TILLAGE EFFECTS ON SELECTED SOIL PROPERTIES AND RAINFED MAIZE GROWTH IN UPPER KABETE CAMPUS, UNIVERSITY OF NAIROBI, KENYA

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DECLARATION

I, Tabitha Nekesa Wanyonyi, hereby declare that this research thesis is my original work and has not been submitted for project research and award of a degree in any other university.

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DEDICATION

I dedicate this thesis to my husband, Tonny, and mother, Miriam, for their love and support.

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LIST OF ACRONYMS AND ABBREVIATIONS

AGB	Above Ground Biomass
ANOVA	Analysis of Variance
ASAL	Arid and Semi-arid Land
BCR	Benefit Cost Ratio
BD	Bulk Density
CAN	Calcium Ammonium Nitrate
CBA	Cost Benefit Analysis
CEC	Cation Exchange Capacity
CNT	Conventional Tillage
CT	Conservation Tillage
DAP	Di-ammonium Phosphate
DWS	Sample Dry Weight
DWSS	Sub-sample Dry Weight
FWS	Sample Fresh Weight
FWSS	Sub-sample Fresh Weight
GAP	Good Agricultural Practice
GB	Gross Benefit
GSA	Geological Society of America
GY	Grain Yield
HH	Hand Hoe
JP	Jab Planter
LA	Leaf Area
LAI	Leaf Area Index
LR	Long Rains
MB	Marginal Benefit
MC	Marginal Cost
MRR	Marginal Rate of Return
MT	Minimum Tillage
NB	Net Benefit
NT	No-Tillage
OM	Organic Matter
OC	Organic Carbon
PD	Particle Density
SOM	Soil Organic Matter
SSR	Soil Surface Roughness
TDW	Standing Biomass
TC	Total Cost
TVC	Total Variable Cost

RCBD	Randomized Complete Block Design
WAE	Weeks after Emergence
WAP	Weeks after Planting
WRB	World Reference Base
ZT	Zero Tillage

GENERAL ABSTRACT

There is a major decline in maize production in Kenya, and this is a serious threat to the national food security reserve; thus, the need for sustainable production approaches Enhancing maize production under rain-fed conditions in arid and semi-arid lands (ASALs) requires efficient tillage and cultivation methods that enable efficient utilization of nutrients and water, as well as conservation of natural resources. Hence this study which was undertaken in the experimental field of Upper Kabete Campus, University of Nairobi for two rainy seasons (long and short rains) aimed to evaluate the effect of different tillage methods on the selected soil properties, maize growth, and yields, as well as to determine the cost-benefit analysis of maize production under selected tillage methods. The soils of the study site were Humic Nitisols. The trial was established on a Randomized Complete Block Design (RCBD) with four replicates that acted as the blocking factor and four treatments comprising Disc Ploughing and Harrowing (DPH), Ripping (R), Jab Planter (JP), and Hand Hoe (HH). Biased randomization of the treatments was done to minimize compaction by tractor wheels under DPH and R during land preparation. The study established variations in the influence of the tillage method on crop and soil parameters according to soil depth, and time as the seasons progressed. Results showed that tillage had a significant ($p < 0.05$) influence on soil moisture, soil nitrogen, and grain yields during both seasons. Tillage and time of measurement significantly influenced soil moisture during both seasons (<0.001). Ripping recorded the highest moisture values (%) with means of 46.91 and 41.59, with the lowest values under HH (29.55) and DPH (26.95) for the consecutive seasons, respectively. Soil surface roughness (SSR) was significantly affected by tillage during the short rains only with average values (%) of HH (3.11), DPH (2.96), R (2.13), and JP (1.68). In the first season, DPH (2.83) had the highest value while JP (1.5) had the least surface roughness. The trends in crust strength (0-10 cm) were consistent between both seasons, with values ranging from 0.5 to 2.8 MPa. Significant effects of tillage and time of measurement on bulk density were observed during the short rains only, however, JP exhibited the highest bulk densities (Mg m^{-3}) for both seasons with average values of 1.04 and 1.11, respectively. An inverse relationship was observed between bulk density and porosity (%), R (63.29) and DPH (63.45) had the highest total porosity values during long and short rains, respectively. Tillage had no significant effect on saturated hydraulic conductivity which ranged from 3.7 cm/hr to 35 cm/hr for the seasons. Tillage significantly contributed to nitrogen

(%) and ripping recorded the highest values during long (0.55) and short (0.56) rains. During both seasons, tillage had insignificant impacts on maize height, leaf area, leaf area index, and biomass yields; while time of measurement had substantial influence on the parameters. Tillage significantly contributed to grain yields during long ($P<0.0284$) and short ($P < 0.01$) rains. The average trend of yield (Mg/ha) during long rains was R (5.69)> DPH (5.32)> JP (4.19) > HH (3.96), while the trend during short rains was R (12.73)> DPH (10.04)> HH (9.78)> JP (8.73). Considering the costs of production and market prices during production and at harvest, financial analysis through partial and marginal analyses indicated a 3302% marginal rate of return (MRR) of adopting R over DPH and, 2577% DPH over JP during long rains. In the short rains, adopting R over DPH yielded an MRR of 24828% while 1077% in the case of DPH over HH. Ripping as a form of conservation tillage accrued the most positive effects on soil properties ultimately improving maize grain and is more economically viable. This study recommends ripping for soil conservation, improved yields, and increased income for farmers in Kabete. Additionally, long-term studies are recommended for a better conception of the effects of tillage on soil properties and crop productivity according to regional and site-specific characteristics.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Maize (*Zea mays* L.) is a staple food and the most cereal crop in terms of production, consumption, and economic value in Kenya with an estimated capital consumption of 98kg per year (Kang'ethe *et al.*, 2020) and it has grown to be the most important crop in the Kenyan Strategic food reserve. In Africa, its production is estimated to be covering 40 million hectares which comprises smallholder farmers producing 81 million tons annually (FAOSTAT, 2019). This crop in Kenya is not only a great contributor to food security and nutrition, but it is also a source of employment and income generation for subsistence farmers that account for almost 70% of the country's production (Njeru *et al.*, 2022). According to FAOSTAT (2019), Kenya produces about 3.897 million tons of maize annually with more than 2.196 million hectares of arable land within all six agroecological zones in Kenya. Maize production in Kenya contributes up to 3% of the total agricultural gross domestic product after the horticultural products (Kang'ethe *et al.*, 2020). It accounts for 20% of total agricultural production and 25% of employment (Marenya *et al.*, 2022). Thus, efforts have been put in place to promote productivity by enhancing technologies such as the use of inorganic fertilizers and improved seeds.

Production of maize in Kenya is mainly done by small-scale farmers under rain-fed conditions, accounting for more than 75% of the maize area (Tarus, 2019). However, small-scale farmers produce maize under difficult conditions (poor soils, low-yielding seeds, information, and technological constraints as well as variation in environmental and climatic conditions) leading to low productivity. Thus, over the years, demand has exceeded supply due to deficits in production (Tarus, 2019). This has led to dependence on imported maize, most of which has been under scrutiny due to poor quality status or controversies in importation processes. The decline in maize production has been a challenge in Kenya and this needs to be addressed since it has caused a significant threat to the national food reserve and trade at large (Kang'ethe *et al.*, 2020). Under good agronomical practices, maize production can attain a yield of up to 6t/ha, but in 2019 a yield of 1.77t/ha was attained (Njeru *et al.*, 2022) which was far lower than the potential. The declining rate of maize production can be attributed to the unfavourable climatic conditions with prolonged drought periods (Munyao *et al.*, 2019), pests and diseases (Muitire *et al.*, 2021), poor agronomic practices, high cost of inputs required during cultivation, and postharvest losses and limited access to improved varieties.

The productivity and performance of crops are affected by tillage (Khan, 2019). Crop yields are influenced by technological innovations and agronomic and management practices. The use of farm machinery leads to soil inversion. Continual soil inversion, a characteristic of conventional tillage methods, leads to the degradation of soil structure, which then decreases available soil water, and ultimately the growth and yields of crops are affected (Castellini & Ventrella, 2012). As such, there is a need to enhance crop productivity without destroying soil health. This could be achieved by adopting conservation tillage (CT) which reduces soil inversion, conserves soil moisture, and minimizes soil organic matter (SOM) loss (Bista *et al.*, 2017). It has been reported that CT practices contribute to improved soil quality through increased SOM and improved soil structure, porosity, and tilt, as well as improved water and air quality and availability, and reduced nutrient losses (Bergtold *et al.*, 2020). Compared to conventional tillage, conservation tillage methods significantly increase soil quality (Chen *et al.*, 2020) by enhancing the soil's overall biomass, which includes microbial and fungal biomass, and also increasing overall C and N contents.

Soil tillage is among the variables that alter soil properties physically, chemically, and biologically (Alam *et al.*, 2014; Khurshid *et al.*, 2006). It contributes to crop yields and has a direct effect on the sustainable use of soil as a natural resource. Conventional tillage has been associated with changing the soil bulk density which consequently affects the soil moisture content (Alam *et al.*, 2014; Miriti et al., 2013). This is supported by Mutonga *et al.* (2019) who showed that under zero tillage, the higher moisture content resulted in higher grain yield. Tillage operations and systems have been reported to play a critical role in soil microstructure features such as water thermal properties and soil nutrients (Liu *et al.*, 2021). Intensive and conventional tillage systems can make the soil bare, predisposing such soils to degradation by facilitating the driving forces of soil erosion, hence affecting the soil profile and structure.

The effects of tillage on the soil properties can vary from beneficial to detrimental depending on the tillage method being used and the frequency of tillage, soil type,jopihy97ghg and other management practices (Liu *et al.*, 2021). Soil structure can be improved by tillage, on the other hand, excessive tillage is detrimental to the structure of the soil and leads to soil degradation. Adoption of CT leads to minimum disturbance of the soil and maintains soil cover which can help to reduce the impacts of tillage operations on the soil properties, ultimately leading to improved crop yields. Hence, the objective of this study was to observe the effect of different tillage methods on selected soil properties and maize growth under rainfed conditions in Kabete, Kenya.

1.2 Statement of the problem

Agricultural productivity in Kenya has been affected by diverse factors including soil fertility, land degradation, population, land pressure, credit access, market limitations, and climate change (Birch, 2018). Production of maize has been fluctuating with demand surpassing domestic production affecting food security and community livelihoods. The low productivity of maize in Kenya, particularly in smallholder systems, is attributed to drought, striga, fall armyworm, and low soil fertility (Marenya *et al*., 2022). Smallholder farmers are limited by the costs of fertilizer and land preparation, land tenure, poor soils, and climate variability. Suboptimal agronomic practices result in low maize productivity in the country (Kipkulei *et al*., 2022).

Certainly, agronomic practices are key factors in crop production, particularly, tillage, which modifies the soil's physical, chemical, and biological properties that in turn affect crop growth and yields. Most farmers have stuck to the traditional farming systems with little consideration for the aftermath. Smallholder maize farms in Kabete Sub-County are characterized by intensive soil use (Templer *et al*., 2017), a phenomenon typical in conventional tillage systems. The aftermath is soil degradation (Zhang *et al*., 2023) leading to poor soil quality and reduced crop yields. Adoption of sustainable land management practices in Kenya is low (Birch, 2018); technologies such as minimum tillage and cover crops have not been largely embraced by farmers. Inefficient tillage and cultivation thus have greatly contributed to a decline in maize yields.

It is worth noting that rain-fed agriculture is still a widespread method of maize production in Kabete as it is all over the country. Though strides have been made toward the promotion of irrigation in the country with the help of government and non-profit organizations, it is still a challenge for most small-scale farmers in Kabete and other parts of the nation. As such, maize production is left at the mercy of the climate. Unfortunately, climate change has resulted in remarkable impacts on agricultural production. One of these impacts is the change in rainfall patterns. Farmers in Kabete suffer from these shifts because the rains are not reliable. Therefore, to ensure consistent agricultural production, efficient tillage methods need to be promoted. While studies have evaluated the effects of tillage on soil properties and crop growth and yield parameters, regional and site-specific characteristics ought to be taken into consideration. An assessment of the effects that different tillage methods will have on the soil and maize production under rainfed conditions in Kabete is what influenced this study.

