.

2.9.2 Soil properties that affect heavy metal transition in rice

Soil is a medium for plant growth which comprises of water, gaseous and mineral components. The soil minerals can be obtained from weathered rock particles and anthropogenic activities such as fertilizer application, pesticides and irrigation water. The transfer and bioavailability of heavy metals are governed by the chemical forms in which they exist in the soil, dissolved forms are the most mobile forms and readily available for biological uptake by plants (Li et al., 2017). When heavy metals are introduced into the soils, their interaction and movement in the soil is determined by the amounts, environmental factors and the soil chemical properties such as pH, organic matter content and the oxides of other minerals (Liu et al., 2011). The extent of interaction largely depends on the ability of heavy metals to be adsorbed by the soil, which is limited due to the nature of heavy metals which are not easily biodegradable. The mobility of heavy metals in the soil is associated with the presence of organic or inorganic substances which are either in ionic form for example Cu^{2+} , Pb^{2+} and Zn^{2+} or in a soluble complex form like CuSO_4 and ZnCl . This condition depends on the pH of the soil but under neutral and basic soil conditions the movement of heavy metals is reduced (Zhao et al., 2012).

According to Huang et al. (2017), the pH of the soil influences the chemical behavior of heavy metals because of the complex nature of soil solution resulting from the hydrogen ions concentration in soil pores. The presence of hydrogen ions (H^+) has the ability to replace negatively charged ions (anions) in the soil particles. As a result of this reaction, the movement of heavy metals is enhanced within the soil. The mobility of heavy metal is also affected by

changes in the redox reaction, under reducing condition the pH of the soil solution increases, and decreases with oxidation (Alloway, 1995).

Organic matter is found in all types of soils and play a big role in the mobility of heavy metals in the soil. The amount and type of organic components vary due to difference in chemical properties of the soil. According to Alloway (1995), organic matter can be categorized into humic and non-humic substances. The humic substances consist of carbohydrates, carbonic acid, waxes and fats. While non-humic substances have acidic polyelectrolytes which consists of biochemical substances, which are capable of being bound to humic polymers. The oxides and hydroxides of other minerals such as Al, Fe and Mn have direct effect on the chemical properties of metals and their colors in the soil. The oxides of these metals display unique colors which serve as indicators during the process and the final product of soil formation. While the hydroxide of Cu and Ni are capable of adsorbing cations of other metals like Al, Pb, Cu, Cr and Ni which makes then excellent sinks for cations because of the high cation exchange capacity due to the absence of $-OH_2$ and $-OH$ groups of the hydroxides (Alloway, 1995).

Clay minerals affect the chemical and physical properties of soil and the behavior of heavy metals in the soils. This is due to the fact that clay minerals have large surface area and permanent negative charges on the soil particles which make them more mobile in the soil than mineral elements. According to Jalali and Khanlari (2008), heavy metals have limited adsorptive capacity and their mobility in the soil depends on their interaction with other soil types.

2.9.3 Phyto-toxicity of heavy metals

Phyto-toxicity refers to a situation normally associated with a phenomenon where by a potentially harmful substances like heavy metals are accumulated in plant tissues to a level that affects optimal growth and development of the plants (Beckett and Davis, 1988). Heavy metal

ions occur naturally in soil environment, and some of these heavy metals (Cu, Fe, Mn and Zn) are required for the maintenance of optimal plant growth, development, and productivity. However, plant growth and development are often limited by both low phyto-availability of heavy metal ions, as well as by the presence of their excessive concentration in the soil solution (Marschner, 1995; Hänsch and Mendel, 2009). Since a range of anthropogenic activities such as application of inorganic and organic fertilizers, pesticides and chemical industries are increasing, significant rise in the concentration of heavy metal ions in soil environment is inevitable, subsequently, soil-plant and food contamination with heavy metals cannot be ignored (Anjum et al., 2014b). Several studies have been conducted on organic amendments to minimize heavy metals concentration in soils and their potential threat to human and the entire ecosystem. According to Kong et al. (2018), heavy metals such as copper, lead, cadmium and zinc have been found to accumulate rice grains, and when consumed by human being, they can cause health problems. Similarly, Lei et al. (2009); Yap et al. (2011) found that the presence of heavy metals in the soil have dangerous effects on human health and poses environmental risks to the ecosystem. Govil et al. (2002), reported contamination of agricultural soils with lead (Pb) and increased concentration in rice grains compared to other heavy metals like cadmium, copper chromium and zinc.

2.9.4 Behavior of heavy metals in soil

The behavior of heavy metals cations in soil is affected by a number of factors; According to Al-Barrak (1990), heavy metals affinity in soil follows the sequence $Pb > Cr > Cd$ for intact soil. This sequence is similar to the one reported by Rikers (1999) which occurs in the sequence of $Pb > Cr > Cd >$. In terms of adsorption level, every heavy metal is sensitive to mineral levels in the soil, for example Cr and Pb are adsorbed in soils with high organic matter content. According to Gome (2001), the ionic and cation forms of heavy metals like Pb, Cd and Cr can create strong

complexes or bond in soil especially when several heavy metals is introduced into the soil, a situation of competition for sorption sites are inevitable. Rabi and Usman (2005) reported that the competition for sorption sites will eventually cause mobility, toxicity and bioavailability of heavy metals such as lead, cadmium, chromium and zinc in the soil.

Lead is one of the heavy metals that is very toxic to human, especially when it is exposed to the environment. The long residence time portrayed by lead as a pollutant makes it low in solubility and inability to be biodegraded by microbial activity. According to Korte et al. (1976), Lead and other heavy metals were found to be very immobile in soils. This is because it tends to adsorb itself to other solid phases, which makes it the least mobile heavy metal in soil. The presence of Mn and Fe oxides and organic matter also play an important role in Pb adsorption. Another interesting fact is that carbonate content in a soil affects the behavior of Lead, for example, when a pH increases; Pb forms PbCO_3 in a calcareous soils.

For Chromium, factors such as redox potential and pH affect its adsorption in soil making it more biodegradable and able to be retained in the soil (Bradl, 2004). Chromium element occurs in a number of oxidation states, the most stable of which are Cr^{3+} and Cr^{4+} , but Cr^{3+} is less mobile and the most common form of chromium found in soils which strongly adhere to soil aggregates (Smith et al., 1989). While Cr^{4+} is the most toxic form of chromium, because it is readily removed from soil and is more stable than Cr^{3+} , and Cr^{4+} is readily reduced to Cr^{3+} in acid soils with high level of organic matter, although the reduction is slower in alkaline soils (Carry et al., 1977).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

3.1.1 Geographical location

The study was conducted at Ngetta Zonal Agricultural Research and Development Institute (Ngetta-ZARDI) of National Agricultural Research Organization (NARO) in Lira district (Figure 1), with approximate coordinate of 2°17'N, 32°55'E at an altitude of 1090 m above sea level. The institute is located in the mid-northern agro-ecological zone, which has an average rainfall between 1200 - 1600 mm and temperature range of 15 - 32.5 °C.

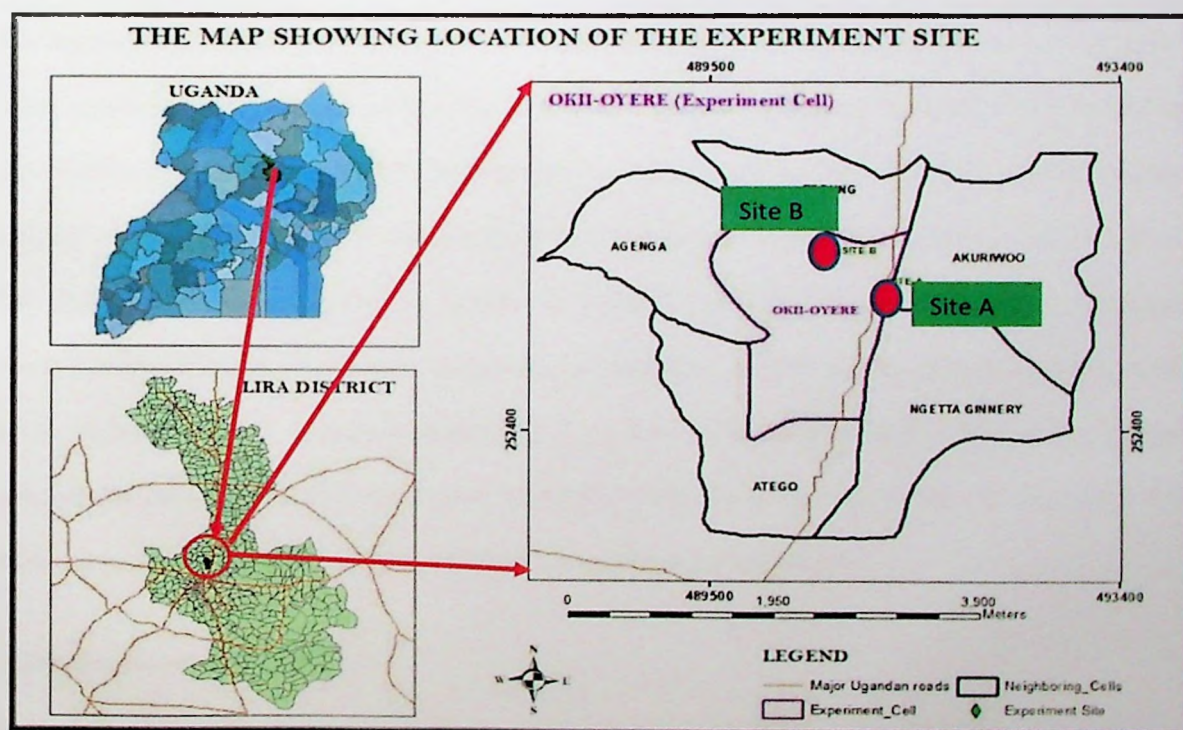


Figure 1. Location of the experiment

3.1.2 Experimental sites

The experiment was conducted from April – July (First season) and August - December (second season) 2021. The experimental sites lie between coordinates 2°17'51.4, 32°54'E for site A, which had darker soils signifying lower iron content, and coordinates of 2°17'51.4, 32°91'E for site B, which had soil richer in iron (Brown color) at an altitude of 1090m above sea level. The vegetation is savannah grassland (FS&LA report, 2013) with soils having a textural class of sandy loam (Table 2).

3.1.3 Rainfall received during the experimental period

The rainfall data was obtained from Ngetta ZARDI meteorological department. In first season, the highest total monthly rainfall received in the study area was 20 mm and 24 mm in April and May, respectively. The study period was characterized by a prolonged dry spell which started in the middle of June, with a drastic drop in total monthly rainfall in July. While in second season, rainfall started in the middle of August up-to November with the highest monthly total rainfall of 8.6, 8.6 and 8.7 mm received in September, October and November respectively. Although second season rainfall was longer, the amount of rainfall received was less than first season, with total monthly rainfall dropping drastically to 2 mm in December 2021. The mean annual cumulative rainfall received in the year was 964.8 mm (Appendix 9) which was far below the total mean annual rainfall of 1200 -1600 mm received in Lira district.

3.2 Experimental design

The total land area used for the study was 9 m x 33.5 m (0.03 ha). The experiment was a three by four factorial experiment with four levels, laid out in a split-plot design with three replications, each replication comprised of 12 plots making a total of 36 plots for the entire experiment. In

each replication, three different treatment levels of solid waste compost, farmyard manure and NPK fertilizer including control were applied in a plot size of 2m x 2m. A space of one meter was left between plots and replicates, and a guard row of 2 meters between experimental area and edges of the field.