1.3 Justification

Agriculture has long been the backbone of the Kenyan economy, with maize being a particularly significant crop. Maize production accounts for approximately 14% of household income (Tarus, 2019), and over 3 million smallholder farmers are involved in its cultivation (FAOSTAT, 2019). As a staple food, maize contributes to about 65% of daily per capita cereal consumption in Kenya (KALRO, 2021). This crop is paramount for ensuring food and nutrition security, supporting household socio-economic welfare, and promoting the overall economic development of the country. However, concerns about the crop's reduction in productivity are alarming. Kabete Sub-County has been counting losses in maize yields over the years and this failure is attributed to inefficient tillage and cultivation methods amongst other factors (MoALFC, 2021).

Improvement in maize staple production assures improvement in the food security status, human health, and community livelihoods. Adopting sustainable tillage methods offers a remedy. Conventional tillage methods can lead to soil degradation, which adversely affects soil health and productivity in the long term. Sustainable tillage methods, such as conservation tillage, can help promote healthy soils by minimizing soil erosion, boosting soil organic matter, and enhancing soil structure, which in turn, lead to increased yields and improved soil health over time.

Sustainable tillage methods can also help mitigate the negative effects of climate change on agriculture. Climate change has resulted in changes in rainfall patterns and magnified the frequency and intensity of severe weather events, such as droughts and floods, which have significant impacts on crop production. Sustainable tillage methods including conservation tillage help to retain soil moisture, reduce water runoff, and enhance soil infiltration. These are beneficial for production as they boost drought tolerance and reduce the risk of soil erosion during heavy rainfall.

Lastly, adopting sustainable tillage methods can reduce input costs for farmers by decreasing the amount of tillage, fuel, and labour required. Conservation tillage methods can also reduce soil compaction thereby reducing the need for additional tillage or subsoiling to alleviate compaction, which can help farmers save on equipment and fuel costs.

Smallholder maize production in Kabete Sub-County and Kenya at large is at the mercy of rainfall. The farming systems are highly vulnerable to fluctuations in rainfall patterns and climate change. Inefficient tillage exacerbates these problems, consequently resulting in soil degradation and decreased yields. By investigating the relationship between tillage methods and maize production, this research study aimed to provide valuable information that can be used to develop more effective and sustainable tillage methods for maize production and contribute to the development of more sustainable agricultural systems for the benefit of smallholder farmers and research community. Adopting sustainable tillage methods aligns with several sustainable development goals (SDGs), including SDGs 1, 2, 3, 6, 8, 13, and 15 as recorded by United Nations (2023). An understanding of the influence of tillage practices on maize growth and yields and its effects on selected soil properties under rainfed conditions underpins this study.

1.4 Objectives

1.4.1 Broad Objective

To determine the effects of tillage methods on maize growth, yields and on selected soil properties under rain-fed conditions in Kabete Sub-County.

1.4.2 Specific objectives

a) To evaluate the effect of different tillage methods on selected soil properties under rainfed conditions.

b) To determine the effect of the different tillage methods on maize growth and yields under rainfed conditions.
c) To analyse the cost-benefit analysis of maize production under different tillage methods under rainfed conditions.

1.5 Research questions

a) How do different tillage methods under rainfed conditions affect soil properties such as nitrogen status, soil water content, bulk density, crust strength, and hydraulic properties?

b) In what ways do tillage methods impact maize productivity under rainfed conditions, considering variations in nitrogen levels, soil water content, bulk density, crust strength, and hydraulic properties?

c) What financial benefits can be attributed to different tillage methods under rainfed conditions regarding maize plant growth**?**

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Maize is a top crop of choice for the majority of smallholder farmers in Kenya, with about 98% of the 3.5 million smallholder farmers involved in its production (Mang'eni, 2022). It is the mainstay for the majority of the country's rural population and is consumed by 85% of the total population in various forms (Marenya *et al*., 2022). In the early years after Kenya's independence the country was self-reliant in maize production and would export as a result of production exceeding demand. This state was however inverted in the early 1980s with rapid population increase amongst other factors. Over the years, Kenya has been experiencing a decline in maize production with recurring deficits. As a result, the country often relies on imported maize to bridge the gap in production (Mang'eni, 2022; Marenya *et al*., 2022). There is a need to grow maize due to the high demand by consumers throughout the year. The Economic Survey (2017) indicates that Kenyans consumed over 2.4 million bags of maize monthly in 2016. However, maize production does not balance with the local demand. Kenya imported 519,611.3 tonnes of maize between January and September, the highest quantity ever since 2017.

Maize remains paramount for food security, employment, and income generation in Kenya. KIPPRA (2023) notes that by 2025 maize demand is expected to reach 60 (90 Kg) million bags. (Mang'eni, 2022) and Marenya *et al*., (2022) note that the country's deficits in maize are attributed to low productivity compared to population growth. Maize growth productivity has stagnated at 2% over the years while population growth stands at 3% (Mang'eni, 2022). The crop's production has faced numerous fluctuations leading to low productivity. Some factors include high fertilizers costs which have led to low usage per crop, which amounts to lower yields (Otieno *et al*., 2021; Spencer, 2022), fall armyworm infestations (De Groote *et al*., 2020) and soil and water management factors (Munialo *et al*., 2019). Soil and water management is important for improving agricultural productivity by building soil health, ensuring water availability, and management of pests and diseases. Some management measures include tillage, irrigation, fertilization, cover cropping and crop rotation. Certainly, tillage is at the core of soil and water management having direct impacts on the natural resources, making it critical for crop production.

2.2 Soil tillage

Soil tillage involves mechanical actions that are done on the soil to alter soil conditions to facilitate the growth of crops (Busari *et al*., 2015; Stewart, 2022). The mechanical actions ensure optimal conditions for the germination of seeds, growth and development of healthy root systems, stifle weeds, maintain soil moisture, and restrain soil erosion (Birkas *et al*., 2014). Tillage modifies soil properties having direct effects on crop production through changes in water retention, infiltration, storage, evapotranspiration, aeration as well as microbial activity amongst other processes. As a crop production factor tillage accounts for up to 20% (Alam *et al*., 2014; Khurshid *et al*., 2006) and affects natural resource conservation having direct effects on soil properties.

Conventional tillage is the most common tillage method in Kenya’s arid and semi-arid lands (ASALs) which cover over 80% of the total land area. While the method enhances relatively uniform seedbed creation and weed control, it is associated with soil erosion, loss of soil structure, and decreased soil health in the long term. Conversely, conservation tillage has the possibility of halting and reversing the negative effects of conventional tillage. However, the adoption of conservation tillage is low in Kenya and needs substantial investments in extension services (Jena, 2022).

2.2.1 Conventional tillage

Conventional tillage (CNT) involves intensive tillage methods that manipulate soil structure where less than 15% of crop residue is left on the soil surface after the next crop is planted (Sumberg & Giller, 2022). The study also describes CNT based on the intensive use of a high volume of agrochemicals to increase production. For soils that have poor structural composition, moldboard tillage that is followed by secondary tillage techniques is the most common option used (Zhang *et al*., 2018). Conventional tillage enhances high crop yields, good soil for seedbed preparation, and exceptional weed suppression. A study by Karuma *et al*. (2016) in Eastern Kenya indicated that CNT (disc plough and disc plough with harrowing) increased crop yield as compared to conservation tillage (subsoiling-ripping). Improved soil aeration and uniform distribution of nutrients have been reported to be associated with CNT (Manyatsi *et al*., 2017).

Other studies show that CNT has many negative soil-related effects. These negative outcomes include soil erosion, soil compaction, poor water infiltration, and excessive time and energy requirement (Köller, 2003). Conventional tillage has been reported to conserve the least amount of soil moisture attributed to an increase in evaporation (Manyatsi *et al*., 2017). Soil physical degradation sets in immediately after CNT (Busari *et al*., 2015); crusting, compaction, erosion, and overall soil structure degradation are aggravated (Ngetich, 2008). Mutonga *et al*. (2019)) note that CNT results in high runoff and erosion due to loose fine soil particles that enhance surface sealing hindering infiltration. These negative outcomes are not only an economic problem but also contribute to a significant percentage of agricultural carbon footprint. These outcomes prompt the need for the use of sustainable tillage methods.

This study focused on disc ploughing and harrowing, a common CNT method in Kenya. Typically, the method involves at least two passes of primary and secondary tillage. First, disc ploughing is done to loosen the soil and bury weeds or crop residues. Usually, this is done in the soil creating a furrow during soil preparation. Harrowing is then done to break up soil clods formed during ploughing and smoothen the soil creating a level seedbed for planting.

2.2.2 Conservation tillage

Conservation tillage (CT) is a method of tillage that results in minimal soil disturbance to conserve soil and water, while at the same time reducing soil erosion (Subbulakshmi & Saravanan, 2009). Conservation tillage includes planting systems that leave crop residue in at least 30% of the soil surface after planting (Derpsch, 2003). Carter (2005) asserts that CT comprises practices that can conserve soil and water by reducing their loss contrary to some form of CNT. Such tillage techniques include no-tillage (zero tillage or direct drilling), reduced or minimum tillage, mulch-tillage, ridge tillage, and techniques of farming that leave at least 30% of residue after planting (Sessiz *et al*., 2010). In no-tillage, the soil is primarily undisturbed from the period between harvesting till planting, apart from instances of nutrient inoculation. Planting is normally done in narrow slots or seedbeds which are made by row cleaners, disk openers, or tine openers. In ridge tillage, the soil is also left undisturbed, and planting is done on ridges. On the other hand, in mulch tillage, the soil is disturbed and tools such as blades and disk openers are used. Control of weeds by smallholder farmers under CT systems is done by application of herbicides, in-row slashing of weeds, crop rotations, and incorporation of cover crops or crop residues.

Studies have shown that CT is important in soil and water conservation and the improvement of crop productivity, decrease in nutrient leaching, and reduction in soil erosion (Subbulakshmi & Saravanan, 2009). Johnson et al. (2017) report that CT practices promote increased surface cover by crop residues resulting in increased moisture retention, soil C and N, and potentially crop yields attributed to decreased soil disturbance and decomposition. CT, therefore, promotes soil aggregation (Busari *et al*., 2015) and improved crop productivity (Munyao *et al*., 2019). The methods in CT such as no-tillage and reduced tillage have been associated with reduced tillage intensity hence preserving straw cover (Sessiz *et al*., 2010). CT methods have manipulated soil positively and they are reported to be a vast solution in poorly managed soils especially in the regions of rice and wheat production systems (Sumberg & Giller, 2022). Soil organic carbon (SOC) has also been reported to increase with the continuous adoption of CT (Alam *et al*., 2014). Further, while continuous use of CNT methods results in finer and loose-setting soil structure, CT methods leave the soil intact thereby controlling soil erosion.

Conservation tillage is gaining momentum in Kenya. The study focused on two conservation tillage methods: ripping, a form of minimum tillage, and the use of a jab planter, a form of zero tillage. Ripping is done using a ripper, tillage implement with a metal tine (one or more) that penetrates the soil to break up compacted layers without turning the soil. The tines may penetrate to different depths according to the length. The ripper can be animal or tractor drawn. A handheld jab planter is used for direct seeding by making a hole and dropping a seed into the hole without soil disturbance.

2.3 Effect of Tillage on soil physical properties

2.3.1 Soil Moisture

Efficient tillage and proper management of crop residues help in the control and storage of the limited precipitation, which aids in the crop production process as soil water is a necessity in crop production. Studies by Shittu *et al*. (2017) indicate that an adequate and balanced moisture supply is vital to plant growth. Additional observations by Okoth *et al.* (2021) show that cases, where soil moisture content is low, have often resulted in decreased crop growth rate and, in turn, the crops have attained lower yields. That happens because water plays various roles in plant growth ranging from active physiological tissue to photosynthetic and hydrolytic roles and the maintenance of turgidity as well as the water is a solvent for solutes, sugars, and salts (Shittu *et al.*, 2017).

Karuma *et al.* (2014a) in Eastern Kenya showed that CNT practices increased soil water content as compared to CT methods due to increased soil porosity. Adoption of CNT has been associated with improving the water-holding capacity of soils and water use efficiency (Fabrizzi et al., 2005). Primary and secondary tillage through implements such as ox-plough increase porosity and thus water holding capacity. In contrast, studies by Pikul and Aase (2003) and (Guto *et al.*, 2011) in the northern Great Plains of the USA and the Central Highlands of Kenya respectively indicate that CT methods increase soil water content as compared to CNT methods. These observations are also supported by Noor *et al.* (2020), in their study in Southeast Rawalpindi, Pakistan, who state that zero-tillage and minimum-tillage practices improve soil water content as compared to CNT under rain-fed conditions within 10-15cm of soil. Reduced tillage enhances soil erosion control as compared to CNT due to increased water infiltration owing to minimal soil disturbance (Seitz *et al.*, 2018). Moreover, increased soil cover increases soil moisture retention and thus increased water storage. On the other hand, CNT exposes soil leading to high rates of evaporation since the ploughing operations expose the soil to the atmosphere increasing the rate of evaporation (Busari *et al.*, 2015). Significant water loss results from higher temperatures, lower humidity and air movement contributing to the high rate of evaporation.

2.3.2 Soil crust strength and crusting

A crust is a thin layer on the soil surface with low porosity, high penetration resistance, high density, and poor hydraulic conductivity (Barreto *et al.*, 2019; Liu *et al.*, 2022). Crusting is a result of heavy raindrop impact resulting from intensive rainstorms, destruction of vegetation cover that shields the soil surface from heavy raindrop impact, weak topsoil structure of most cultivated soil types, and generally low organic matter contents of soils resulting from high temperatures and cultivation (Barreto *et al.*, 2019; Chen *et al.*, 2013; Liu *et al.*, 2022). The crust is not only important in infiltration but also influences soil erosion (Pi *et al*., 2020). The problem of crusting and sealing is usually common in arid and semi-arid areas with adverse environmental and agricultural implications (Chen *et a*l., 2013; Liu *et al*., 2022; Nciizah & Wakindiki, 2015).

Tillage methods that lead to the destruction of aggregate stability and compaction promote sealing and crusting decrease the soil's infiltration capacity. Owing to this, a decline in infiltration capacity and hydraulic conductivity is often used as an indicator of soil sealing and crusting (Nciizah & Wakindiki, 2015). The decrease in infiltration rate is a result of crust formation (Jiang *et al*., 2018) and enhances soil erosion by runoff (Liu e*t al*., 2022). Reduced hydraulic conductivity is also associated with crust formation (Jiang *et al*., 2018). Further, increased penetration resistance can be linked to low moisture levels in the soil (Lardy *et al*., 2022; Shittu *et al*., 2017). Moreover, the decrease in moisture content of the soil has been attributed to crust formation (Le Bissonnais *et al*., 1995). However, the higher moisture content in the soil leads to higher productivity and flexibility in the tillage equipment.

Usón and Poch (2000) report that the crust is affected by tillage methods and also that management practices that leave crop residues on the soil surface may eliminate the crusting. This implies that CT methods have the potential to reduce crusting. (Bronick and (2005) and Telak *et al*., 2020 note that intensively tilled soils are prone to surface crusts, compaction and consolidation. Conversely, a study in Catalonia, Spain, by Usón and Poch (2000) established that reduced tillage resulted in thicker and more complex crusts as compared with traditional tillage for 2 years. Support findings by Shittu *et al.* (2017) of a study in Southwestern Nigeria indicated higher penetration resistance at the surface of 0-5 cm under no-tillage in comparison with CNT due to interacting factors of raindrop impact and soil compaction due to human traffic during weeding. At a depth of 10-15cm, CNT had higher values than zero tillage attributed to compaction resulting from heavy farm machinery. Miriti et al. (2013) attributed the loosening of soil during weeding and ridge construction under tied ridges resulting contributing to low penetration resistance. However, the study recorded the lowest penetration resistance under ox-ploughing contrary to tied ridges and subsoiling-ripping. The impacts of tillage methods on soil strength may vary both spatially and temporally.

2.3.3 Soil surface roughness

Soil surface roughness (SSR) is an important parameter in soil processes. SSR influences surface water storage, infiltration, runoff, and erosion and is therefore important in soil management (Alvarez-Mozos *et al.*, 2011). Soil surface roughness (SSR), defined as the irregularities of the soil surface, is a result of land management practices, vegetation cover, soil texture, and aggregation as well as rock fragmentation (da Rocha Junior *et al.*, 2016). Studies by Karuma *et al.* (2014) and Miriti *et al.* (2013) conducted in Kenya found that SSR is highest immediately after tillage and decreases as the growing season. Similar findings were established by (Bramorski *et al.*, 2012) in São Paulo State, Brazil, and Sun *et al.* (2021) in the Loess Plateau region, China. In their study, Karuma *et al.* (2014) recorded the highest SSR under the treatments of hand hoeing with tied ridges in comparison to subsoiling-ripping, ox-ploughing, disc-ploughing, and harrowing due to raised ridges and basins created during tied ridging. Similarly, Miriti *et al.* (2013) realized the highest SR under tied ridges in comparison to subsoiling-ripping and ox-plough. The two studies concluded that tillage practices should be done to enhance water conservation through increased SSR.

In CT management the reduction in the loss of sediment has been attributed to the increase in SSR (da Rocha Junior *et al.*, 2016). Conservation tillage methods enhance litter deposition contributing to SSR. Additionally, SSR has been found to have a direct relation with soil moisture as an increase in SSR leads to increases in water infiltration and surface storage. While SSR is beneficial for soil water storage and erosion control, SSR may also increase soil detachment in sloping lands. The study by Sun *et al.* (2021) in China established the highest soil detachment rate under tillage; contour drilling (6.762 g m^{-2} s^{-1}), manual hoeing (4.180 g m^{-2} s^{-1}) and manual dibbling (3.334 g m^{-2} s^{-1}) as compared to non-tillage (3.214 g m^{-2} s^{-1}) in a sloping land. Certainly, SSR can be maintained by tillage (da Rocha Junior *et al.*, 2016; Sun *et al.*, 2021). However, it should be noted that there are other soil physical properties to be put into consideration before arguing for the superiority of CNT over CT methods.

2.3.4 Hydraulic conductivity

To conserve and enact soil management programs, soil hydraulic properties are necessary as well as the impact of tillage on the properties including saturated hydraulic conductivity (Blanco-Canqui *et al*., 2017). Saturated hydraulic conductivity (Ksat) is a measure of the ability of saturated soil to pass water whenever it is subjected to hydraulic pull (Haruna *et al*., 2018). Saturated hydraulic conductivity is an important parameter for water movement and solute transport in soil. Islam *et al*. (2017) and Kargas *et al*. (2021) note that it is crucial for designing irrigation, drainage and wastewater systems and studying soil water dynamics such as runoff characteristics and groundwater recharge. Further, it is important for the movement of solutes such as pesticides (Jarvis *et al*., 2013) and nutrients in or from agricultural lands. It, therefore, has a connection to irrigation, drainage, erosion and seepage, and is used in water as well as solute movement models. Ksat has a connection to the infiltration capacity of the soil, bulk density, and the general strength of the soil (Haruna *et al*., 2018; Karunatilake & Van, 2002). Hydraulic conductivity, infiltration and water retention are critical as they affect the soil's ability to harvest and retain precipitation or irrigation water, ultimately affecting crop production (Blanco-Canqui *et al*., 2017).

A study by Singh *et al.* (2021) in Eastern Himalayas, India, showed higher near-saturated values in minimum and zero tillage systems as compared with CNT. This was attributed to better-connected macropores under CT systems. Similar observations were made by Osunbitan *et al*. (2005) in the Obafemi Awolowo University research farm. Conservation tillage methods improve soil aggregation and biological activity increasing macro-pores which then increase Ksat. While excessive tillage under CNT methods results in a decline in earthworm populations, CT methods create a favorable environment for earthworms to thrive (Chan, 2001; (Martella, 2017). The earthworms alongside roots enhance the formation of macropores (Fischer *et al*., 2014). Nevertheless, results in a study conducted in the USA by Haruna *et al*. (2018) indicated higher Ksat under moldboard plough tillage as compared with the no-tillage system. The values were attributed to the increased proportion of coarse mesopores in the short term under moldboard plough tillage in comparison with no-tillage. Soil Ksat has also been reported to decrease with time after tillage (Kribaa et al., 2001). The differences that rises in soil hydraulic qualities among the tillage operations adopted usually fluctuate with time after tillage, Strudley *et al*. (2008) and

Osunbitan *et al*. (2005) suggest that 8 weeks after tillage is enough to note the decrease in soil Ksat.

Soils need optimal Ksat as extremes have negative effects on soil and crop production. Extremely high values mean soils hold less water due to rapid drainage (Bouwer, 1986; Osunbitan *et al*., 2005) and it results in water loss and may cause nutrient leaching, in particular nitrogen losses, as well as groundwater contamination. On the other hand, extremely low values mean drainage will be slow, which translates to a loss of oxygen and nitrogen, and crop damage (Undersander, 2011).

2.3.5 Soil Bulk Density and Porosity

Soil bulk density is significant for soil health and crop production. It affects the soil's ability to infiltrate and store water, root penetration and proliferation, nutrient availability, microbial activity, and soil porosity (Indoria *et al.*, 2020). It is defined as the ratio of the total dry mass of soil to its volume (Walter *et al*., 2016). Soil porosity is inversely related to bulk density; a decrease in bulk density means an increase in porosity. It is the portion of total soil volume taken up by pores (Nimmo, 2013; Ramesh *et al*., 2019)) which can be filled by water or air. Reichert *et al*. (2009) reports that bulk density is affected by multiple variables such as soil texture, particle size, and structure, crop types, mineralogy, and management practices including tillage and residues. These factors similarly affect porosity. Porosity is important in production as it influences the transmission of water, air and solutes as well as soil biodiversity (Nimmo, 2013; Ramesh *et al*., 2019)

Findings by (Karuma *et al*., 2014b) in Eastern Kenya indicated insignificant changes in bulk density for four consecutive seasons (short period) under both conventional and conservation tillage methods. Averagely, the bulk density trend observed was disc ploughing and harrowing>subsoiling-ripping>hand hoeing>ox ploughing> hand hoeing with tied ridges>disc ploughing. In this study, porosity was greater under CNT in comparison to CT methods. Similar results are reported by Haruna *et al*. (2018) as the bulk density was 13% lower on till soils relative to no-tillage and this was at a depth of 0-10cm and porosity was greater in CNT plots than under

CT (Karuma *et al*., 2014b). This is probably because CNT tends to increase macro porosity as opposed to CT (Blanco-Canqui *et al*., 2017). Findings by Veiga *et al*. (2008) of a study in Brazil indicated significant changes in bulk density for 9 years (long period) within the surface layer. Thus, differences occur depending on time and soil layers amongst other factors. Bulk density and porosity change with soil depth (Noor *et al*., 2020). Minimum tillage has been reported to increase bulk density relative to chisel plough and conventional tillage methods (Osunbitan et al., 2005; (Steign et al., 1995; Osunbitan et al., 2005). The findings indicated lower bulk densities in lower horizons under CNT and chisel ploughing as compared to minimum tillage.