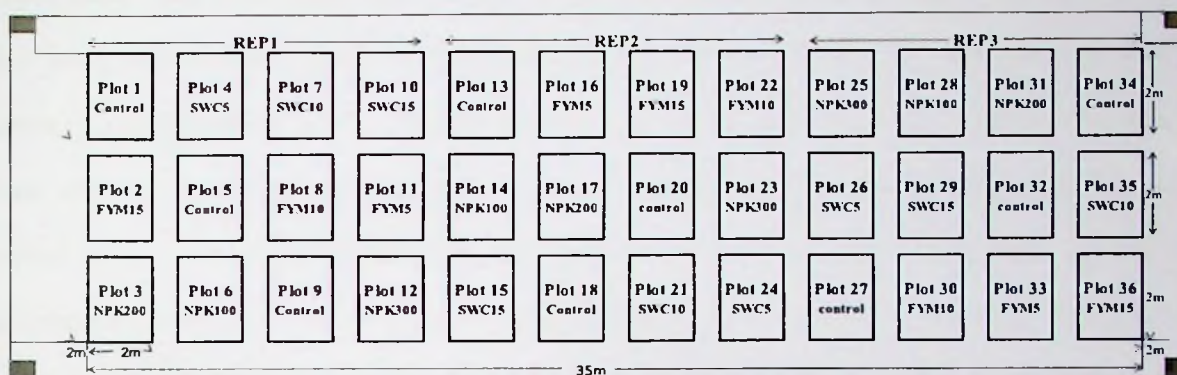


Figure 2. Field layout of the experiment

3.3 Soil Amendment preparation and application

3.3.1 Preparation and application of solid waste compost

Soil amendment is a substance (compost or manure) applied in the soil with the intention to change the chemical or physical properties of soil. In this study, decomposed solid waste compost (SWC) was obtained from Lira city solid waste processing plant, dried and sieved through a 2 mm mesh. The samples were sieved to remove bigger particles of plastic and other non-biodegradable materials from the compost. About 0.5 kg of solid waste compost was taken to the laboratory and analyzed for N, P, K, Ca and Mg and heavy metals such as Cd^{3+} , Cr^{3+} and Pb^{2+} using analytical methods and procedures outline in (Okalebo et al., 2002). The compost application rates were determined for this study based on the recommended rate of 10 tons/ha. The bulk of the compost was weighed at the rates of 2 kg/4m², 4 kg/4m² and 6 kg/4m², and was

evenly applied in the respective plots by hand and immediately incorporated into the soil using hand hoe (Table 1).

3.3.2 Preparation and application of farmyard manure

Fresh cattle dung mixed with feed remains and urine were collected from Ngetta ZARDI dairy unit using wheel barrow, spade, fork rake and bucket. The mixture of cattle dung was piled in layers in a well prepared manure pit of dimension 2m x 2.5m. Each layer was separated by a thin layer of top soil, ash and chopped fresh grass until the pit was full. The pit was covered for a period of six weeks to obtain fully decomposed farmyard manure. After 1½ months, the fully decomposed farmyard manure was dried, crushed and sieved through a 2 mm mesh. About 0.5 kg of farmyard manure was taken to the laboratory and analyzed for nutrients (N, P, K, Ca and Mg), and Cd^{2+} , Cr^{3+} and Pb^{2+} using analytical methods and procedure outline in (Okalebo et al., 2002). The remaining dry farmyard manure was weighed and evenly applied in the respective plots at the rates of 2 kg/4m², 4 kg/4m² and 6 kg/4m², by hand and immediately incorporated into the soil using hand hoe (Table 1).

3.3.3 Application of NPK fertilizer

NPK fertilizer was obtained from a licensed Agro-input dealer in Lira city. The nutrient content of NPK fertilizer (17:17:17) was predetermined by the manufacturer as was indicated on the fertilizer package. NPK fertilizer application rates were determined based on the soil testing results. The fertilizer was weighed at the rates of (40 g), (80 g) and (120 g), and was applied in the respective plots (4m²) at the time of planting (basal). Prior to planting, NPK fertilizer was first applied along the furrow line, covered with a thin layer of soil before rice seed was placed on top to avoid contact with fertilizer (Table 1).

Table 1. Application rates of amendments and NPK fertilizer.

Solid waste compost			Farm yard manure			NPK fertilizer		
Treatment	Amount (tons/ha)	Amount (kg/ha)	Treatment	Amount (tons/ha)	Amount (kg/ha)	Treatment	Amount (Tons/ha)	Amount (kg/ha)
Control	0	0	Control	0	0	Control	0	0
SWC5	5 tons/ha	2 kg/4m ²	FYM5	5 tons/ha	2 kg/4m ²	NPK5	5 tons/ha	2 kg/4m ²
SWC10	10 tons/ha	4 kg/4m ²	FYM10	10 tons/ha	4 kg/4m ²	NPK 10	10 tons/ha	4 kg/4m ²
SWC15	15 tons/ha	6 kg/4m ²	FYM15	15 tons/ha	6 kg/4m ²	NPK 15	15 tons/ha	6 kg/4m ²
Key: Solid waste compost (SWC), Farm yard manure (FYM), Fertilizer (NPK) and Control								

3.4 Land preparation and planting

Land for the experiment was mapped and all the grass cut using hand slashers. The grass was allowed to dry for two weeks and later removed to avoid decomposition to form organic matter. The field was ploughed three times, levelled and divided into replicates before field marking. The plot size of 2m x 2m was measured at a spacing of (30 cm x 12.5 cm), 30 cm between the rows and 12.5 cm within the rows. Later, planting holes were made along the furrow lines which were opened using planting fork. A standard seed rate of seven seeds were planted per hole at a depth of 3-4 cm and thinned 14 days after germination. Trenches of dimension (2 ft x 2 m x 0.3 m), 2 feet width by 2 meters length and 30 cm depth were dug at intervals, between the plots and replicates to minimize surface run-off. These were regularly maintained after every two weeks to ensure their effectiveness in controlling erosion. Upland rice variety, NERICA4 was used as a test variety.

3.4.1 First season experiment

The experiment was established on 20th/04/2021 for first season, and was managed with regular weeding to maintain a weed free field throughout the study period. Data on growth performance and yield components were collected at the end of the season when rice was at full maturity stage. Growth performance data on culm length, tiller number, panicle length and 1000 grain weight were collected from 10 hills selected from the 40 hills which were harvest from each experimental plot. Data on the number of tillers per hill were counted and recorded while culm length and panicle length were measured and recorded in centimeters. The data collected were analyzed to determine the effect of different treatment levels of solid waste compost, farm yard manure and NPK fertilizers on grain yield and yield parameters.

3.4.2 Second season experiment

In second season, the same experiment was established on 4th/August/ 2021, but in another site within Ngetta ZARDI farmland. At this time, land preparation, planting, treatment application and field management were done as in first season. Thinning and gap filling were done in the second week following first weeding to achieve optimum plant population in each plot.

3.5 Soil and grain sample collection

3.5.1 Soil sample collection

Two sets of soil samples were collected from each season. The first set of the composite samples was collected and analyzed before planting the experiment, while the second one was collected after harvesting rice from the experimental plots. Soil samples were collected zigzag pattern within the experimental field using soil auger, individual cores were thoroughly mixed to obtain composite sample. A total of 84 composite samples were collected from the experimental fields,

12 soil samples were collected before planting the experiment, while 72 soil samples (36 from each site) were collected after harvesting rice from each plot. All the soil samples were analyzed in the laboratory for chemical properties.

3.5.2 Rice grain sample collection

At physiological maturity, grain samples were collected from ten hills selected from the forty hills harvested from each plot. The ten hills were grouped according to the panicle numbers; three hills out of the ten hills with the highest number of panicles were selected, cut, dried and threshed by hand. A total of 48 grain samples were processed, packaged and submitted to Gulu university laboratory to analyze for concentration of heavy metals (Cd^{2+} , Cr^{3+} and Pb^{2+}) using routine laboratory methods and analytical procedures (Okalebo et al., 2002).

3.5.3 Yield components data collection

Yield data was collected from forty hills in each plot to determine yield using partial harvesting method. The forty hills were selected from the fifth plant in the third row from each plot to determine the yield components such as; number of panicle, number of spikelet per panicle, 1000 grain weight, number of panicles per square meters and full grain ratio. The samples with the same number of panicles were grouped and two representative hills with average number of panicles close to each other were selected and dried. The grains were threshed by hands; empty and filled grains were separated in salt solution of specific gravity 1.03, filled grains were then counted by hand and weighed to obtain 1000 grain weight. The weight of the mature grains and the partial grain yield in g/m^2 obtained from the 40 hills were then converted to 14% moisture content to determine the grain yield in tons/ha.

3.6 Analysis of soil and rice grain samples

3.6.1 Laboratory procedures for analysis of soil samples

The soil samples were analyzed for total nitrogen, available phosphorous, available potassium, available calcium, available magnesium, pH, organic matter and heavy metals concentration using routine laboratory methods and procedures (Okalebo et al., 2002).

3.6.2 Determination of total nitrogen

Total nitrogen was determined using Kjeldahl technique. Two g of air dried soil was weighed and put into digestion tubes. One gram of a catalyst (copper sulphate) and selenium powder was added followed by sulphuric acid. The mixture was heated in a digestion block up-to 420 °C for about 3 hours until the solution turned green. The solution was allowed to cool, and the digest was removed, transferred and distilled using Markham distillation apparatus. The distillate was titrated with 0.1M HCl solution, and the total nitrogen was calculated in percentage.

3.6.3 Determination of available phosphorus

Available phosphorous (P) in the soil samples was determined using Bray 2 method (Bray and Kurtz 1945). Two grams of soil was weighed, transferred into a conical flask and 0.03 M NH_4F and 0.1 M Conc. HCl was added. The mixture was stirred, allowed to settle and filtered through Whatman filter paper. The filtrate was then transferred in the second test tube, and 10 ml of boric acid, 4 ml of ascorbic and 2 ml of sulfomolybdic reagents were successfully added into the filtrate. The solution was properly homogenized, heated in a water bath at 85 °C for 10 minutes, allowed to cool and were analyzed for available P using Spectrophotometer (Unicam R 969 series). Absorbance readings of the Spectrophotometer were related to the actual concentration of available P (PPM) in the soil samples using a calibration curve. The calibration curve was

obtained from reading absorbance of standard solutions of known concentration (Figure 4). The standard solutions, blank and duplicate reference analyses were performed for all analyses as part of the quality assurance procedures.

$$\text{P concentration (kg/ha)} = \frac{A \times 50 \times 2000000}{100000 \times 5 \times 5} = 4A$$

Where; Weight of soil = 2 g, Volume of the extract = 50 ml, Volume of the extract = 5 g, Volume for estimation (dilution=5 times) = 25 ml, and Amount of P observed in the sample on the std curve = A g/ml.

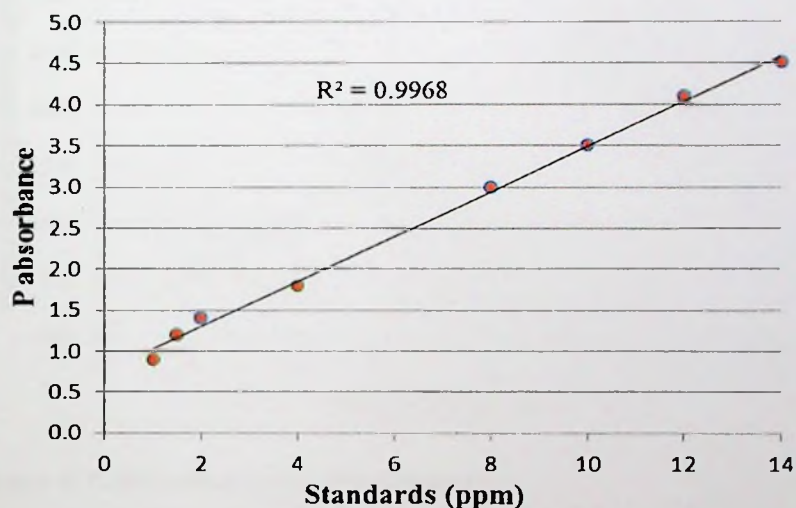


Figure 3. Calibration curve of phosphorous

3.6.4 Determination of exchangeable potassium

Exchangeable Potassium (K) in the soil samples was determined by flame photometry (Savoy, 2009). Ten grams of soil sample was weighed, mixed in 50 ml of Ammonium acetate solution, shaken for 5 minutes, and allowed to settle. The solution was filtered through watmann filter

paper No. 40 to obtain a clear filtrate. The filtrate was transferred into falcon tubes, homogenized, capped and stored in a rack. Concentration of K in the soil was analyzed using flame photometer equipped with gas acetylene flame as an oxidant. The photometer readings were recorded in parts per million as the actual concentration of K in the soil. The standards, blanks and duplicated reference analyses were also performed for all samples as part of the quality assurance procedures, and the readings recorded from the standards were used to obtain a standard calibration curve (Figure 5).