2.4 Effect of Tillage on Soil Nitrogen

Conventional tillage is a common practice where the soil is cultivated using different equipment while conservation tillage is the practice where the cultivation is reduced or rather no tillage at all (Hafif, 2014), both methods affect soil nitrogen. Nitrogen is the most fundamental nutrient for crop production as it constitutes the building blocks for almost all plant structures and is required in rather higher amounts as compared to other essential nutrients. According to Hofman and Cleemput (2004), nitrogen stimulates root growth and crop development; it is an essential component of protein, enzymes, and chlorophyll. Nitrogen availability in the soil is therefore crucial for crop performance (Havlin *et al*., 1999). Diverse studies have reported that soil management practices such as tillage affect the nitrogen status in the soil (Hafif, 2014), Vu *et al.* (2009) note that NT may result in nutrient stratification. A long-term study (6 years) in China by Tan *et al.* (2015) indicated a gradual increase in organic matter and nitrogen under CT systems namely no-tillage; straw mulching; plastic-film mulching and ridging and plastic-film mulching. A decrease was observed under CNT (traditional tillage) due to the increased frequency of soil disturbance that exposed N to losses. CT reduces the frequency of soil disturbance ensuring the soil surface is covered; Tan *et al*. (2015) suggest that the degradation of soil is then reduced through reduced erosion and decomposition. Another study (short-term) in Northeast China by You *et al*. (2017) indicated an increase in SOC and total nitrogen in the surface soil layers under rotary-till (0-20cm) and no-till(0-10cm), with a decrease under plough till. Nitrogen losses also occur in the form of $N0_3$-N through leaching. According to Myrbeck and Stenberg (2014), the total leaching of

NO_3-N in a CNT method was reported to be significant, 46 % and 33 % more than in a CT method for 2 consecutive crop rotation cycles. Higher N concentration under the CT method could be attributed to the lack of soil disturbance. This can also be attributed to the residual N from fertilizer application that was retained on the soil organic matter-SOM fractions (Hafif, 2014) or retained residues on the soil surface that released more N to the soil . Nitrogen is closely related to SOM since a greater percentage of nitrogen is obtained from the organic matter or humus (Tan *et al*., 2015).

Hafif (2014) notes that under NT systems residues left on the surface are a source of food for microorganisms that continue to fix N in the soils, and compared to CNT methods NT increased N mineralization and total N. Corresponding conclusions were drawn by (Campbell *et al*., 1996), (Havlin *et al*., 1999), and (Kristensen *et al*., 2003). This mineralization may however contribute to higher N losses in CT methods contrary to CNT methods through emission from the soil in the form of N_2O fluxes from soils (MacKenzie *et al*., 1997; Venterea *et al*., 2005) and leaching. In conclusion, tillage methods significantly affect N dynamics and the adoption of CT in the long term positively contributes to total N thus posing a remedy to the management of soils with low N (Hafif, 2014; MacKenzie *et al.*, 1997).

2.5 Effect of Tillage on crop performance

Optimal soil management is important for crop production (Hafif, 2014). A study by Alam *et al.* (2014) in Bangladesh investigating the outcome of four tillage methods, Minimum tillage (MT), Conventional Tillage (CNT), Zero tillage (ZT) and deep tillage (DT) on crop yields and soil properties showed that tillage affects crop yields positively and ZT had the highest SOM accumulation couple with maximum root mass density that resulted to higher final yield in mung bean. Bulk and particle densities reduce as a result of tillage (Osunbitan *et al*., 2005). Tillage affects root distribution, fertility, and soil moisture thus having an impact on crops (Alam *et al*., 2013).

As a result of intensive cultivation that happens in conventional land preparation techniques of disking and ploughing, a significant proportion of the initial fertility of the surface soil is lost due to either erosion or depletion of organic matter (Campbell *et al*., 1996) and lower yields of grains may result from the depreciation of soil properties by tillage (Alam *et al*., 2013). Such techniques may also reduce soil water storage capacity and moisture retention capacity of soils (Bekele, 2020). Zero tillage has been associated with a change in soil structure since it modifies the soil bulk density and moisture content, contrarily, CNT's long-term effects include finer and loose setting soil structure relative to the CT that leaves the soil intact (Rashidi & Keshavarzpour, 2007). Alam *et al*. (2014) report the great contribution of bulk density, particle density, field capacity, permanent wilting point and porosity in the final yields of grains as influenced by tillage methods. In the study conducted in Bangladesh, both the bulk density and particle density were found to decrease due to tillage methods with the highest decrease of 6.41% observed under ZT and the lowest reduction observed in deep tillage in this study, consequently, ZT recorded higher yields. In addition, the reduction in soil carbon has also been linked with the increased level of tillage and correlated with the final yields of the grains (Sarwar *et al*., 2008).

Tillage practices affect the soil moisture content which in turn affects crop productivity (Bekele et al., 2022) as in the case maize's developmental and physiological process heavily relies on water. Instances of water stress have thus affected production. A study by Orfanou *et al*. (2019) in Georgia, USA noted that low soil moisture content affected maize growth. When there is reduced water, the number of kernels per ear tends to be less. Another study by Zhu *et al*. (2018) notes that soil water limits crop production, especially under rain-fed agricultural conditions. The study conducted in Loess Plateau in China indicated increased water stress due to plough pans at a depth of 20-40cm. Moisture stress affects maize yield in various stages and as such, yield parameters such as grain yield are affected by fluctuations in water availability (Admasu *et al*., 2019). The tillage systems determine the water retention ability (Haruna *et al*., 2018). Furthermore, the findings note that there is a need for proper irrigation depending on the type of soil and tillage system used. Wang *et al*. (2015) recognized that sub-soiling enhances moisture conservation in the soil profile relative to rotary tillage and no-tillage systems, leading to higher maize-grains yields. Soils with adequate retention tend to reduce the chances of water stress by the plant. Water stress proves to affect plant yield and managing maize production involves considering the water content in the soil at a suitable field capacity. Besides, the climate of a region defines maize production, in instances where there is a decrease in the amount of moisture needed for growth during maize production there is a call for irrigation to improve the maize yields. Majorly, irrigation should focus on increasing agricultural production with less water usage. Therefore, maintaining the water content during agricultural output is a crucial factor.

Contemporary studies by Brunel-Saldias *et al*. (2018) indicate that there is a need to maintain water balance during maize production. In their research, the authors showed that it is necessary to estimate the soil water balance by conducting a measurement of the infiltration process after irrigation and rainfall. It enables determining the water uptake of plants by the plants after the transpiration and evaporation process. The water balance can be based on tillage systems. Majorly, the tillage system defines water retention mechanisms. A decline in maize yields can also be attributed to subsoil compaction. Tillage practices that enhance soil compaction inhibit proper root distribution; restrict water infiltration and retention and increase runoff and erosion, but CT has been documented to amplify grain yields significantly (Liao *et al*., 2002) and this can be associated with improved soil chemical and physical properties under ZT and MT. Mkomwa *et al*. (2015) argue that tractor-drawn and ox-drawn implements such as disk ploughs lead to the development of plough pans. This is attributed to the same depth ploughing yearly. Averagely, farmers meet the optimum planting dates by ploughing when the soil is still dry, which increases the chances of shallow planting. The shallower the tillage depth, the greater the chances of plough pan development near the soil surface (Tsimba, 2000) and ultimately this leads to low crop yields.

In addition, findings from Shittu *et al*. (2017) indicate that adequate moisture presence is vital to plant growth. In their study, they describe how moisture presence facilitates nutrient and mineral absorption by plants. Water is an essential element in plants. Low crop water presence translates to low yields. According to Shittu *et al*. (2017), water is vital as it helps in physiological processes such as photosynthesis. Water also maintains the turgidity of the various cells and thus facilitates growth. Crop management practices should be directed toward water and soil conservation measures to realize high yields. The choice of tillage system should facilitate proper growth. Thus, the choice of tillage determines the soil moisture content through porosity. Studies by Khan *et al*. (2017) note that soil tillage is a vital practice in maize production. Tillage practices affect agronomic maize parameters: grain yield, plant biomass and height, leaf area, and leaf area index.

In their study, the highest grain yield was obtained from plots under deep tillage as compared to plots under conventional and minimum tillage.

2.6 Cost-benefit Analysis of different tillage methods

Cost-benefit analysis (CBA) is a fundamental consideration when undertaking any project requiring capital investment. Just like in other major projects, CBA is not different in agriculture, particularly in the context of tillage. The selection of a tillage method with a great benefit-cost ratio (BCR) and net benefits (NB) is important considering that most smallholder farmers rely on little capital for farming. Regarding CT and CNT methods, various studies seem to strongly support that CT methods have greater BCR. A long-term study by Van Huyssteen and Weber (1980) in Stellenbosch, South Africa involved six different tillage methods that exemplified both CNT and CT. Observations from this study showed that CT methods had superiority in economic performance as compared to CNT methods. Herbicide treatment of crops was the most profitable contrary to deep trenching, shallow trench furrow, straw mulch, clean cultivation, and permanent sward. Notably, deep trenching, a method used in CNT, also provided considerably favourable outcomes concerning profits.

A second study that supports the superiority of CT methods over CNT regarding CBA was done by Aryal *et al.*, 2014) in North-West India. This research sought to evaluate the economic and environmental impacts of zero tillage methods on wheat farming. In this study, results showed that farmers could save up to USD 97.5/ha while using CT methods. In this case, the experiment used zero tillage as the main CT method. Notably, the net benefits under the CT methods were 1.43 against 1.31 under the CNT methods. A study by Zhou *et al*. (2009) revealed interesting dimensions related to the cost efficiency of CT methods through the prevention of soil losses through erosion. In their study, they noted the rate of sediment yield and surface run-off was 22.5, 17.7, and 3.3 tonnes/ha/ year from chisel plough, disk tillage, and no-tillage, respectively. In this study, the authors insisted that it was necessary to factor in soil losses when estimating the CBA of CT and CNT methods. There is therefore a need to assess the CBA of using CT and CNT to grow maize and identify which method best suits smallholder farmers.

CHAPTER THREE: EFFECT OF TILLAGE METHODS ON SELECTED SOIL PROPERTIES

3.1 Abstract

Understanding the effects that tillage has on the soil properties indicates the general soil productivity which can enable planning for soil management programs. Tillage may have either a negative or positive effect on the soil, modifying the soil composition and structure, and ultimately impacting the final maize grain yield. An experiment was conducted to evaluate the effects of different tillage methods on soil properties during the long rains (LR) and short rains (SR) of 2021 at Upper Kabete Campus, University of Nairobi. The trial was set up in a Randomized Complete Block Design (RCBD) with four replicates representing four treatments. The treatments were Disc Ploughing and Harrowing (DPH), Ripping (R), Jab Planter (JP), and Hand Hoe (HH). Maize was grown for two seasons test crop and data on soil moisture content, soil surface roughness (SSR), crust strength (CS), saturated hydraulic conductivity (Ksat), porosity, bulk density, and soil nitrogen (N) contents were evaluated at different times and depths (0-20 and 20-40 cm). Soil moisture was significantly ($p<0.05$) affected by the different tillage methods in both LR 2021 and SR 2021. There was also a significant ($p<0.05$) interaction between tillage and sampling depth. The mean soil moisture for LR 2021 and SR 2021 decreased in the order R > DPH >JP > HH and R > JP > HH > respectively. For both seasons and all sampling depths, R-ripping recorded the highest moisture content. Bulk density (BD) and porosity were only significantly ($p<0.05$) influenced by tillage during SR 2021. The JP exhibited the highest BD during both seasons with mean values of 1.04 and 1.11 Mg m^{-3}, respectively. The average total porosity values (%) in descending order for LR 2021 was R > HH > DPH > JP and for SR 2021 was DPH > R > HH > JP. Tillage significantly affected the N content (%) during both seasons with R being the highest; the first season's trend was R > JP > HH > DPH, while the second season's was R > JP > DPH > HH. This study confirms that the tillage method affects soil properties and that ripping enhances soil conservation and soil productivity method in Kabete.