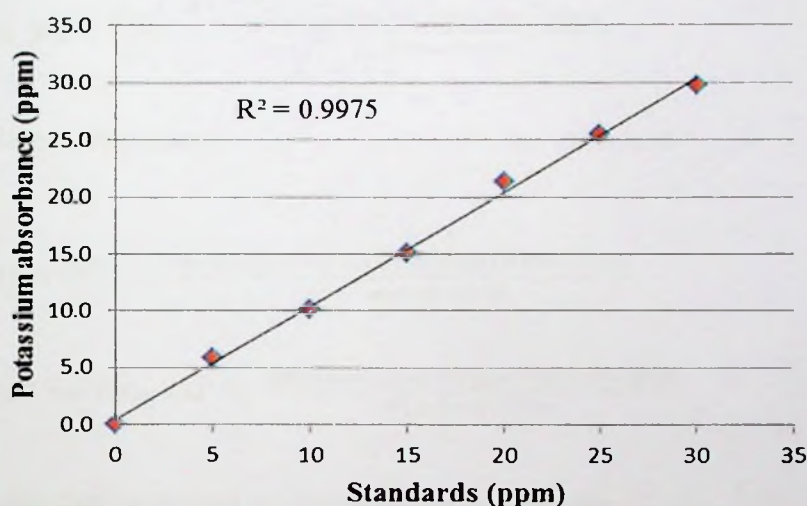


Figure 4. Calibration curve for potassium

3.6.5 Determination of exchangeable calcium

Exchangeable calcium in the soil was determined using titration method. 5 g of air dried soil was weighed and transferred in a conical flask. 25 ml of ammonium acetate solution was added and filtered to obtain a clear filtrate. 10 ml of aliquot solution was pipetted into a conical flask, 2-3 drops of crystal carbamate, 5 ml of 16% NaOH and 0.04 g of the indicator powder was added

and titrated with 0.01 M EDTA solution till the color gradually changed from orange red to reddish violet (purple). The volume of EDTA used for titration was noted and the concentration of calcium in soil solution was calculated and expressed in cmol/kg of soil weight basis as below:

If N_1 is normality of Ca^{2+} , V_1 is volume of aliquot taken, N_2V_2 is the normality and volume of EDTA used respectively, then,

$$N_1V_1 = N_2V_2$$

$$\text{Or } N_1 = \frac{N_2V_2}{V_1} = \frac{\text{Normality of EDTA} \times \text{Volume of EDTA}}{\text{ml of aliquot taken}}$$

Here N (Normality) = Ca^{2+} present in one litre of aliquot

$$N_1 = \frac{N_2V_2}{V_1} = \frac{\text{Normality of EDTA} \times \text{Volume of EDTA} \times 1000}{\text{ml of aliquot taken}}$$

$$\text{Ca}^{2+} \text{ me/100g soil} = \frac{100 \times \text{extraction Volume} \times \text{Ca as me/litre}}{\text{Wt of soil} \times 1000}$$

3.6.6 Determination of exchangeable magnesium

Exchangeable magnesium was determined using titration method in which the concentration of both Calcium and Magnesium were first determined in the solution. In this procedure, five grams of air dried soil was weighed, 25 ml of ammonium acetate solution was added, shaken for 5 minute, allowed settle and filtered through watmann filter paper No.1. 5 ml of the aliquot containing 0.1 mcg of calcium and magnesium was added into the filtrate followed by 2-5 drops of crystal carbamate, 3-4 drops of enchrom black-T indicator and 5 ml of ammonium chloride and ammonium hydroxide buffer solution. The solution was titrated with 0.01 M versenate till the color changed to bright blue or green and no tinge of wine red color remained. The volume of

EDTA used for titration was noted and the concentration of both calcium and magnesium was calculated using the formula below:

$$\text{Hence Ca}^{2+} \text{ and Mg}^{2+} \text{ me/litre} = \frac{\text{Normality of EDTA} \times \text{Volume of EDTA} \times 1000}{\text{ml of aliquot taken}}$$

Where; Normality = 0.01, Volume of EDTA = V2 – V1

Note: The concentration of Mg^{2+} was obtained by subtracting the concentration of Ca^{2+} and Mg^{2+} me/litre from the concentration of Ca^{2+} me/litre,

$$\text{Hence Conc. of Mg}^{2+} \text{ me/litre} = \text{Ca}^{2+} \text{ and Mg}^{2+} \text{ me/litre} - \text{Ca}^{2+} \text{ me/litre}$$

3.6.7 Determination of organic matter content

The organic matter was determined by volumetric method of Walkley and Black (1934). One gram of air dried soil sample was weighed and transferred in a 500 millilitress conical flask. Ten mililitres of 0.1667 M $\text{K}_2\text{Cr}_2\text{O}_7$ solution and 20 ml concentrated H_2SO_4 were added. The solution was mixed thoroughly and the reaction was allowed to complete for 30 minutes. The solution was then diluted with 150 ml water and 10 ml H_3PO_4 was added followed by 2 ml of diphenylamine indicator; this was then titrated with standard 0.5M FeSO_4 solution until the color changed to a brilliant green color. The percentage of organic carbon in soil was calculated as below;

$$\text{Percent of organic carbon X} = \frac{10 (S-T) \times 0.003 \times 100}{S \times \text{wt of soil}}$$

Since 1g of soil was used, the equation is simplified to

$$\text{Percent of organic carbon X} = \frac{3(S-T)}{S}$$

Where;

S= ml of FeSO₄ solution required for blank

T= ml of FeSO₄ solution required for soil sample

3 = Eq W of C (weight of C is 12, valency is 4, hence Eq W is $12/4 = 3.0$)

0.003 = weight of C (1000ml of 0.1667M K₂Cr₂O₇ = 3g C. Thus, 0.1667M K₂Cr₂O₇ = 0.003g C).

OC recovery is estimated to be 77%.

Therefore the amount of OM (Y); % of OM = $\frac{X \times 100}{77}$

3.6.8 Determination of pH of soil

Soil pH was determined using glass electrode pH meter (Model H1 10917) microprocessor in soil-water suspension ratio of 1:2.5 weight to volume basis (Okalebo et al., 2002; Dewis and Freitas, 1970). Twenty five grams of soil was weighed and transferred into 100 ml glass beaker and 62.5 ml of distilled water was added to the soil. The soil solution was stirred thoroughly and allowed to stand for 30 minutes. The pH values obtained were taken as the actual pH of the soil samples.

3.6.9 Determination of soil texture

The soil textural class was determined by the hydrometer method as outlined by Okalebo et al. (2002). Forty grams of air dried soil was weighed and transferred into a 250 ml beaker; 100 ml of sodium hexametaphosphate were added separately into the soil. This was then placed on a hot plate at 100 °C and removed when the solution started boiling. The solution was then transferred into 250 ml conical flask and shaken for 20 minutes using an electric shaker. The solution was then transferred into 1000 ml measuring cylinder and dispersed sample was allowed to stand for 2 hours before the textural class was determined. After 2 hours, the cylinder with the soil suspension was agitated using a plunger to allow the particle to be in suspension, each cylinder was then placed on a table and hydrometer readings were recorded at 30 seconds, 4 minutes, 1

hour, 4 hours and 24 hours intervals. The percentage of sand, silt and clay were calculated and used to determine the soil texture class using the textural triangle.

3.7 Analysis of heavy metals in soil and grains

The grain and soil samples were analyzed for Cd^{2+} , Cr^{2+} and Pb^{2+} using analytical methods and procedures outline in Okalebo et al. (2002). Two grams of soil and grain samples were separately weighed in crucibles using a scout proSPU402R electronic top loading scale, and each sample was heated in a furnace at 550 °C for 3 hours. The samples were allowed to cool, transferred into 250 ml conical flash and 10 ml of concentrated HNO_3 was added, and the mixture was heated on a hot plate at 80 °C. The digest solution was filtered into second conical flask using watmann filter paper number 42. The filtrate was then transferred into falcon tubes and topped up-to 40 ml mark with acetic acid. The digest solutions were analyzed for Cd^{2+} , Cr^{2+} and Pb^{2+} using an Atomic Absorption Spectrophotometer (Model Buck 210VGP) equipped with gas acetylene flame as an oxidant. Concentration of metals in the soil and grain samples were recorded in parts per million (ppm) and were taken as actual concentration of the heavy metals in soil and grain samples. The standard solutions, blanks and duplicated reference material analyses were performed for all analyses as part of the quality assurance procedures.

3.8 Data analysis

The data generated was analyzed using statistical software MINITAB version 17 for windows. Analysis of variance (ANOVA) was conducted on the measured dependent variables including soil properties, nutrients, heavy metal concentration and grain yields as a function of independent variables (fertilizer dosages). Turkey's multiple range test at 5% probability level ($P < 0.05$) was used to compare differences between means. Correlation and regression analyses were used to show relation between different treatment levels and grain yield as well as heavy metal

concentration in soil and grains. Micro soft excel (for windows 2010) was used to generate tables of results and graphical presentations.

3.9. Quality control and ethical consideration

3.9.1 Quality control

The study was conducted in a clean and safe environment which did not expose grain and soil samples to contamination during sample collection, processing and packaging. A meeting was held with field assistants for one day before establishing the experiment. During the meeting, they were trained on how to precisely collect, measure, record and weigh samples to ensure that valid and reliable data was collected with utmost accuracy. Field Assistants were also taken through calibration of small equipment and tools such as weighing scales and moisture meter which were used for data collection. In addition, all workers were at all times wore protective gears like face masks, overall, gumboots, hand gloves and laboratory coat during execution of various field and laboratory activities.

3.9.2 Ethical consideration

The permission to conduct this study was sought from the Uganda national council of science and technology through Gulu University Research and Ethics Committee. A meeting with field assistant and laborers was held and they were informed about their participation in the study. During the meeting, participants willingly signed the consent forms as evidence that they understood the purpose of the study, and that the methods and procedures used in data collection and handling of samples did not cause any harm to human and the environment.

CHAPTER FOUR: RESULTS

4.1 Soil characteristics

The initial soil characteristics of the experimental field are as shown in Table 2. The pH values of solid waste compost and farm yard manure used as organic amendments were 8.3 and 8.7, respectively. While the mean pH values of soil for site A and B was 6.1 and 6.3 respectively, with no significant difference ($p>0.05$) observed between the sites (Table 2). The mean percentages of organic matter and total nitrogen in the soil for site A and B was 2.55 and 2.75%, and 0.10 and 0.11%, respectively with no significant difference observed between the sites. Similarly, there was no significant difference ($P>0.05$) in the concentration of other nutrients except for P and K. Overall, the mean pH, organic matter and nutrient content for solid waste compost and farmyard manure was significantly higher than in the soil after crop harvest.

Table 2. Soil characteristics before establishing the experiment.