3.2 Introduction

Soil resources and water are the most limiting factors in the sustainable production of maize in Kenya. Application of appropriate tillage methods has been successfully used to conserve these limiting factors of production, soil moisture, and N levels in the soil (Afzalinia & Zabihi, 2014). Soil management practices have influenced soil and water dynamics and their use in crops (Khorami *et al*., 2018) and tillage has been a major factor that affects soil properties and crop yields (Alam *et al*., 2014) with a high influence on sustainable use of soil resources (Lal & Stewart, 2013). The selection of an appropriate tillage method is thus a very important factor for long term maize cultivation. Inappropriate tillage has caused undesirable results such as a change in soil structure, loss of SOM and loss of soil carbon (Alam *et al*., 2014). Reduced tillage on the other hand has resulted in desirable effects on the soil as well as alleviation of the soil-related constraints, the adoption of other CT methods improves the soil physical, chemical, and biochemical mechanisms of SOM (Plaza-Bonilla *et al*., 2018; Sharma *et al*., 2009). In contrary a study by Afzalinia & Zabihi (2014) in Fars province, Iran indicated that zero tillage increased BD more that CNT and reduced tillage methods with a significant effect on the topsoil (0-20 cm). As such, zero tillage enhances soil compaction. Khorami *et al*. (2018) also support that zero tillage leads to higher bulk density on the soil surface contributing to lower cumulative water infiltration. The study conducted in Iran concluded that tillage affects BD, hydraulic conductivity, moisture content and porosity capacity. Moreover, BD increases with an increase in soil depth (Haruna *et al*., 2018; Khorami *et al*., 2018). The huge difference in BD at different tilling depths has been attributed to shallow tillage (shallow ripping) and soil disturbance in less than 10 cm contributing to subsurface soil compaction at plough pan (Gathala *et al*., 2017; Jat *et al*., 2017). The plough pan layer is usually formed below the tilled soil layer which usually contributes to higher BD at 10-20 cm.

Research by Manyatsi *et al*. (2017) in Swaziland recorded high soil moisture content under zero tillage (jab planter) relative to CNT. reports. Similarly, zero tillage conserved 31.63% more moisture relative to CNT in Turkana County, Kenya (Khaemba *et al*., 2017). Soil surface roughness is also influenced by the tillage methods, with an increase immediately after tillage (da Rocha Junior *et al*., 2016). About Miriti *et al*. (2013) study in Eastern Kenya, SSR was higher on a tied-ridge tillage method relative to ox-plough. A long-term study by Wang *et al*. (2008) in China recorded higher N values under no-tillage contrary to CNT, while Khorami *et al*. (2018) recorded higher N values under no-tillage relative to reduced tillage and CNT methods. Although these studies provide insightful results, none of the study areas have the ambient conditions found in Kabete. It is important to consider regional as well as site-specific characteristics in tillage studies. Thus, this study sought the effects of different tillage methods on soil moisture, soil surface roughness, crust strength, saturated hydraulic conductivity, bulk density, porosity, and total nitrogen in Kabete.

3.3 Materials and Methods

3.3.1 Study site

The field experiment was conducted in one of the fields at Kabete Sub-County of Kiambu County; in the experimental field of Upper Kabete Campus, University of Nairobi., covering an area of 168.63 ha. The site lies at 1°15´S, 36°44´ E. It has an elevation of 1876m above sea level.

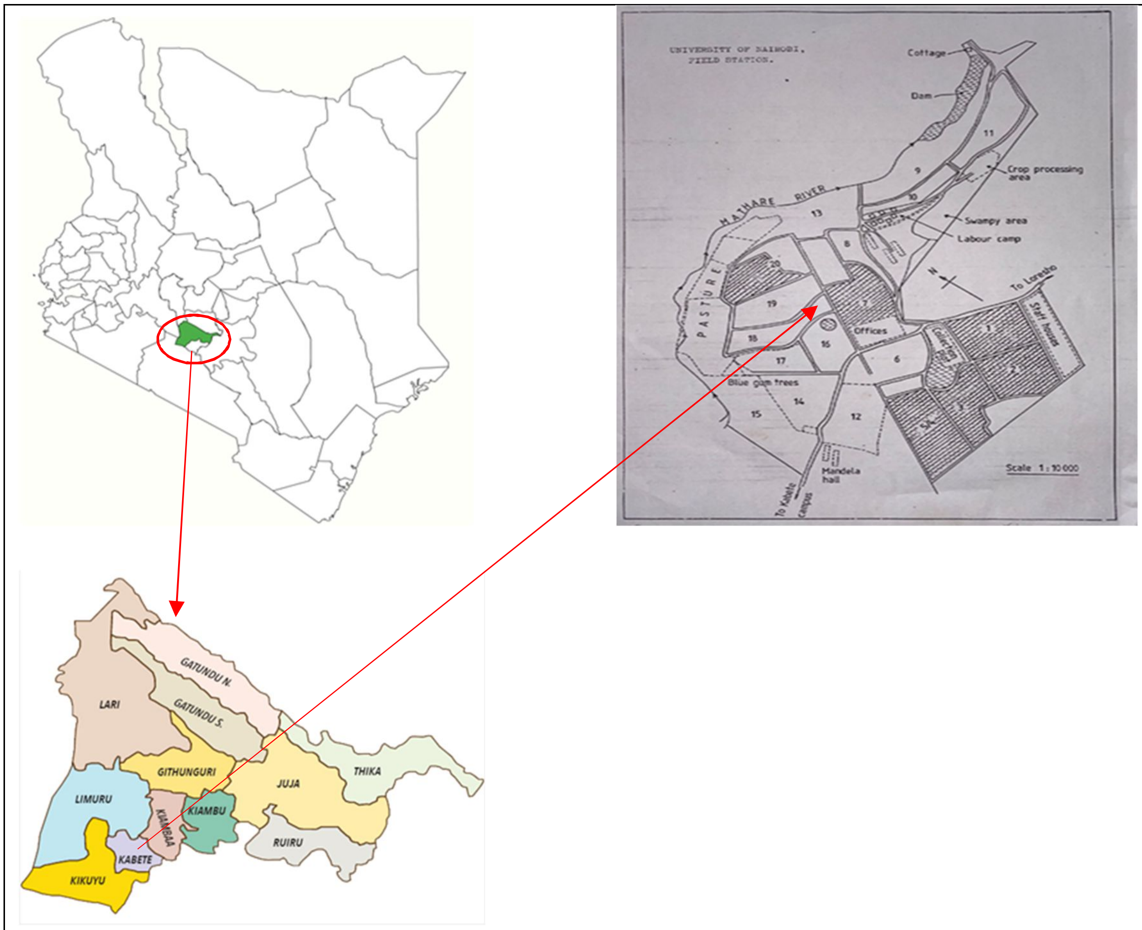

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Figure 3.1: Map of the study area

The site is in Agro-climatic zone III (Sombroek *et al*., 1982; Gachene, 1989) classified as sub-humid (Jaetzold *et al*., 2007). The site has a bimodal rainfall pattern; the long rains fall between mid-March and May while the short rains fall between mid-October and December. The soils of the study area are well-drained, very deep (> 180 cm), dark red to dark reddish brown, and friable clay and are classified as Humic Nitisols (Gachene, 1989). The soil and climatic conditions of the area are representative of areas in the Central Highlands of Kenya. The geology of Kabete comprises of grey-green porphyritic trachyte that is indistinguishable from the Ruiru Dam trachyte (GSA, 2014).

Land in Kabete is put to diverse uses; agricultural, industrial, and commercial (County Government of Kiambu, 2018). Agriculture is an important economic activity in the area. Small-holder farmers integrate crop and livestock production systems. Coffee and tea are the main industrial crops grown in the area, while the primary food crops grown are maize, beans, Irish potatoes, bananas, and vegetables (County Government of Kiambu, 2022). Poultry and dairy farming are also practised in the studied area. Upper Kabete Campus consists of student facilities and cultivated and grazing areas. Horticultural crops and coffee are the main enterprises at the field station (Mwendwa *et al*., 2019). Horticultural crops grown include tomatoes (*Solanum Lycopersicum L*.), black nightshade shade (*Solanum nigrum*), cowpeas (*Vigna unguiculata*), carrots (*Daucus carota*) and kales (*Brassica oleracea*) and spinach (*Spinacia oleracea*) amongst others. In the preceding cultivation cycle, carrots were grown in the study plot (18-1) after which the land was left fallow for one year before the commencement of this study.

3.3.2 Experimental Design and Layout

The trials were established for two seasons during the long (March-May) and short (October-December) rains of the year 2021 (i.e., LR 2021 and SR 2021). The treatments consisted of four tillage methods: disc ploughing and harrowing (DPH), ripping (R), use of a jab planter (JP), and hand-hoeing (HH). The experimental design was a randomized complete block design with the treatments replicated four times, with a spacing of 2 m² between blocks and 1m² between treatments (Appendix 1). The plot size for each treatment was 25 m². Time in weeks after planting (WA P) and season were considered experimental factors to test the changes within a growing season and across the different cropping seasons.

3.3.3 Field management

Land preparation was done before the onset of the rains. As the land had been fallow, the land clearing was first done using a panga and cutlass, followed by cleaning through raking. Baseline soil data was collected and laboratory analyses were done using standard methods as indicated in Okalebo *et al*. (2002). Analysis was done for selected chemical and physical properties outlined in Table 3.1. The soil had medium nitrogen (N), sufficient potassium as well as phosphorus, and adequate organic carbon quantities. The site had low bulk density implying low resistance to root penetration (Karuku *et al*., 2012).

Table 3.1: Baseline soil physical and chemical characteristics of the study site

Soil property	Values	
	0-20cm	0-40cm
pH	6.43	5.92
%N	0.32	0.31
%O.C	3.13	2.96
Ca (Cmol/kg)	6.6	5.85
Mg (Cmol/kg)	2.62	3.01
K (Cmol/kg)	1.16	1.08
Na (Cmol/kg)	0.25	0.25
P (ppm)	54.6	28.39
Mn (ppm)	79.1	65.7
Zn (ppm)	9.3	11.4
Fe (ppm)	71.2	68.2
Cu (ppm)	1.75	1.52
Bulk density (g/cm^3)	1.08	
Porosity (%)	59.38	
Saturated hydraulic conductivity Ksat (cm/h)	19.41	

Tractor-drawn disc plough was used for plots under DPH for ploughing and harrowing. The disc blade plates had a diameter of 65cm and ploughed land to a depth of 35cm. For the ripping treatment (R), a ripper was used in the land preparation. The tractor-drawn ripper consisted of 2 tines that created furrows 30cm deep and 9cm wide. Clean slashing was done for plots under the jab planter (JP). A hand hoe, commonly referred to as jembe, was used under HH. Biased randomization was done to limit compaction due to pressure by tractor wheels. Thus, in each block, the first plot was DPH and the second was R (Appendix 1). SC Duma 43 (SC 403) hybrid maize was planted in the two seasons. Fertilization was done alongside planting using Di-ammonium phosphate (DAP, 18:46:0) at a rate of 123.55kg/ha (KALRO, 2022). A hand hoe was used for planting under DPH and HH plots. A jab planter was used under JP and a panga was used under R. Planting was done along ripped lines under R. A spacing of 75cm by 30cm was used in all the plots for the pure stand. Pre-emergent herbicide (Primagram gold 660Sc) was applied to the R and JP plots after planting at a rate of 3 litres/ha. Weeding was done 3 weeks after the emergence (WAE) of maize during the first season, while in the second season, it was done 5 WAE with an initial weeding after replanting (KALRO, 2021). DPH and HH plots were hand hoed. A cutlass was used for weeding plots under SSR and JP treatments. Innovate 240 SC (post-emergent herbicide) was applied under JP and SSR plots at a rate of 2 litres/ha. The top dressing was done only during SR 2021 using CAN at a rate of 60 kg N ha^{-1}. Harvesting was done at the physiological maturity of maize.

3.3.4 Soil properties measurements

Selected soil physical properties were monitored at different weeks after planting (WAP). Soil moisture content was monitored from crop emergence to harvesting at depths of 0-20cm and 20-40cm. Karuma *et al.* (2014b) state that there is active root concentration at the depth of 0-40cm, therefore, soil sampling was done within this depth. Two random samples from each plot were taken at the two depths and composite samples were made. The disturbed soil samples were subjected to the gravimetric method for moisture analysis (Black, 1995).