Site	pH	OM	N	P	K ⁺	Ca ²⁺	Mg ²⁺	Texture			
								Sand %	Silt %	Clay %	Texture class
			(%)	(ppm)		(cmol/kg)					
A	6.3	2.55	0.11	2.76	32.81	0.42	0.56	72	12	16	Sandy loam
B	6.1	2.75	0.10	1.20	25.58	0.25	0.51	70	10	18	Sandy loam
A	0.3	0.31	0.01	2.98	14.13	0.23	0.14	-	-	-	-
B	0.2	0.26	0.01	0.22	7.41	0.06	0.06	-	-	-	-
SWC	8.3	4.26	0.47	50.20	207.17	1.73	1.45	-	-	-	-
FYM	8.7	3.22	1.88	78.10	482.17	2.71	2.73	-	-	-	-

4.2 Effect of amendments on soil chemical properties

4.2.1 Effect of NPK fertilizer on soil chemical properties

NPK fertilizer application did not affect the pH of the soils in the two sites ($P>0.05$), with pH values ranging from 6.4 - 6.7 for the different fertilizer rates including control. For organic matter, the highest percentage was obtained in NPK300 at 2.7% compared to control at 2.1%. While treatments NPK100 and NPK200 indicated organic matter contents at 2.1 and 2.5 %, in site A. whereas in site B, a similar organic matter content was recorded in treatments NPK300, NPK200, NPK100 and control with the mean values ranging from 2.0 - 2.75%. There was no significant difference ($P>0.05$) in the organic matter content in all the treatments that received NPK fertilizers. For total nitrogen, the highest percentage of total nitrogen was obtained in NPK300 at 0.12% while the least was recorded in control at 0.08% in site A. The results showed that NPK fertilizer had no significant ($p>0.05$) difference in the content of total nitrogen between the treatments applied, and there was also no significant difference ($p>0.05$) in the total nitrogen content between the treatments in the two sites.

For available phosphorous, the highest mean concentration of total nitrogen was obtained in NPK300 at 9.7 ppm compared to control at 2.3 ppm, with no significant difference in P concentration for NPK100 and NPK200 treatments (Table 3). Similarly in site B, NPK300 recorded the highest concentration of available P at 2.17 ppm compared to control at 1.31 ppm. For treatments NPK100 and NPK 200, there was no significant difference ($P>0.05$) in concentration of P between as in site A.

The concentration of exchangeable K was highest in treatment NPK 300 treatment at 28.7 cmol/kg, and was significantly different ($P>0.05$) compared to control at 19.6 cmol/kg. Meanwhile, treatments NPK 100 and NPK 200 did not show significant difference in K

concentration at 24 ppm and 26 cmol/kg, respectively. In site B, NPK300 recorded the highest mean concentration of K at 19.0 cmol/kg compared to control at 12.9 cmol/kg. There was no significant difference ($P>0.05$) in K concentration between NPK100 and NPK 200 treatments. For exchangeable Ca, the highest concentration Ca was recorded in treatment NPK300 at 0.79 cmol/kg compared to control at 0.52 cmol/kg in site A, with no significant difference ($p>0.05$) in the mean concentration of Ca between the treatments. Meanwhile in site B, the mean concentration of Ca was highest in treatment NPK300 at 0.39 cmol/kg and lowest in control at 0.28 cmol/ kg with no significant difference ($P>0.05$) between the treatments. Exchangeable Mg^{2+} had the highest mean concentration of Ca in treatment NPK300 at 0.68 cmol/kg compared to control at 0.30 cmol/kg, with no significant difference ($P>0.05$) in the mean concentration of Mg^{2+} between the treatments. Meanwhile treatments NPK100 and NPK200 had the mean concentration of Mg^{2+} at 0.54 cmol/kg and 0.65 cmol/kg, respectively. Overall, the effect of NPK fertilizer application on concentration of Mg^{2+} was not significant in both site A and B.

Table 3. Effect of NPK fertilizer application on soil chemical properties.

Site	Treatment	pH	Δ pH	OM %	Δ OM %	N %	Δ N %	P	Δ P	K+	Δ K	Ca2+	Δ Ca	Mg2+	Δ Mg %
A	Control	6.4	0.1	2.0	-0.5	0.10	-0.03	2.27	-0.50	19.6	-13.2	0.52	0.10	0.65	-0.50
	NPK100	64.0	0.3	2.6	-0.4	0.11	0.00	4.00	1.90	25.3	-8.8	0.78	0.10	0.38	-0.21
	NPK200	6.4	0.3	3.2	0.2	0.12	0.00	4.73	2.50	26.3	-6.8	0.79	0.36	0.33	-0.02
	NPK300	6.4	0.4	3.4	-0.1	0.13	0.01	7.73	6.90	29.3	-4.1	0.63	0.37	0.49	-0.12
B	Control	6.4	0.1	2.0	0.5	0.09	0.02	1.31	-1.45	12.4	12.0	0.28	-0.14	0.42	-0.14
	NPK100	6.5	6.5	2.4	-2.4	0.09	-0.09	1.40	1.40	14.7	14.7	0.29	0.29	0.45	0.45
	NPK200	6.6	6.6	2.6	-2.6	0.09	-0.09	1.90	1.90	16.7	16.7	0.34	0.34	0.50	0.50
	NPK300	6.4	6.4	2.8	-2.8	0.09	-0.09	2.17	2.17	19.0	19.0	0.39	0.39	0.56	0.56

4.2.2 Effect of solid waste compost on soil chemical properties

The application of solid waste compost in site A and B, irrespective of the doses did not significantly alter the pH of the soils ($p>0.05$) with the pH ranging from 6.7 – 6.8. The highest mean pH value of 6.8 was observed in SWC15 compared to control at 6.5. For organic matter, SCW15 recorded the highest percentage of organic matter at 3.4% compared to control at 2.0%, with no significant difference ($p>0.05$) in the organic matter. While SWC5 and SWC10 indicated significant difference ($P<0.05$) in organic matter content at 2.6% and 3.2%, respectively. Similarly, in site B, there was no significant difference in the organic matter content between the treatment (Table 4).

For total nitrogen, application of solid waste compost significantly increased the total nitrogen contents of the soil, with the highest total nitrogen percentage in treatment SWC15 at 0.13% compared to control at 0.10% in site A. The lower doses SWC5 and SWC10 did not significantly increase total nitrogen contents in the soil at 0.11%. Whereas in site B, there was no significant difference in solid waste compost treatments on total nitrogen irrespective of the doses applied (Table 4).

For the available P, the effect of solid waste compost was significant with the highest mean concentration of P at 7.7 ppm for treatment SWC15 and control at 2.27 in site A. Intermediate doses of SWC5 and SWC10 had significantly higher concentration of P at 4.0 ppm and 4.7 ppm, respectively compared to control at 2.27 ppm, but lower P concentration than SWC15. While in site B, there was no significant effect of solid waste compost on P concentration although SWC15 had the highest P concentration at 2.13 ppm compared to control at 1.77 ppm. For exchangeable K, the concentration of K was highest in SWC15 at 29.3 cmol/kg compared to

control at 19.6 cmol/kg, with significant difference ($P < 0.05$) between the two treatments. Meanwhile treatments SWC5 and SWC10 had the concentration of K at 26.3 cmol/kg and 25.3 cmol/kg, respectively, with no significant difference ($P > 0.05$) between them. Similarly in site B, treatment SWC15 recorded the highest concentration of available K at 21.0 cmol/kg compared to control at 12.4 cmol/kg with significant difference in K concentration between the treatments (Table.4). Meanwhile the concentration of K in treatments SWC5 and SWC10 was not significant at 26.3 cmol/kg and 25.3 cmol/kg, respectively. Overall, application of solid waste compost had significant effect on K concentration in site A. Similarly site B, solid waste compost showed significant effect on K concentration between the treatments.

For exchangeable Ca, SWC15 had the highest concentration at 0.79 cmol/kg compared to control at 0.52 cmol/kg in site A, with no significant difference ($p > 0.05$) in the mean concentration of Ca between the treatments. Meanwhile treatments SWC5 and SWC10 had the mean concentration of Ca at 0.29 cmol/kg and 0.32cmol/kg, respectively, with no significant difference between the treatments. Similarly in site B, SWC15 recorded the highest concentration of Ca at 0.43 cmol/kg compared to control at 0.29 cmol/kg with no significant difference ($P > 0.05$) in the concentrations of Calcium. There was also no significant difference ($p > 0.05$) in concentration of Ca between the SWC applied in site B.

Exchangeable Mg^{2+} had the highest mean concentration of 0.46 cmol/kg in SWC15 compared to control at 0.30 cmol/kg, with no significant difference ($P > 0.05$) in the mean concentration of Mg^{2+} between the treatments. Meanwhile treatments SWC5 and SWC10 recorded the mean concentration of Mg^{2+} at 0.33 cmol/kg and 0.38 cmol/kg, respectively. Overall, the effect of SWC application on concentration of Mg^{2+} was not significant in site A. Similarly, in site B, SWC application did not affect the concentration Mg^{2+} in the soil ($P > 0.05$).

Table 4. Effect of solid waste compost application on soil chemical properties.

Site	Treatment	pH	Δ pH	OM %	Δ OM %	N %	Δ N %	P	Δ P	K+	Δ K	Ca ²⁺	Δ Ca	Mg ²⁺	Δ Mg %
		%		%		%		(ppm)		cmol/kg					
A	Control	6.7	0.4	2.0	0.4	0.10	0.11	2.30	-0.50	19.6	-13.2	0.52	0.10	0.04	-0.52
	SWC5	6.7	6.7	2.6	0.4	0.11	0.11	4.00	1.20	25.3	-7.5	0.42	3.22	0.33	-0.23
	SWC10	6.7	6.7	3.2	0.2	0.12	0.11	4.70	2.00	26.3	-6.5	0.42	3.61	0.38	-0.18
	SWC15	6.7	6.7	3.4	0.0	0.13	0.11	7.70	5.00	29.3	-3.5	0.42	3.87	0.49	-0.07
B	Control	6.5	6.5	2.0	-13.2	0.09	-0.01	1.10	-0.10	12.4	-13.2	0.28	0.03	0.45	-0.06
	SWC5	6.5	6.5	3.2	-10.6	0.08	-0.02	1.20	0.00	15.0	-10.6	0.29	3.22	0.46	-0.05
	SWC10	6.6	6.6	3.6	-8.3	0.09	-0.01	1.20	0.00	17.0	-8.3	0.32	3.61	0.48	-0.03
	SWC15	6.1	6.1	3.9	-1.6	0.09	-0.01	2.10	0.90	21.0	-4.6	0.34	3.87	0.49	-0.02

4.2.3 Effect of farm yard manure on soil chemical properties

The application of FYM had no effect on the pH of the soil in site A and B with pH values ranging from 6.4 - 6.7 for the different farmyard manure application rates including control. For organic matter, the highest percentage was obtained in FYM15 at 3.6% compared to control at 2.0%, with significant difference ($P < 0.05$) between the two treatments in site A. While treatments FYM5 and FYM10 had organic matter contents at 2.5% and 3.1% respectively. Whereas in site B, a similar trend in organic matter content was recorded in treatments FYM5, FYM10, FYM15 and control with the mean organic matter percentage ranging between 2.0 – 3.3%. However, there was no significant difference ($P > 0.05$) in the mean percentages of organic matter in all the treatments that received farmyard manure fertilizer. For available nitrogen, The highest percentage of available nitrogen was obtained in FYM15 at 0.12% while the lowest was found in control at 0.10% in site A, with had no significant difference ($P > 0.05$) in the percentage of available nitrogen between the treatments applied. While in site B, FYM fertilizer had no effect of available nitrogen content just as it was found in site A (Table 3).

For available phosphorous, the highest concentration of was obtained in FYM15 at 10 ppm compared to control at 2.27 ppm. While P concentration in FYM5 and FYM10 treatments

recorded the P concentration at 3.77 ppm and 4.97 ppm, respectively in site A, with significant difference ($P < 0.05$) between FYM15 and the lower treatment rates. There was significant difference ($P < 0.05$) in the concentration of P between the treatments in site A. Similarly for site B, FYM15 recorded the highest P concentration at 9.43 ppm compared to control at 1.31 ppm, with significant difference between the treatments.

Exchangeable potassium showed the highest concentration of K in FYM15 at 25.7 cmol/kg compared to control at 19.6 cmol/kg, with significant difference ($P < 0.05$) between the treatments. Meanwhile treatments FYM5 and FYM10 recorded the mean concentration of K at 20.7 cmol/kg and 22.3 cmol/kg, respectively, was no significant difference between the treatments. While in site B, treatments FYM10 and FYM15 had the same mean concentration of K at 20.0 cmol/kg compared to control at 14.3 cmol/kg. This showed no significant difference between the treatments except for control with the least concentration of potassium.

For exchangeable Ca, treatment FYM15 had the highest concentration of 0.79 cmol/kg compared to control at 0.52 cmol/kg, with no significant difference ($p > 0.05$) in the mean concentration of Ca between the treatments. Meanwhile in site B, the mean concentration of Ca was highest in treatment FYM15 at 0.69 cmol/kg and lowest in control at 0.28 cmol/kg, with no significant difference ($P > 0.05$) between the treatments. Similarly, treatment FYM5 and FYM10 had the concentration of Ca at 0.42 cmol/kg and 0.84 cmol/kg, with no significant difference between the treatments, and the higher rates. Overall, the effect of farmyard application was not significantly different ($P > 0.05$) for site A and B. Exchangeable Mg^{2+} had the highest mean concentration of 0.74 cmol/kg for FYM15 compared to control at 0.19 cmol/kg of soil. Treatment FYM5 and FYM10 recorded the concentration of Mg^{2+} at 0.04 cmol/kg and 0.19 cmol/kg, respectively. There was no significant difference ($P > 0.05$) in Mg^{2+} between the treatments in site A. Similarly in site B, FYM15 recorded the highest mean concentration of Mg^{2+} at 0.69 cmol/kg compared to

control at 0.19 cmol/kg, with no significant difference between the treatments. Treatments FYM5 and FYM10 had the concentration Mg^{2+} at 0.30 cmol/kg and 0.65 cmol/kg, respectively, with no significant difference ($p>0.05$) between the treatments (Table 6).

Table 5. Effect of farmyard manure on soil chemical properties.

Site	Treatment	pH	Δ pH	OM %	Δ OM %	N	Δ N	P	Δ P	K+	Δ K	Ca ²⁺	Δ Ca	Mg ²⁺	Δ Mg %
				%	%	%	%	(ppm)				cmol/kg			
A	Control	6.3	0.0	2.5	0.0	0.09	-0.02	2.30	-0.50	19.6	-13.2	0.52	0.10	0.19	-0.37
	FYM5	6.5	0.1	2.5	-0.1	1.00	-0.02	3.80	1.60	20.7	-12.1	0.42	0.00	0.30	-0.26
	FYM10	6.5	0.2	3.1	0.5	0.11	-0.01	5.00	2.20	22.3	-10.5	0.84	0.42	0.65	-0.09
	FYM15	6.6	0.2	3.3	0.9	0.12	0.01	10.00	7.30	25.7	-7.1	0.74	0.32	0.74	-0.18
B	Control	6.5	0.4	2.0	-0.7	0.09	-0.01	1.31	0.10	12.4	-13.2	0.28	0.03	0.45	-0.06
	FYM5	6.6	0.5	2.8	0.1	0.10	0.00	1.53	0.30	14.3	-11.3	0.36	0.11	0.51	0.00
	FYM10	6.6	0.5	3.0	0.3	0.10	0.00	2.80	0.60	20.0	-5.6	0.42	0.17	0.58	0.07
	FYM15	6.6	0.5	3.3	0.6	0.10	0.00	9.43	8.20	20.0	-5.6	0.47	0.22	0.69	0.18

4.3.1 Effect of NPK fertilizer on grain yield

As shown in Table 7, NPK300 produced the highest grain yield of 4.1 tons/ha in site B, but was not significantly different ($p>0.05$) from the yield obtained from NPK100 and NPK200, which produced grain yields of 3.1 ton/ha and 3.6 tons/ha, respectively. While in site A, the highest yield of 3.8 tons/ha was obtained in NPK300 treatment followed by NPK200 and NPK100 at 3.6 tons/ha and 3.1 tons/ha respectively. Yield obtained from control treatments was at 1.5 tons/ha and 1.84 tons/ha in site A and B, respectively, with significantly lower grain yield than other treatments. The average grain yield for all NPK fertilizer treatments in site A increased by 51.6%, 58.3% and 60.5% for NPK100, NPK200 and NPK300 over control. While in site B, the yield increased by 40%, 48.6% and 56.1% for NPK100 NPK200 and NPK300 respectively, compared to control treatment.

4.3.2 Effect of solid waste compost on grain yield

The effect of solid waste compost on grain yield is presented in Table 7. The highest grain yield of 2.8 tons/ha was obtained from the treatment SWC15 in site B, while in site A, the highest grain yield of 2.8 tons/ha was produced from the treatment SWC10 followed by SWC15 at 2.5 tons/ha. This showed no significant difference ($P>0.05$) between the treatments and the two sites. The average grain yields for site A increased with increasing application of fertilizer rates by 22.2%, 38.2% and 46.2% for SWC5, SWC10 and SWC15 treatments, respectively, whereas for site B, the yield increases was 0%, 41.6% and 50%, for SWC5, SWC10 and SWC15 treatments respectively, over control treatment.

4.3.3 Effect of farmyard manure on grain yield

The effect of farm yard manure on grain yield is as shown in Table 7. The highest grain yield of 2.94 tons/ha was obtained from treatment FYM15 in site A. This was not significantly different ($p>0.05$) from treatments FYM5 and FYM10 which obtained grain yield of 1.2 tons/ha and 2.6 tons/ha, respectively. In site B, treatment FYM15 produced the highest grain yield of 2.7 tons/ha followed by FYM5 and FYM10 with grain yields of 1.9 tons/ha and 2.2 tons/ha, with no significant difference ($p>0.05$) between the treatments except for control treatment. Notably, the grain yield obtained from FYM15 was significantly higher ($P>0.05$) than control treatments, which produced an average of 1.5 tons/ha.

There was no significant difference ($p>0.05$) in grain yield between the two sites in respect to the different treatments applied. The average yields in site A increased by 13.6%, 37% and 32.1% for treatments FYM5, FYM10 and FYM15, respectively, over the control treatment. For site B, the yield increment of 10.3%, 3.6% and 51.7% for FYM5, FYM10, and FYM15, respectively, over the control treatment.

Table 7. Effect of organic amendments and NPK fertilizer of grain yield of rice.

Site	Treatments	N	Panicle number	Panicle length (cm)	Culm length (cm)	1000 gwt (g)	Yield (tons/ha)
A	Control	3	6 ^a	34.4 ^a	58.7 ^a	23 ^a	1.5 ^c
	NPK100	3	6 ^a	34.6 ^a	64.1 ^a	24 ^a	3.1 ^a
	NPK200	3	7 ^a	34.8 ^a	65.6 ^a	23 ^a	3.6 ^a
	NPK300	3	8 ^a	37.1 ^a	71.1 ^a	24 ^a	3.8 ^a
	SWC5	3	6 ^a	35.2 ^a	56.3 ^a	22 ^b	1.4 ^b
	SWC10	3	7 ^a	35.8 ^a	76.6 ^a	24 ^a	2.8 ^b
	SWC15	3	7 ^a	37.8 ^a	81.3 ^a	25 ^a	2.6 ^a
	FYM5	3	8 ^a	20.3 ^b	56.3 ^a	24 ^b	1.2 ^b
	FYM10	3	8 ^a	20.7 ^a	76.0 ^a	24 ^a	2.6 ^a
	FYM15	3	8 ^a	20.9 ^a	81.7 ^a	24 ^a	2.9 ^a
B	Control	3	8 ^a	34.2 ^a	58.7 ^c	23 ^a	1.8 ^c
	NPK100	3	8 ^a	34.6 ^a	65.2 ^b	24 ^a	3.1 ^b
	NPK200	3	9 ^a	34.8 ^a	66.6 ^b	23 ^a	3.6 ^b
	NPK300	3	11 ^b	37.1 ^a	78.6 ^a	24 ^a	4.1 ^a
	SWC5	3	8 ^a	21.6 ^b	51.8 ^b	25 ^a	1.4 ^b
	SWC10	3	7 ^a	20.9 ^b	56.3 ^b	24 ^a	1.4 ^b
	SWC15	3	7 ^a	20.7 ^b	76.0 ^a	24 ^a	2.8 ^a
	FYM5	3	6 ^a	21.6 ^b	51.8 ^b	25 ^a	1.9 ^b
	FYM10	3	8 ^a	20.9 ^b	56.3 ^b	24 ^a	2.2 ^a
	FYM15	3	8 ^a	20.7 ^b	76.0 ^a	24 ^a	2.7 ^a
	LSD (0.05)		NS	NS	NS	NS	

LSD (p<0.05). (NPK0=0kg/ha), (NPK100= 100kg/ha), (NPK200=200kg/ha), (NPK300=300kg/ha).

4.4. Rice yield response to organic and NPK fertilizer application rates

The response of rice to fertilizer treatments was significantly different ($p < 0.05$) for the three fertilizer packages. NPK fertilizer dose of 300 kg/ha gave the highest grain yield of 4.1 tons/ha compared to other application rates. This was followed by solid waste compost SWC10 and farmyard manure (FYM15), which also gave the highest yield of 2.83 tons/ha and 2.9 tons/ha respectively, in their different categories. Generally, grain yield was observed to increase with increasing application rates of different fertilizer packages, but with no significant differences observed between the application rates.

It is evident that, grain yield increased with increasing fertilizer application rates, except for farmyard manure FYM10 which gave higher yield than FYM5 and FYM15. The increase in grain yield as a result of NPK fertilizer application was linear as grain yield increased with increasing application rates of 100, 200 and 300 kg/ha. Solid waste compost grain yield generally increased with increasing application rates, but with SWC10 and SWC15 having almost the same grain yield of 2.8 and 2.6 tons/ha and 2.6 and 2.5 tons/ha for sites A and B, respectively. Comparatively, SWC5 and control treatments had lower grain yield of 1.5 tons/ha and 1.4 tons/ha, and 1.6 and 1.4 tons/ha for sites A and B respectively. While in farmyard manure treatments, grain yield increased with increasing application rates for FYM5, FYM10 and FYM15, but with FYM15 and FYM10 producing highest grain yield at 2.9 and 2.6 tons/ha and 2.7 and 2.4 tons/ha for sites A and B, respectively. Comparatively, yield responses between different treatment categories, NPK fertilizer NPK 300kg/ha produced higher yield of 4.1 tons/ha and 3.8 tons/ha than solid waste compost and farm yard manure. The highest grain yield for solid waste compost and farmyard manure was obtained from treatments SWC10 and FYM15 at 2.8 and 2.5 tons/ha, and 2.7 and 2.4 tons/ha respectively from two seasons (Figure 5 and 6).