The formula for soil moisture determination:

$$\mathrm{MC}\ (\%) = \frac{\mathrm{Ww} - \mathrm{Wd}}{\mathrm{Wd}} \times 100$$

Where MC is the moisture content (%), Ww is the weight of wet soil (g) and Wd is the weight of dry soil (g).

Soil surface roughness (SSR) was monitored after tillage operations, before weeding, and at harvest. A relief meter similar to that described by (Kuipers, 1957) and Miriti *et al*. (2013) was used in measuring soil surface roughness. The relief meter shown in Plate 3.2 was a pinboard consisting of a 1m by 0.4m horizontal wooden board with a scale calibrated in centimetres. Attached to the pinboard were 20 perpendicular metallic pins with a spacing of 5cm apart. The pins slid down till they touched the soil surface during data collection. Three randomly selected samples were taken from each plot. The equation used for the calculation of SSR was as follows:

$$\mathrm{SR}\ (\%) = \mathrm{LOG(STDEV)x}\ 100$$

Where SR is the surface roughness, LOG is the logarithm, and STDEV is the standard deviation of the pin height measurements.

Crust strength was measured at the soil surface of 0-10cm using a handheld penetrometer (Plate 3.3) similar to the ones used by Karuma *et al*. (2014b) and Miriti *et al.* (2013). The type 1B penetrometer (Eijkelkamp equipment) consisted of cones and springs that were adjusted according to the strength of the soil. 10 randomly selected samples were taken per plot and the average was computed. Cone resistance that represents crust strength was calculated as follows:

$$\mathrm{CR} = \mathrm{I\ x}\frac{\mathrm{Cs}}{\mathrm{AC}}$$

Where CR is the resistance (N cm2), I is the impression on the scale (cm), Cs is the spring constant (N cm^{-1}), and AC is the area of the cone (cm^{2}).

Plates 3.2a (left) and 3.2b (right): Relief meter and a handheld penetrometer

Sampling for saturated hydraulic conductivity (Ksat), bulk density, and porosity was done at the beginning of the season and harvest. Undisturbed soil samples were collected at two depths 0-20 cm and 20-40 cm. The constant head method as described by Klute and Dirksen (1986) was used in the measurement of Ksat. Log-transformed Ksat values were utilized in the subsequent statistical analysis.

Afterwards, the Ksat soil samples were used for analysing bulk density using the core sample method (Blake & Hartge, 1986). Samples were oven-dried at 105 °C overnight and weighed. The weight of dry soil was divided by the soil volume. Porosity was then derived from bulk density as:

$$\text{Porosity (\%)} = 1 - \frac{\text{BD}}{\text{PD}} \text{x } 100$$

Where BD is the soil BD (Mg m^{-3}), and PD is the average particle density (2.65 Mg m^{-3}).

3.3.4.1 Soil nitrogen

Disturbed soil samples were collected using a soil auger at 2 depths of 0-20 cm and 20-40 cm during harvest. The Kjeldahl method was used in the N analysis. The soil samples were air-dried, ground, and sieved through 2 mm mesh. 1 g per sample was weighed into a 250ml flask. 1g of mixed catalyst and 8 ml of concentrated sulphuric acid was added to the flask, shaken gently and the contents were placed in a Kjeldahl digestion block at a temperature of 120 °C for 1 hour. The temperatures were then raised to 330 °C until the solution was colourless. After cooling, 25 ml of water was added and mixed with the contents and transferred to plastic beakers. 10 ml of the digest was transferred to a Kjeldahl distillation flask and 10 ml of 40% boric acid was added. The sample was then distilled into the 2% boric acid with 4 drops of mixed indicator in the 250ml conical flask. Ammonium-N was determined by titrating distillate against 0.01N sulphuric acid (Bremner & Mulvaney, 1982; Okalebo et al., 2002).

$$\%\text{ Total N} = \frac{\text{Titre x 14 x Normality of acid used x Volume extracted x 100}}{\text{Weight of sample x 1000 x Aliquot taken in ml}}$$

3.3.5 Statistical analysis

The soil data were subjected to analysis of variance (ANOVA) using R statistical software (R version 4.2.1 [2022-06-23 ucrt]), according to the different WAP. Means were separated using Tukey's Honestly Significant Difference (Tukey's HSD) test. A significant level of $P \leq 0.05$ was adopted to determine statistical significance.

3.4 Results

3.4.1 Effect of tillage methods on soil moisture

Soil moisture was significantly affected by tillage and time during both seasons and exhibited significant interactions between tillage and time at $P < 0.001$ during both LR 2021 and SR 2021 (Table 3.2). The average observed trends in soil moisture were R > DPH > JP > HH during the long rains and R > JP > HH > DPH during the short rains. Significant interactions were also observed between tillage, time, and depth at $P < 0.001$ (LR 2021) and $P < 0.01$ (SR 2021).

Table 3.2: Average soil moisture (%) as affected by tillage, time of measurement, and depth during LR and SR 2021

Tillage method	Long rains 2021	Short rains 2021
DPH	31.41b	26.95b
R	46.91a	41.59a
JP	29.6b	28.38b
HH	29.55b	28.32b
Significant levels		
Tillage	**<0.001**	**<0.001**
Time	**<0.001**	**<0.001**
Depth	0.3329	0.3872
Tillage*Time	**<0.001**	**<0.001**
Tillage*Depth	0.9483	0.969
Tillage*Time*Depth	**<0.001**	**<0.01**

Tillage: DPH: disc ploughing and harrowing, R: ripping, JP: jab planter, HH: hand hoeing. Different letters down the columns indicate significant differences at a 5% probability level. Bold *P*-values are significant at $P < 0.05$.

Soil moisture values under R treatment were significantly different from DPH, JP, and HH across the two seasons (Table 3.2). The values varied across all tillage methods in line with soil depth (Figures 3.2 a, b, c, d). DPH exhibited higher moisture content at the depth of 0-20cm and 20-40cm during LR 2021 and SR 2021 respectively. During both seasons, R, JP, and HH exhibited higher values within 20-40cm.

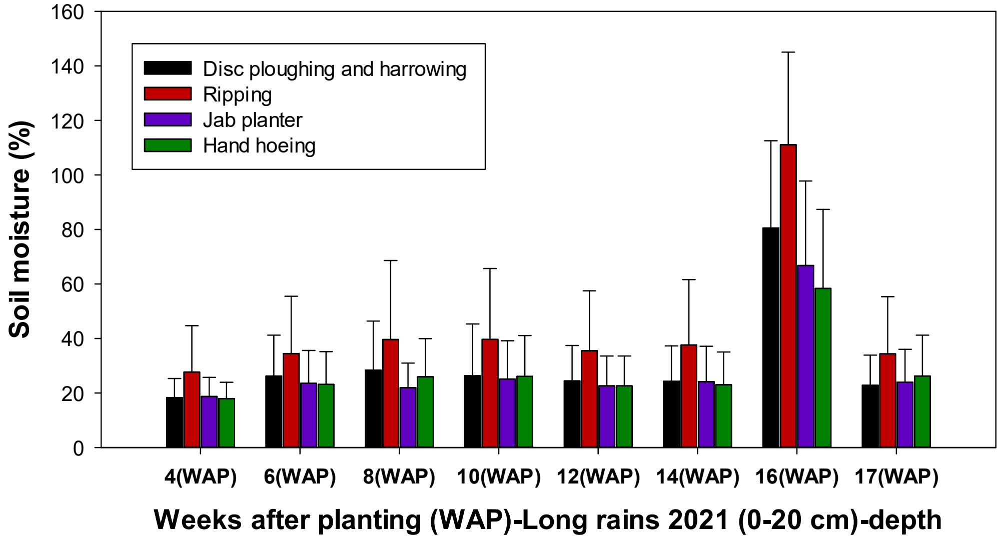

Figure 3.2a: Soil moisture (%) as influenced by tillage and time of measurement within 0-20cm

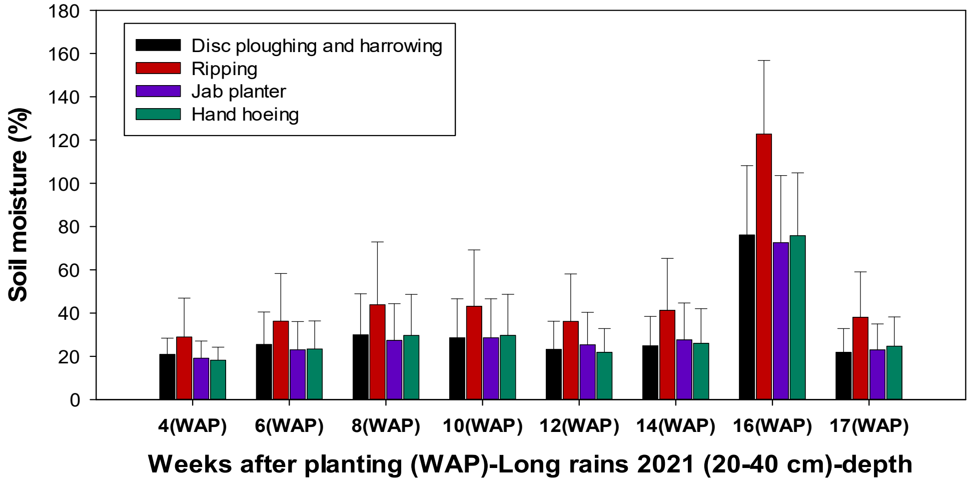

Figure 3.2b: Soil moisture (%) as influenced by tillage and time of measurement within 20-40cm

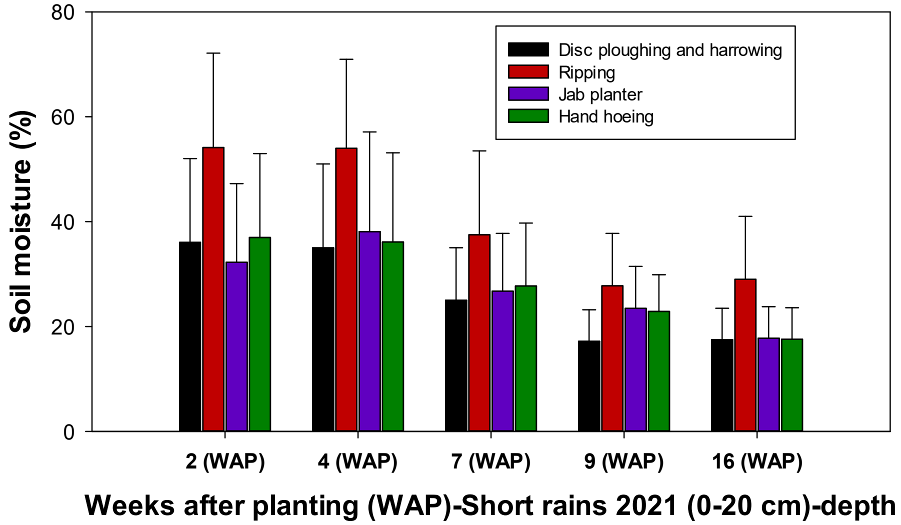

Figure 3.2c*:* Soil moisture (%) as influenced by tillage and time of measurements within 0-20cm

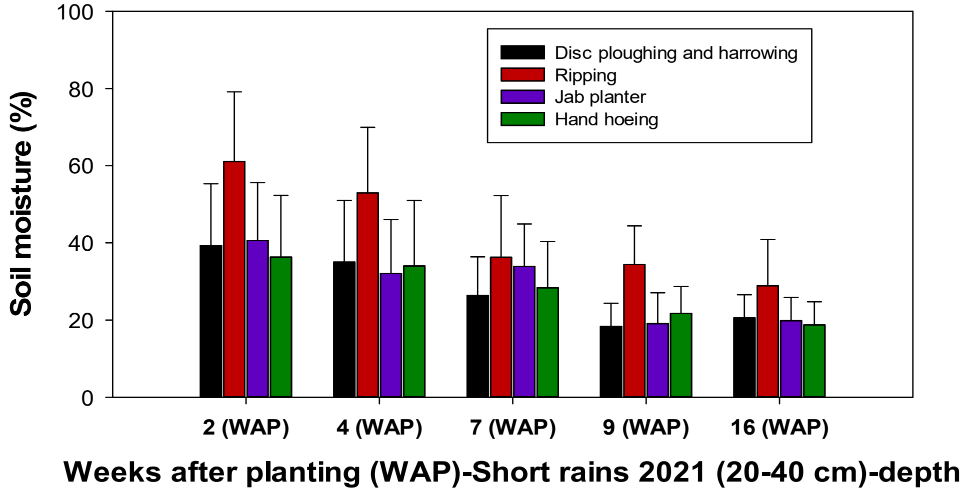

Figure 3.2d: Soil moisture (%) as influenced by tillage and time of measurements within 20-40 cm

3.4.2 Effect of tillage methods on soil surface roughness

Soil surface roughness observations (Table 3.3) indicated that time of measurement significantly influenced the parameter, while tillage significantly contributed to the parameter during SR 2021 only. The average observed trend in SSR was DPH > R > HH > JP during the LR 2021, and HH > DPH > R > JP during the SR 2021. SSR was highest immediately after tillage and decreased progressively throughout the two seasons.