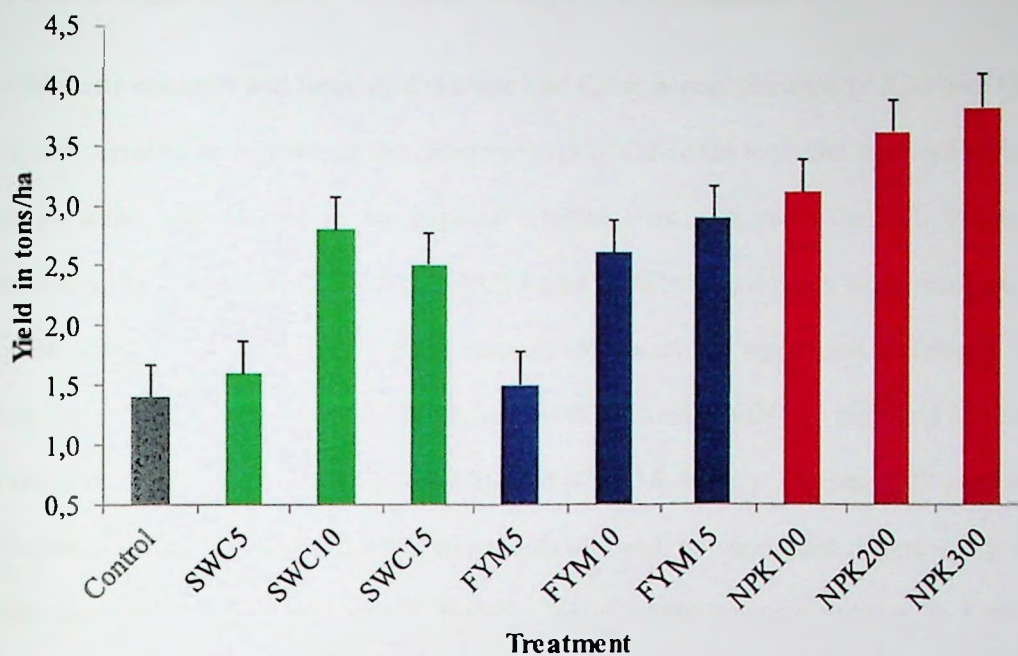


Figure 5. Effect of soil Amendment on yield.

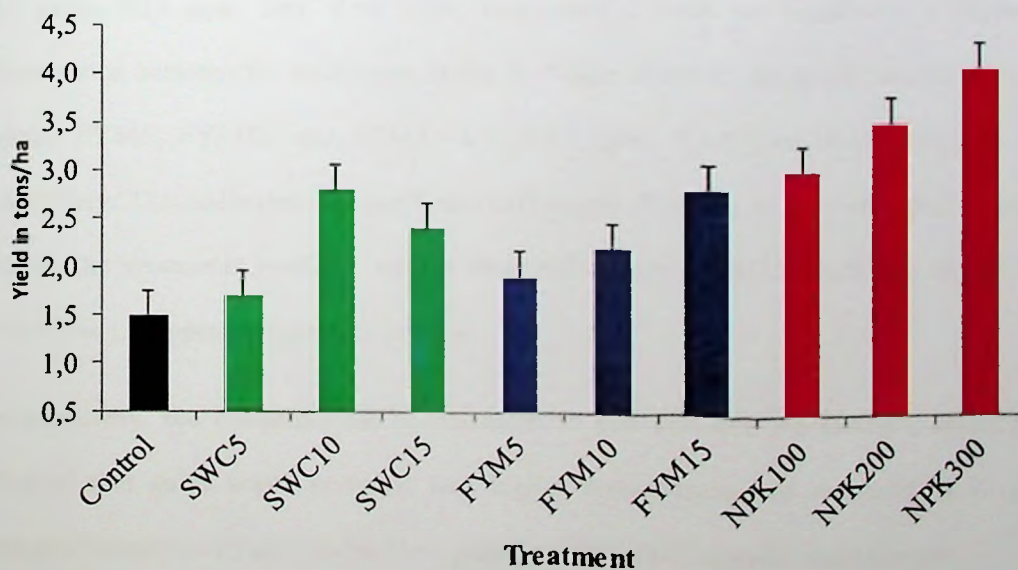


Figure 6. effect of soil amendments on yield

4.5.1 Effect of organic fertilizers on concentration of heavy metals in soil

The solid waste compost and farm yard manure had Cd at a concentration of 2.32 and 1.93 ppm, respectively, causing an increase in the concentration of Cd in the soil after application. Lead and Chromium were, not detected in the organic fertilizers as well as in the soil. In site A, the concentration of Cd in control, SWC5, SWC10 and SWC15 treatments were recorded at 0.10 ppm, 0.28 ppm, 1.14 ppm and 1.77 ppm, respectively, with no significant difference ($p>0.05$) between the treatments control and SWC5, and SWC10 and SWC15. Similarly in site B, the mean concentration of Cd for SWC5, SWC10 and SWC15 were, 0.10 ppm, 0.22 ppm and 0.26 ppm respectively. The control and SWC treatments showed no significant difference ($p>0.05$) in the mean concentration of Cd in site B. Notably, solid waste compost package had the highest mean concentration of 2.32 ppm compared to control and other treatment levels (Figure 9).

The mean concentration of Cd in soil for control, FYM5, FYM10 and FYM15 was 0.01 ppm, 0.10 ppm, 0.15 ppm and, 0.99 ppm, respectively, with no significant difference in the concentration between the treatments in site A. While in site B, the mean concentration of Cd for control, FYM5, FYM10 and FYM15 was 0.01 ppm, 0.15 ppm, 0.67 ppm and 1.13 ppm respectively. This indicated no significant difference ($P>0.05$) in the concentration of cadmium between the treatments in site B, except farmyard manure FYM15 which was significantly high ($P<0.05$) at 1.13 ppm compared to control.

Comparatively, the concentration of cadmium in soil between the different treatment groups indicated that solid waste compost had higher concentration of cadmium (2.32 ppm) than farmyard manure (1.93 ppm) which were used as sources of organic amendments.

4.5.2 Effect of organic fertilizers on concentration of heavy metals in grains

As shown in Figure 8, the mean concentration Cd in grains for solid waste compost for treatments control, SWC5, SWC10 and SWC15 was 0.01 ppm, 0.10 ppm, 0.23 ppm and 0.29 ppm, respectively in site A. This indicated no significantly difference ($P>0.05$) in the mean concentration of Cd between the treatments. In site B, the effect solid waste compost on concentration of Cd was not significantly different ($p>0.05$) for all treatments. Meanwhile, the concentration of Chromium and Lead in grains in the two sites was below detection limits of Atomic Absorption Spectrophotometer (AAS).

The effect of farmyard manure on concentration of Cd in grains for control, FYM5, FYM10 and FYM15 was not significantly different ($p>0.05$) in site A. Similarly, in site B, the concentration of Cd did not show significant difference in the mean concentration of Cd in all the treatments. The results further indicated that, farmyard manure and solid waste (FYM1 and SWC1), the organic fertilizer package which were tested before application, showed higher concentration of Cadmium at 1.93 ppm and 2.23 ppm respectively. Conversely, the concentration of Chromium and Lead was analyzed but their (chromium and lead) in soil and grain samples were below detection limits by the atomic absorption spectrophotometer.

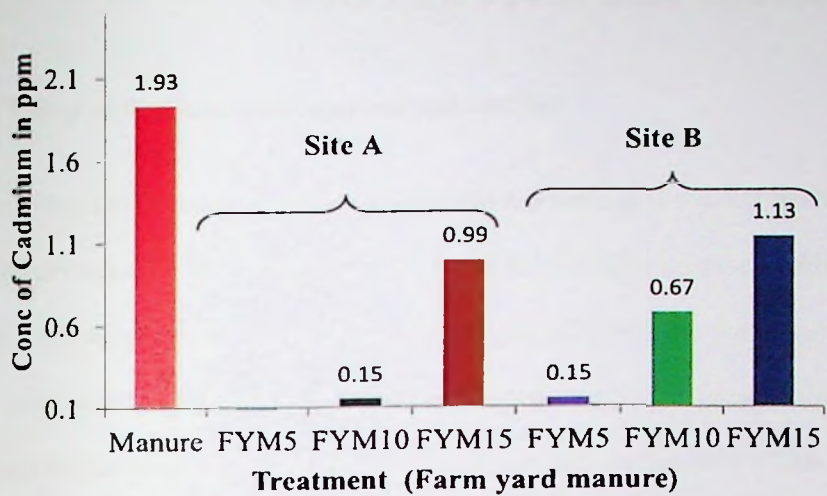


Figure 7. Effect of farmyard manure on conc. of cadmium

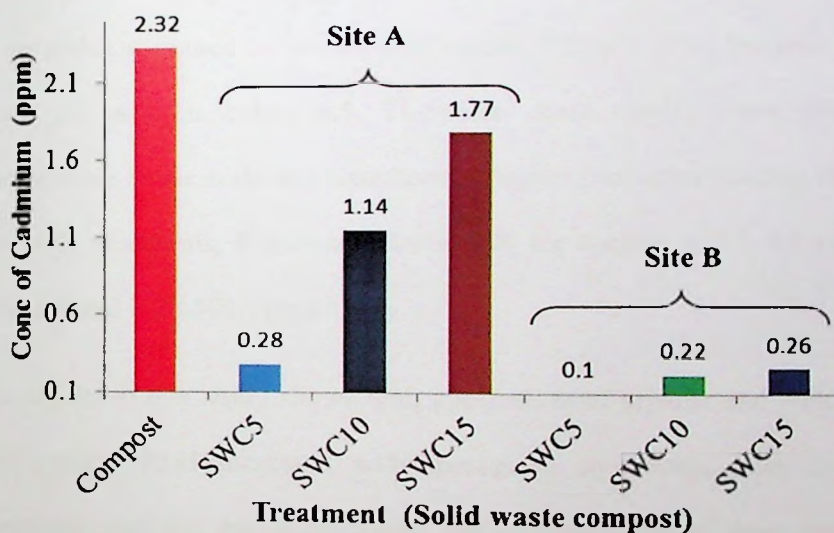


Figure 8. Effect of solid waste compost on conc. of cadmium

CHAPTER FIVE: DISCUSSION

5.1 Effect of fertilizer packages on soil fertility

The initial characteristics of the organic amendments and the soil in site A and B showed that the mean pH values was between 8.3 - 8.7 and 6.1 - 6.3, respectively. Although the soils in the two sites had acceptable pH range for growing upland rice (Ilagan et al., 2014), the higher pH values of solid waste compost and farmyard manure, suggested presence of alkalinity in them. This would in turn reduce the relative acidity of the soils in the field (Whalen et al., 2000). Soil in the study area was slightly acidic, just below the optimal range for phosphorous availability, calcium and Magnesium (Neina, 2019). According to Pierzynski et al. (2005) phosphorous accumulation in the soil is attributed to its immobile nature, ability to resist leaching, and persistence in the soil when pH value is below 6.5. Therefore, these results affirm that, the level of available phosphorous in the soils was significantly higher than other nutrient after crop harvest (Table 3). For NPK treatments, P increased from 2.76 for control to 4.7, 5.3 and 9.67 ppm for NPK100, NPK200 and NPK300, respectively.

The results of this study shows that, application of organic and NPK fertilizers positive effect, soil nutrient level increased with increasing application rates for; nitrogen, phosphorous, potassium, calcium and magnesium. The concentration of these nutrients in the soil slightly decreased after harvesting of rice. This means, the use soil amendment packages to rehabilitate degraded soils in rice field, was important in two folds; firstly, it increased the levels of soil nutrients after application in the respective experimental plots. Secondly, it helped to recapitalize nutrients in the soil. However, the reduction in the levels of essential nutrients (N, P and K) is an indication that some nutrients were utilized by plants and this was translated into increase in

grain yield. This is in agreement with a study conducted by Kaizzi et al. (2018) which reported that application of NPK fertilizer improved soil nutrient status and increased grain yield by 20%.

The level of organic matter before crop establishment reflected the amount of decomposed crop residues from the previous seasons. In addition, site A and B equally received doses of fertilizers in the previous season at a recommended rate of 75 kg/ha of DAP and Urea to enhance soil fertility thus explaining the high level of N, P and K elements in the soil.