Table 3.3: Average soil surface roughness (%) as influenced by tillage, and time of measurement

Tillage method	**Long rains 2021**				**Short rains 2021**			
	A	**B**	**C**	**x̄ Tillage**	**A**	**B**	**C**	**x̄ Tillage**
DPH	4.23a	2.76b	1.52c	2.83a	3.76a	2.67ab	2.45b	2.96a
R	2.84a	2.67a	2.02a	2.51a	3.6a	1.64b	1.14b	2.13ab
JP	2.68a	1.48a	1.39a	1.85a	2.66a	1.5b	0.86b	1.68b
HH	3.8a	2.0b	1.18b	2.33a	4.1a	2.82b	2.42b	3.11a
Significant level								
Tillage	0.1943				**< 0.001**			
Time	**< 0.001**				**< 0.001**			
Tillage*Time	0.0766				0.0818			

Tillage: DPH: disc ploughing and harrowing, R: ripping, JP: jab planter, HH: hand hoeing. A: After tillage, B: before weeding, C: at harvest. x̄: Mean. Different letters down the columns indicate significant differences at a 5% probability level. Bold P-values are significant at $P < 0.05$.

3.4.3 Effect of tillage methods on crust strength

Trends in crust strength were similar during both the LR 2021 and SR 2021. The overall trend in decreasing order was JP > R > DPH > HH at $P < 0.05$ (Figures 3.2 and 3.3). Tillage was nonetheless insignificant. During both seasons time of measurement significantly influenced crust strength ($P < 0.001$). Values at 2WAP and 7WAP were significantly different from those at 10WAP and harvest. The lowest values were recorded after weeding across all tillage methods. The findings also established significant interactions between tillage and time in both seasons, LR 2021 and SR 2021, as $P < 0.001$ and $P < 0.0464$ respectively

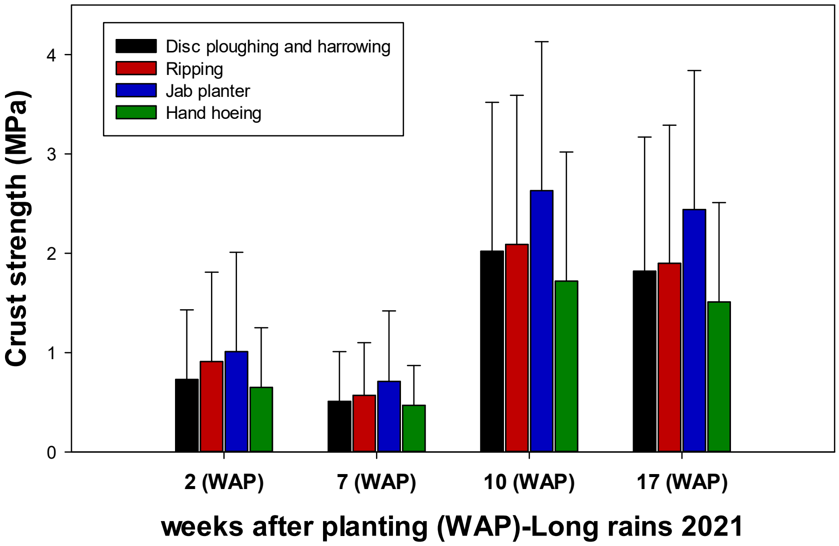

Figure 3.3: Crust strength (MPa) as influenced by tillage and time of measurement during LR 2021

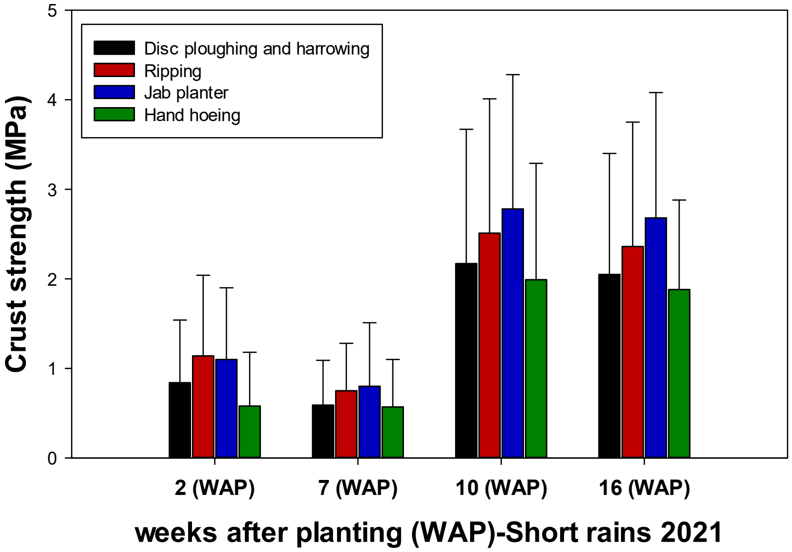

Figure 3.4: Crust strength (MPa) as influenced by tillage and time of measurement during SR 2021

3.4.4 Effect of tillage methods on bulk density, porosity, and saturated hydraulic conductivity

The effect of tillage on BD varied across the two seasons, long rains (LR 2021) and short rains (SR 2021) within the range of 0.85 Mg m^{-3} and 1.14 Mg m^{-3} as shown in Table 3.4. During the LR 2021 tillage (P=0.3144), time of sampling (P=0.1053) and depth (0.3144) did not significantly affect BD. Bulk density (Mg m^{-3}) was greatest under jab planter (JP), followed by disc plough and harrowing (DPH), which was followed by hand hoeing and the lowest value was under ripping R in the order 1.04, 1.01, 0.98, and 0.97 respectively. Bulk density was higher during harvest than at the beginning of the season at the depth of 0-20cm across all tillage methods. Within 20-40 cm BD increased under DPH, a decrease was observed under HH and JP while R had similar values as the season progressed. DPH had higher BD values within 0-20 cm in comparison to 20-40 cm while JP had lower BD values within 0-20 cm as compared to 20-40 cm. R and HH had lower BD values within 0-20 cm in comparison to 20-40cm at the beginning of the season only. Bulk density significantly varied at the two depths 0-20 cm (0.97 Mg m^{-3}) and 20-40cm (1.12 Mg m^{-3}) under the treatment JP at the beginning of the season. The observations indicated significant interactions between tillage*time (P<0.001), tillage*depth (P=0.0388) as well as tillage*time*depth (P=0.0488).

During the SR 2021 tillage (P=0.0047) and time of measurement (P<0.001) significantly affected BD as shown in Table 3.4. There were also significant interactions between tillage*time (P<0.001). The average overall trend in BD (Mg m^{-3}) in decreasing order was JP (1.11) > HH (1.03) > R (1.02) > DPH (0.97). The highest significance was observed between JP and DPH. Across all tillage methods, BD increased within 0-20 cm as the season progressed. Between 20 and 40 cm, BD increased under DPH, R as well as HH and decreased under JP as the season progressed. Despite the depth having no significance, DPH exhibited significant differences in the BD (Mg m^{-3}) values across the depths 0-20cm (1.01) and 20-40 cm (1.14) at harvest. DPH, R had higher values within 0-20 cm in comparison to 20-40 cm at the beginning of the season only while JP had higher values within 0-20cm in comparison to 20-40 cm during harvest only. HH had similar BD harvest within both depths at the season's beginning and lower values within 0-20 cm as compared to 20-40 cm at harvest.

Table 3.4: Bulk density (Mg m^{-3}), porosity (%) and saturated hydraulic conductivity (cm/hr), as influenced by tillage, time of measurement, and depth during LR and SR 2021

Soil properties	Depth (cm)	Tillage system																*p*-value					
		Disc ploughing + Harrowing				Ripping				Jab planter				Hand hoe									
		Time of sampling																					
		A	**B**	**x̄ Dp**	**x̄Tg**	**A**	**B**	**x̄Dp**	**x̄ Tg**	**A**	**B**	**x̄ Dp**	**x̄ Tg**	**A**	**B**	**x̄ Dp**	**x̄ Tg**	**Tg**	**Tm**	**Dp**	**Tg*Tm**	**Tg*Dp**	**Tg*Tm*Dp**
		LR 2021																					
Bulk density	0-20	0.95a	1.14a	1.05a	1.01a	0.95a	0.99a	0.97a	0.97a	0.97b	1.0a	0.98b	1.04a	0.96a	1.01a	0.98a	0.98a	0.3144	0.1053	0.3144	**<0.001**	**0.0388**	**0.0488**
	20-40	0.85a	1.11a	0.98a		0.98a	0.98a	0.98a		1.12a	1.07a	1.1a		1.07a	0.89a	0.98a							
Porosity	0-20	64.15a	57.04a	60.6a	61.85a	64.28a	62.7a	63.49a	63.29a	63.54a	62.3a	62.92a	60.77a	63.89a	61.75a	62.82a	62.97a	0.3192	0.1	0.5911	**<0.001**	**0.0373**	0.0517
	20-40	68.03a	58.19a	63.11a		63.05a	63.12a	63.08a		57.69b	59.54a	58.62b		59.93a	66.33a	63.13a							
Hydraulic conductivity	0-20	1.15a	0.50a	0.82a	0.96a	1.34a	1.25a	1.29a	1.19a	1.48a	1.14a	1.31a	1.01a	1.11a	0.91a	1.01a	1.04a	0.6421	**<0.01**	0.3434	**0.0255**	**0.0372**	0.3267
	20-40	1.54a	0.67a	1.10a		1.14a	1.05a	1.10a		1.18a	0.26a	0.72a		0.85a	1.31a	1.08a							
		SR 2021																					
Bulk density	0-20	0.88a	1.01b	0.93a	0.97b	0.97a	1.1a	1.03a	1.02ab	1.11a	1.13a	1.12a	1.11a	0.97a	1.04a	1.01a	1.03ab	**0.0047**	**<0.001**	0.4136	**<0.001**	0.1237	0.1565
	20-40	0.85a	1.14a	1.01a		0.86a	1.13a	1.01a		1.13a	1.07a	1.1a		0.97a	1.12a	1.04a							
Porosity	0-20	67.96a	61.7a	64.83a	63.45b	63.65a	58.5a	61.07a	61.61ab	58.14a	57.15a	57.64a	58.11b	63.35a	60.66a	62.01a	61.31ab	**0.0049**	**<0.001**	0.4414	**<0.001**	0.1254	0.1502
	20-40	66.94a	57.21b	62.08a		66.75a	57.56a	62.15a		57.63a	59.51a	58.57a		63.33a	57.92a	60.62a							
Hydraulic conductivity	0-20	1.60a	1.39a	1.49a	1.17a	1.52a	1.30a	1.41a	1.12a	1.39a	1.21a	1.30a	1.13a	1.44a	1.40a	1.42a	1.o8a	0.9694	**<0.001**	**<0.001**	0.6223	0.4342	**<0.001**
	20-40	1.47a	0.24b	0.86b		1.31b	0.35b	0.83b		1.21a	0.73a	0.97a		1.32a	0.18b	0.75b							

A: Beginning of the season, B: Harvest. x̄: Mean. Tg: Tillage, Tm: Time, Dp: Depth. Different letters down the columns indicate significant differences at a 5% probability level. Bold P-values are significant at $P < 0.05$.