The results further showed that soils in the study area contain N, P, K and organic matter after crop harvest, which is attributable to fertilizer packages of solid waste compost and farmyard manure having sufficient level of soil nutrients (nitrogen 0.09 - 0.12%, organic matter 2.0 – 3.87%, and phosphorous 1.77 – 10.3 ppm) and therefore, the nutrients were made readily available for rice plants through the roots (Geng et al., 2019). Application of organic and NPK fertilizer packages had significant effected the levels of total nitrogen and exchangeable potassium, calcium (Ca) and magnesium (Mg) in the soils. The decrease in the level available nitrogen in the soil after crop harvest was higher than other elements (P, K, Ca and Mg) probably because nitrogen is the most limiting nutrient in rice (Saito et al., 2019), and could also be attributed to high demand for nitrogen by the rice plant. Senyonga and umemiya, (2021), reported that nitrogen requirement by rice plant is big, thus deficient symptoms can easily be noticed in the field. The high demand for nitrogen by the rice plant for growth, grain filling and other metabolic processes could also explain the decrease in nitrogen level after crop harvest. The results further showed that fertilizer packages had a positive influence on the soil nutrient content for calcium and magnesium. This may have arisen from the nutrient interaction potassium has on calcium and Magnesium. According to Walsh and O'Donohoe (1945), deficiencies of Ca and Mg affect soil potassium supply for the plants. In this respect, care must be taken when using soil amendment packages with low level of Ca and Mg which may cause

imbalance of potassium amounts in the soil. Therefore, the significant increase in soil nutrient content for N, P and K levels in this study is an indicator of the availability of plant nutrients in solid waste compost, farm yard manure and NPK fertilizer which were applied in the different experimental plots.

Meanwhile, the level of phosphorous remained higher after crop harvest compared to nitrogen, potassium, calcium and magnesium. This is attributed to Phosphorous being very immobile in soil, and its ability to be adsorbed to soil particles. Therefore, the significant effect of fertilizer doses on soil nutrients contents for N, P, K, Ca and Mg after crop harvest is an indication that fertilizer packages had plant nutrients in them, leading to increased grain yields. This is agreement with the hypothesis that increasing doses of NPK fertilizer, solid waste compost and farmyard manure will produce similar increasing effect on soil chemical fertility indicators such as soil pH, OM, N, P, K, Ca and Mg of soil.

5.2 Effect of organic and NPK fertilizer packages on rice grain yield

The application of fertilizer packages had significant effect on rice grain yield. The highest grain yields of 4.1 tons/ha and 3.87 tons/ha were obtained from the treatments where NPK300 was applied. This was followed by SWC10 and FYM15 with grain yield of 2.8 tons/ha and 2.9 tons/ha, respectively. Comparatively, control treatments gave lower grain yield within the ranges of 1.5 – 1.9 tons/ha, suggesting that the increase in grain yield was attributed to application of fertilizer packages. In this case, the rice plant was availed the three essential nutrients (N.P.K) including exchangeable bases (Ca and Mg), which enhanced soil nutrient content and better growth performances for rice crop (Scanchez et al., 1997). Therefore, NPK fertilizer package had significant effect on nutrient level and grain yield (Kaizzi et al., 2014). This result suggests that,

addition of single doses of solid waste compost and farmyard manure in a short term was beneficial in terms increased soil nutrient content and also gave grain yield close to NPK fertilizer which produced the highest grain yield of 4.1 tons/ha. Therefore, the increases in grain yields were attributed to fertilizer application packages (Tsuboi et al., 2018).

5.3.1 Effect of organic fertilizer on concentration of heavy metals in soils

The solid waste compost before application in the field had significantly had higher concentration of Cd at 2.32 ppm compared to other treatment levels. The highest mean concentration of Cd was recorded in treatment SWC15 at 1.77 ppm, followed by SWC10 and SWC5 at 1.43 and 0.28 ppm, respectively. On the other hand, the control treatment had significantly lower mean concentration of Cd at 0.10 ppm, which suggests that Cd was present in the soil at the experimental field. The presence of Cd in the SWC is supported by Kaschl et al. (2002), who reported that the composition of solid wastes used in composting is possibly the major source of heavy metals such as of Cd in the soil. Similarly, Muhammad Shahid et al. (2016), reported that Cd have high phyto-accumulation index because of its low adsorption coefficient and high soil-plant mobility which may enter the food chain. In addition, Cd is not easily metabolized by plants because it is mobile and easily transported in plants through non-specific and specific essential plant nutrients. According to Genchi et al. (2020), heavy metals like Cd accumulate in rice grains and can enter in food chain through contaminated soil, and pose a big threat to soil quality and human health.

The result further indicated that farmyard manure before application in the field had significantly higher concentration of Cadmium at 1.93 ppm. Farmyard manure treatment FYM15 had the highest mean concentration of Cd at 0.99 ppm followed by FYM10 and FYM5 at 0.15 ppm and 0.1, respectively. The control treatment had lower mean concentration of 0.01 ppm. These results

suggest that Cd was present in farmyard manure package. This is in agreement with Penn et al. (2016), reported that Cd may be released into the environment through natural and anthropogenic sources such agrochemical, irrigation water including farm yard manure. This finding is in agreement with a study conducted by Indraratne et al. (2021), who reported that farmyard manure is a possible source of heavy metal (Cd) in the soil. Similarly, studies done by Hammad et al. (2011); Huang et al. (2020) reported that accumulation of Cd in soil increased when animal manure was applied in rice field. Notably, the observed mean concentration of Cd in the study area was below the established recommended limits by codex alimentarius WHO/FAO which is at 0.4 mg/kg, (2015). Conversely, the concentration of Chromium and Lead in the soil samples was below the detection limits of the atomic absorption spectrophotometer.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Grain yield significantly increase with increasing application rates of soil amendments, however there was no significant difference between the treatment levels. The increase in yield was due to soil nutrients which were supplied by addition of soil amendments, and the change in nutrient contents for essential elements in the soil after crop harvest is an indication that because some nutrients were utilized by the rice plant. The residual nutrients that remained in the soil after crop harvest was tested and reported in the results.

The concentration of cadmium in soil increased with increasing organic amendments; however, there was no significant difference in the concentration of cadmium between the different treatments of solid waste co post and farm yard manure. Notably, the increase in the concentration of cadmium could possibly be as a result of the concentration of cadmium which was detected in compost and manure. Although soil and grain samples had cadmium in them, the concentration chromium and lead was below detection level by the atomic absorption spectrophotometer

6.2 Recommendations

Based on the results and the environmental concern, i recommend that NPK fertilizer rate of NPK100 (100 kg/ha), solid waste compost application rate SWC10 (10 tons/ha) and farmyard manure application rate of FYM10 (10 tons/ha) should be used for optimal yield in northern Uganda. The implication is that these fertilizer rates will have a bearing on improved productivity, food security and soil quality with less financial input.

I also recommend that a similar research should be conducted in lowland field in northern Uganda to find out the effect of soil amendments in lowland.

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APPENDICES

Appendix 1: One-way ANOVA: Grain yield response to fertilizer application

Factor Information

Factor	Levels	Values
treatment	12	FYM0, FYM10, FYM15, FYM5, NPK0, NPK100, NPK200, NPK300, SWC0, SWC10, SWC15, SWC5

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
treatment	11	22.9984	2.09076	65.29	0.000
Error	24	0.7685	0.03202		
Total	35	23.7669			

Means

treatment	N	Mean	StDev	95% CI
FYM0	3	1.426	0.221	(1.212, 1.639)
FYM10	3	2.7559	0.1093	(2.5426, 2.9691)
FYM15	3	2.9363	0.0869	(2.7230, 3.1495)
FYM5	3	2.6158	0.1635	(2.4026, 2.8290)
NPK0	3	1.4900	0.0722	(1.2768, 1.7033)
NPK100	3	3.0560	0.1375	(2.8427, 3.2692)
NPK200	3	3.620	0.255	(3.407, 3.833)
NPK300	3	3.7953	0.1595	(3.5821, 4.0085)
SWC0	3	1.456	0.221	(1.243, 1.669)
SWC10	3	2.3761	0.0244	(2.1628, 2.5893)
SWC15	3	2.391	0.309	(2.178, 2.604)
SWC5	3	1.5581	0.1724	(1.3449, 1.7713)

Pooled StDev = 0.178946

Appendix 2: One-way ANOVA: Relationship between culm length and treatments

* NOTE * Cannot draw the interval plot for the Tukey procedure. Interval plots for comparisons are illegible with more than 45 intervals.

Method

Null hypothesis All means are equal
 Alternative hypothesis At least one mean is different
 Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatments	12	FYM0, FYM10, FYM15, FYM5, NPK0, NPK100, NPK200, NPK300, SWC0, SWC10, SWC15, SWC5

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Trteaments	11	432.2	39.30	1.95	0.084
Error	24	484.9	20.20		
Total	35	917.1			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.49472	47.13%	22.90%	0.00%

Means

Trteaments	N	Mean	StDev	95% CI
FYM0	3	61.13	6.31	(55.78, 66.49)
FYM10	3	64.53	4.96	(59.18, 69.89)
FYM15	3	68.800	0.500	(63.444, 74.156)
FYM5	3	63.63	4.85	(58.28, 68.99)
NPK0	3	58.70	3.75	(53.34, 64.06)
NPK100	3	64.07	4.00	(58.71, 69.42)
NPK200	3	65.63	5.14	(60.28, 70.99)
NPK300	3	71.07	4.96	(65.71, 76.42)
SWC0	3	58.80	5.13	(53.44, 64.16)
SWC10	3	62.27	1.95	(56.91, 67.62)
SWC15	3	63.03	3.10	(57.68, 68.39)
SWC5	3	62.63	5.78	(57.28, 67.99)

Pooled StDev = 4.49472

Appendix 3: One-way ANOVA: Relationship between panicle length and treatments

* NOTE * Cannot draw the interval plot for the Tukey procedure. Interval plots for comparisons are illegible with more than 45 intervals.

Method

Null hypothesis All means are equal
 Alternative hypothesis At least one mean is different
 Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Trteaments	12	FYM0, FYM10, FYM15, FYM5, NPK0, NPK100, NPK200, NPK300, SWC0, SWC10, SWC15, SWC5

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Trteaments	11	57.5	5.231	0.01	1.000
Error	24	14916.6	621.525		
Total	35	14974.1			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
24.9304	0.38%	0.00%	0.00%

Means

Trteaments	N	Mean	StDev	95% CI
FYM0	3	37.3	26.9	(7.6, 67.0)
FYM10	3	37.0	27.7	(7.3, 66.7)
FYM15	3	38.3	26.4	(8.6, 68.0)
FYM5	3	37.4	27.5	(7.7, 67.1)
NPK0	3	34.8	23.0	(5.1, 64.5)
NPK100	3	34.6	21.6	(4.9, 64.3)
NPK200	3	34.4	21.9	(4.7, 64.1)
NPK300	3	37.1	24.5	(7.4, 66.8)
SWC0	3	36.3	24.6	(6.6, 66.0)
SWC10	3	35.8	22.9	(6.1, 65.5)
SWC15	3	35.2	23.5	(5.5, 64.9)
SWC5	3	37.7	27.3	(8.0, 67.4)

Pooled StDev = 24.9304

Appendix 4: One-way ANOVA: Relationship between panicle number and treatments

* NOTE * Cannot draw the interval plot for the Tukey procedure. Interval plots for comparisons are illegible with more than 45 intervals.

Method

Null hypothesis All means are equal
 Alternative hypothesis At least one mean is different
 Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Trteaments	12	FYM0, FYM10, FYM15, FYM5, NPK0, NPK100, NPK200, NPK300, SWC0, SWC10, SWC15, SWC5

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Trteaments	11	42.13	3.830	3.40	0.006
Error	24	27.05	1.127		
Total	35	69.19			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.06171	60.90%	42.98%	12.02%

Means

Trteaments	N	Mean	StDev	95% CI
FYM0	3	5.967	0.404	(4.702, 7.232)
FYM10	3	7.533	1.193	(6.268, 8.798)
FYM15	3	8.000	1.153	(6.735, 9.265)
FYM5	3	8.467	0.351	(7.202, 9.732)
NPK0	3	7.667	0.651	(6.402, 8.932)
NPK100	3	8.733	1.060	(7.468, 9.998)
NPK200	3	8.900	1.386	(7.635, 10.165)

NPK300	3	10.633	1.301	(9.368, 11.898)
SWC0	3	7.667	1.464	(6.402, 8.932)
SWC10	3	7.433	0.208	(6.168, 8.698)
SWC15	3	7.900	0.265	(6.635, 9.165)
SWC5	3	7.20	1.75	(5.93, 8.47)

Pooled StDev = 1.06171

Appendix 5: One-way ANOVA: Effect of organic fertilizer on concentration of Cadmium in soil

Method

Null hypothesis All means are equal
 Alternative hypothesis At least one mean is different
 Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Treatment	8	FYM0, FYM10, FYM15, FYM5, SWC0, SWC10, SWC15, SWC5

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	7	0.07308	0.01044	0.37	0.905
Error	16	0.44810	0.02801		
Total	23	0.52118			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.167351	14.02%	0.00%	0.00%

Means

Treatment	N	Mean	StDev	95% CI
FYM0	3	0.0928	0.0300	(-0.1120, 0.2977)
FYM10	3	0.200	0.267	(-0.005, 0.404)
FYM15	3	0.099	0.328	(-0.106, 0.303)
FYM5	3	0.1079	0.1037	(-0.0969, 0.3127)
SWC0	3	0.2455	0.0454	(0.0407, 0.4503)
SWC10	3	0.0753	0.1363	(-0.1295, 0.2802)
SWC15	3	0.1372	0.0978	(-0.0677, 0.3420)
SWC5	3	0.1627	0.0594	(-0.0422, 0.3675)

Pooled StDev = 0.167351

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping
SWC0	3	0.2455	A
FYM10	3	0.200	A
SWC5	3	0.1627	A
SWC15	3	0.1372	A
FYM5	3	0.1079	A

FYM15	3	0.099	A
FYM0	3	0.0928	A
SWC10	3	0.0753	A

Means that do not share a letter are significantly different.

Appendix 8: Yield and yield components data sheet

MSc. Experiment Yield component data sheet version 3.0

Trial:	Season:				Recorder:					
DATE	Block ID		Plot No.		Treatment			Month:		
Culm length	1	2	3	4	5	6	7	8	9	10
Panicle length	1	2	3	4	5	6	7	8	9	10
Tiller number	1	2	3	4	5	6	7	8	9	10

Spacing 30 x 12.5

No. of sample 40 hills

Total full grain Wt g

Full grain No/5g ① ② ③ Average

M.C ① ② ③ Average

1000 grain wt g

Yield g/m²

Appendix 10. NERICA4 at active tillering and flowering stage



Appendix 11. COVID-19 risk management plan

Measures for the Prevention and control of risk of spread of COVID-19 during the implementation of research

Version 3.0

RESEARCH STUDY TITLE:

Effect of organic manure sources and NPK fertilizer on the soil nutrient status, soil-plant heavy metal concentrations and yield of upland rice in northern Uganda

Investigator(s):

Name	Institution	Position	Project role	Tel.
Mr. Ogwal Lawrence	Gulu University	Student	Researcher	0772476938

Introduction:

The novel Coronavirus is transmitted from human to human through droplets and direct or close personal contact with an infected individual. Novel Coronavirus signs of infection include respiratory symptoms, fever, cough, shortness of breath and breathing difficulties. In more severe cases, infection can cause pneumonia, severe acute respiratory syndrome, kidney failure and even death

Prevention and control measures of COVID-19

During the implementation of the research activities, I will be committed to ensuring the safety of research participants and communities where the study will be conducted. The study team by all means will observe the Standard Operating Procedures issued by the Ministry of Health, and presidential directives to prevent and control the risk of spreading COVID-19 that may occur in the process of carrying out the study. This will be achieved through: Wearing face mask, physical distancing (At least 2 meters from one another), use of hand sanitizer, regular washing hands, avoid unnecessary touching of face, eyes and nose, personal screening and use of temperature guns

Procedures to be followed during the implementation of SOP prior to execution of field or laboratory activities

1. **Health guidance:**

There will be training sessions dedicated for COVID-19 sensitization and awareness, to equip the research team with knowledge of signs and symptoms of the COVID-19, and preventive measures as mentioned above.

2. **Personal Screening:**

All research assistants, research participants and any other individuals who will be engaged in research activities will have his/her body temperature checked daily for fever. Screening for temperature will be carried out before the start of any field activity. Any individual found with COVID-19 symptoms will be withdrawn and referred to the COVID-19 district task force or any nearby health facility for further assessment and management. The withdrawn individual will be allowed to return only if they present a valid certification of their COVID-19 status showing negative result or vaccination card.

3. **Wearing face coverings:**

All research assistants and any other individuals engaged in research activities that require interaction with research participants or members of the community will have to wear a face mask that fully covers the mouth and nose at all times. The study will provide face masks for individuals who do not have.

1. **Physical Distancing:**

All research Assistants and any other individual who will be engaged in any research activities will be required to keep a social distancing of at minimum of 2 meters. During breaks, the team will not be allowed to congregate in common areas and hand shaking will be prohibited.

2. **Good hygiene:**

All team members will be required to wash their hands or use hand sanitizers before and after entering the training room, and other common areas. Hand washing equipment shall be provided and made available at all times. All surfaces and equipment shall be sanitised frequently.

During implementation of field activities

1. **Personal Protective Equipment (PPE):**

All research assistants involved in data collecting, establishment and management of the experiment will use PPE including a properly fitted face mask. Research participants will wash hands with soap and water or use hand sanitizer prior to the start of any research activities interview. Handshakes and hugging are prohibited. Physical distancing of at least 2 metres in all research related activities shall be observed.

2. **Consent Process:**

The researcher and research assistants will observe social distancing when taking consent upon arrival and meeting other research participants. Enumerators/Researchers and research participants will wash hands with soap and water or use hand sanitizer prior to the interview. Participant will then be sensitized on covid-19 and presented with preventive measures.

3. **Equipment sanitization:**

Shared devices or equipment used to measure or record data will be sanitized regularly.

During Dissemination/Community engagement

1. **Community Engagement:** The research team shall carry educational materials on prevention of COVID-19 in a language understood by the participants. These materials shall also have visual images to support understanding. Researcher assistants and any other research participants will wash hands with soap and water or use hand sanitizer prior to the meeting or start of any field activity. Screening for temperature will be carried out prior to conducting community engagements.

4. **Equipment sanitization:** shared devices of equipment used during community engagements to shall be sanitized regularly.

Name OLIVIA S. SAM Signature/thumbprint of participant [Signature] Date 26/02/2021

Name AMUCHE HARRIET Signature of witness [Signature] Date 30/03/2021

Name Daniel Lawrence Signature of interviewer [Signature] Date 30/03/2021

Appendix 12. Informed consent form

Gulu University

Informed consent version 3.0

Title of the study:

Effect of organic manure and NPK fertilizer on soil-plant heavy metal concentration and yield of upland rice in northern Uganda.

Name	Institution	Position	Project role	Tel.
Dr. Obia Alfred	Gulu University	Lecturer	Supervisor	0771421124
Mr. Otim Fred	Gulu University	Lecturer	Supervisor	0773176289
Mr. Ogwal Lawrence	Gulu University	Student	Researcher	0772476938

Investigator(s):

Institution:

Gulu University
Faculty of Agriculture and Environment
P.O.BOX 166, Gulu City

Introduction

My name is **Lawrence Ogwal**, i am a student of Gulu University carrying out a study at NARO-Ngetta ZARDI under the research topic "Evaluating the effect of organic manure and NPK fertilizer on soil-plant heavy metals concentration and yield of upland rice in northern Uganda" for a Master of Science in environmental science and natural resources management of Gulu University. The ultimate aim is to study the effects of organic manure in comparison with inorganic fertilizers for safe production and grain quality of upland rice under rain-fed condition. Your honest participation in this study will only be used to inform Gulu University for purposes of the study and information obtained will therefore be treated with utmost confidentiality. Your participation is highly valued. You are free to ask me questions about this assessment or study, and you have decided to participate in the study, you will be asked to sign consent form and which you will be given a copy to keep.

Sponsor of the research project

The study is a self /privately sponsored academic research project under supervision and technical guidance of Gulu University.

Purpose:

The study seeks to investigate the effects of organic manure and NPK fertilizer on soil-plant heavy metal concentration and yield of upland rice in northern Uganda. The findings of this study will provide

additional information on use of organic fertilizer as an alternative source of plant nutrients for increased upland rice yield. The information will also help students and other researchers of Gulu University or other universities for further studies in the field of soil science and solid waste management.

The specific objectives of this study are:

1. To examine the effects of municipal solid waste compost and farm yard manure in comparison to inorganic fertilizer on soil chemical and physical properties such as pH, organic carbon (OC), cation exchange capacity (CEC) , and nutrient (Nitrogen , phosphorous and potassium (NPK) content.
2. To determine the effects of municipal solid waste compost and farm yard manure in comparison to inorganic fertilizer on growth and yield of upland rice.
3. To establish the effects of municipal solid compost and farm yard manure in comparison to inorganic fertilizer on heavy metals accumulation in grains of upland rice.

Procedures:

Who will participate in the study?

You have been chosen to participate in this study because of your vast knowledge and skills in the activities you will be involved in during the study. The experiment/study will last for four months and four people will actively participate in the various activities of the study from land preparation to harvesting/yield survey.

Risks/discomforts:

Under normal circumstances you will participate in the study with no foreseeable risk of harm or discomfort that will arise from your participation in this study. However, in the events of drought, weed and pest invasion, you will be expected to operate irrigation water pumps, carry hose pipes, handle agricultural chemicals and work over time. This may expose you to risks or discomfort but you will have the instructors to guide and advise you on what to do in the field.

Benefits:

All participants who will be involved in the various activities will be paid amount commensurate to the work done upon completion of the work. You will be expected to acknowledge receipt of the payment by the responsible person who assigned you work on daily /weekly /monthly basis.

As a participant, you will get feedback on findings and progress of the study and any new information (whether incidental) that will directly or indirectly affect you during or after the study.

Confidentiality:

Your identity will not be revealed to any one as we shall only use codes to identify participants. Information obtained will only be accessible by the research team. Soft copies of the data will be protected by password and hard copy files will be kept under lock and key. Confidential information will only be accessed by the principal investigator.

Alternatives:

You do not have to participate in this study if you are not interested. You will not lose any benefit in case of no participation.

Cost:

There will not be any additional cost incurred as a result of participating in this study.

Questions:

In case you have any questions related to the study as a research participant, you can contact the principal investigator, Mr. Ogwal Lawrence on telephone number 0772476938/0773195923 or via email on lawrenceogwal@yahoo.com

Statement of voluntariness:

Participation in the research study is voluntary and you may join on your own free will. You have a right to withdraw from the study at any time without penalty.

If you have any issues pertaining to your rights and participation in the study, please contact the Chairperson, Gulu University Research Ethics Committee, Dr. Gerald Obai Tel: No., 0772305621; email: lekobai@yahoo.com/lekobai@gmail.com; or the Uganda National Council for Science and Technology, on plot 6 Kinera road, Ntinda, Kampala on Tel 0414705500.

Statement of consent

Mr. Ogwal Lawrence has described to me what is going to be done, the risks, the benefits involved and my rights as a participant in this study. I understand that my decision to participate in this study will not affect me in any way. In the use of this information, my identity will be concealed. I am aware that I may withdraw at any time. I understand that by signing this form, I do not waive any of my legal rights but merely indicate that I have been informed about the research study in which I am voluntarily agreeing to participate. A copy of this form will be provided to me.

Name OGWAL LAWRENCE SAM Signature/thumbprint of participant [Signature] Date 30/05/2021

Name AMUGU HARVEY Signature of witness [Signature] Date 30/05/2021

Name Ogwal Lawrence Signature of interviewer [Signature] Date 30th/5/2021