The results indicated variations in total porosity during LR 2021 and SR 2021 within the range of 57% and 68% shown in Table 3.4. During LR 2021, tillage ($P=0.3192$) had no significant effect on total porosity. However total porosity values (%) were greatest under R (63.29), followed by HH (62.97) then DPH (61.85), and lastly JP (60.77). Similarly, time of measurement (0.1) and depth (0.5911) had no significant effects on total porosity. As the season progressed, total porosity decreased at the depth of 0-20cm for all tillage methods. At the depth of 20-40cm a decrease was observed under DPH with an increase under R, JP, and HH as the season progressed. Total porosity values were lower within 0-20cm in comparison to 20-40cm under DPH while the values were higher within 0-20cm as compared to 20-40cm under JP. HH and R had higher values within 0-20cm as compared to 20-40cm at the beginning of the season only. According to the study, there were significant interactions between tillage*time ($P<0.001$) and tillage*depth ($P=0.0373$) that influenced total porosity.

During the SR 2021 tillage ($P=0.0049$) and time of measurement ($P<0.001$) significantly influenced total porosity. The average trend of total porosity (%) established in decreasing order was DPH (63.45) > R (61.61) > HH (61.31) > JP (58.11). The highest significance was established between DPH and JP. At harvest, total porosity was lower than at the beginning of the season under all treatments in the depth of 0-20cm. Within 20-40cm total porosity decreased under DPH, HH as well as R and increased under JP as the season progressed. There was a significant difference in total porosity between the depths of 0-20cm (61.7%) and 20-40cm (57.21%) at harvest under DPH. DPH exhibited higher values within 0-20 cm as compared to 20-40 cm while R had a lower value within 0-20 cm as compared to 20-40 cm at the beginning of the season with JP exhibiting higher values within 0-210cm in comparison to 20-40cm at the beginning of the season only. HH had similar values at both depths at the season's beginning and lower values within 0-20 cm as compared to 20-40 cm at harvest. The observations also indicated a significant interaction between tillage and time ($P<0.001$).

The average trend in total Ksat (Table 3.4) in the LR 2021 in decreasing order was R > HH > JP > DPH at $P<0.05$. Tillage had no significant influence on Ksat. The observations further indicated a significant influence of time (WAP) and interaction between tillage and time (WAP). The depth

0-20cm exhibited higher Ksat values across the tillage methods, except for HH. Higher values were observed at the beginning of the season contrary to harvest time.

Similarly, during the SR 2021, tillage exhibited no significant influence on Ksat indicated in Table 3.4. However, the time of measurement and depth were found to be significant factors affecting this parameter ($P<0.001$). The average trend of Ksat in decreasing order was DPH > JP > R > HH at the significance level of $P < 0.05$. Generally, Ksat decreased as the season progressed across all tillage methods in both depths, with 0-20cm recording higher values.

3.4.5 Effect of tillage methods on soil nitrogen

During LR 2021, tillage significantly affected N (Table 3.5). The treatments R, JP, and HH exhibited higher amounts of N at the depth of 0-20 cm. The average observed trend of N was R > JP > HH > DPH ($P < 0.05$). Tillage and depth significantly influenced N during the SR 2021, $P < 0.001$ and $P < 0.01$ respectively (Table 4.4). Generally, the treatments had higher N values at the depth of 20-40 cm (Figure 3.4). The average observed of N was R > JP > DPH > HH.

Table 3.5: Soil nitrogen (%) at harvest as influenced by tillage and depth

Tillage method	Long rains 2021	Short rains 2021
DPH	0.3213b	0.3475b
R	0.5544a	0.5558a
JP	0.3513b	0.4113b
HH	0.3363b	0.3263b
Significance level		
Tillage	**<0.001**	**<0.001**
Depth	0.2684	**<0.01**
Tillage*Depth	0.8563	0.438

Tillage: DPH: disc ploughing and harrowing, R: ripping, JP: jab planter, HH: hand hoeing. Different letters down the columns indicate significant differences at a 5% probability level. Bold P-values are significant at $P < 0.05$.

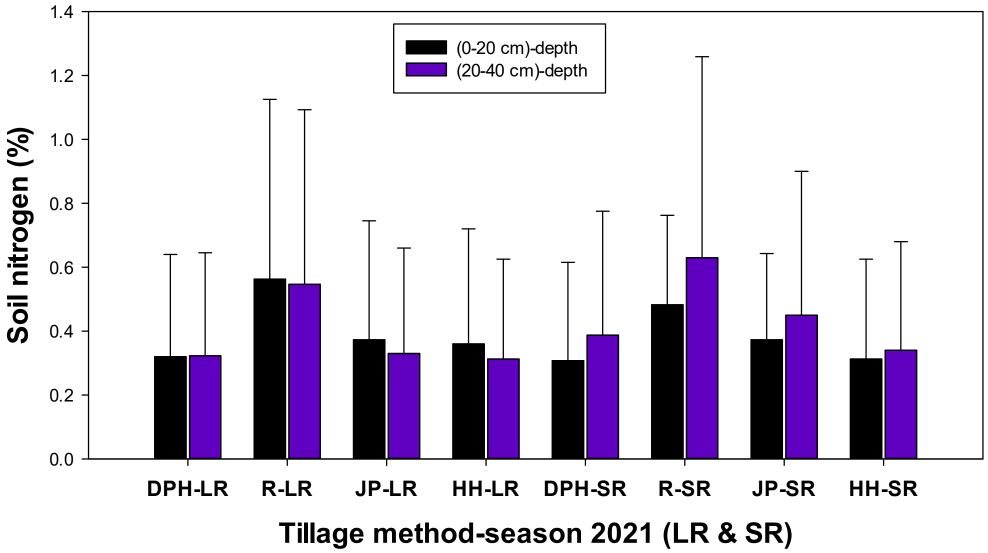

Figure 3.5: Influence of tillage and depth on nitrogen (%) during LR and SR 2021

3.5 Discussion

3.5.1 Effect of tillage methods on soil moisture content

Results showed a significant difference between the various tillage practices and soil moisture with the ripping method having the highest soil moisture result during both the long and short rain seasons. This could be attributed to less exposure to evaporation and increased infiltration through the ripped lines enhancing water storage. Correspondingly Zapata *et al*. (2021) in Texas, USA, observed that both CT and NT significantly influenced soil moisture with NT recording higher values under soybeans and wheat production. Tillage is a key factor in soil microclimate in agricultural production (Hatfield & Prueger, 1996; Zapata *et al*., 2021) including soil moisture.

Contrary to DPH and JP, R resulted in the added advantage of soil moisture content by 15.5% and 17.31% during the long rains; and 14.64% and 13.31% during the short rains respectively. Similarly, a study by (Bekele *et al*. (2022) conducted in Ethiopia for 3 years found that conservation tillage methods were more advantageous in soil moisture conservation; one-time tillage, two-time tillage, and no-tillage had 57%, 46.6%, and 41.1% respectively added advantage in soil moisture as compared to conventional tillage due to higher water infiltration. Conservation tillage methods that result in the formation of slots enhance rainwater harvesting and storage as compared to CNT and they result in reduced evaporation and steam transfer near the soil surface due to thermal insulation by crop residues (Kyalo, 2021). The study by Kyalo (2021) at Kenya Agricultural and Livestock Research Organization farm in Embu County, Kenya recorded higher moisture content under CT, furrow/ridge, and NT methods, contrary to CNT. To further support these findings (Bekele *et al*. (2022) and Temesgen *et al*. (2007) note that CT methods are suitable for arid and semi-arid areas as they increase grain yield and reduce drought risk by reducing surface runoff and increasing soil moisture storage. Therefore, ripping resulted in the accumulation of crop residues reducing evaporation and increasing infiltration of water.

While NT-JP exhibited the lowest moisture content relative to R and JP in the LR 2021 in this study, a study by Omondi (2013) in Rarieda, Western Kenya recorded higher values under NT relative to CNT. The sandy loam texture resulted in higher water losses under CNT through evaporation and deep percolation due to soil disturbance. Another study by Karuma *et al*. (2014b) in Mwala District, Kenya recorded higher moisture values under ox-ploughing (14.1%) relative to subsoiling-ripping (13.43%). While both tillage methods allowed water penetration to deeper soil layers, ox-ploughing did so to a greater extent.

During both seasons, ripping recorded the highest soil moisture at both 0-20cm and 20-40cm depths. JP exhibited the lowest moisture levels during long rains. This may be a result of limited water infiltration. Rusu *et al.* (2011) note that zero and minimum tillage methods may result in soil compaction in the first years of application, the compaction diminishes over time depending on soil type and its extent of degradation. This compaction reduces water infiltration leading to low moisture levels. DPH exhibited variations in soil moisture conservation across the two seasons, recording relatively high values during the long rains and lowest values during the short rains. This could be due to the reapplication of DPH during the short rains enhancing further soil exposure to evaporative soil moisture losses.

3.5.2 Effect of tillage methods on soil surface roughness

Soil surface roughness is significant in agriculture as it correlates with aspects such as erosion, runoff, and surface water storage which in turn has a direct effect on crop growth and yield (Thomsen *et al*., 2015). Tillage only significantly influenced SSR during the long rains. SSR is directly affected by management practices, rain and wind (da Rocha Junior *et al*., 2016; (Karuma *et al*., 2014b). Disc ploughing and harrowing had the highest values, however, during the short rains the HH as the control had higher values. These could be as a result of the high degree of soil disturbance for the two methods. The tillage depth of 35 cm of tillage under DPH contributed to SSR. In support, findings by da Rocha Junior *et al.* (2016) at the University of Illinois, USA, noted that SSR increases based on a tillage method that most disturb the soil surface. Further, Karuma *et al*. (2014b) attributed high SSR under DPH treatment to greater plough depth. Across both seasons SSR was highest after tillage as recorded by da Rocha Junior *et al.* (2016), Karuma *et al.* (2014b), and Miriti *et al*. (2013).

Jab planter, on the other hand, had the least SSR during both the long rain season and the short rain season. This may be due to zero soil disturbance as only seed and fertilizer slot is opened during planting. Correspondingly, findings by da Rocha Junior *et al.* (2016) indicated the least SSR value under no-tillage compared to bare soil, contour tillage, and downhill tillage attributed to the least soil disturbance. R had higher values than JP because of ripped lines forming furrows.

The highest decline in SSR was observed under DPH during the long rains by 2.71%. This may be a result of kinetic energy that occurs on rain drops during the rainy season having a direct impact on soil micro elevations and aggregates, leading to decreased SSR, especially on methods with most soil disturbance (da Rocha Junior *et al*., 2016). During the short rains, however, R had the highest decline of 2.46%. This may be due to the decomposition of crop residues.

3.5.3 Effect of tillage methods on Crust strength

Soil crust is significant in agriculture as it indicates the soil's ability to permit the flow of water through it (Miriti *et al*., 2013). Even though tillage had an insignificant influence on crust strength during both the long and short rains, JP had the greatest value, while the control treatment had the lowest followed by DPH and R respectively. This could be explained by increased soil disturbance in CNT methods breaking down the crusts. Moreover, low residue retention could have contributed to raindrop impact at the beginning of the seasons resulting in soil surface compaction. Corresponding observations were made by Gicheru *et al*. (2004) and Miriti *et al*. (2013) in Eastern Kenya where CT methods had higher penetration resistance than CNT methods. Further, a study by Shittu *et al.* (2017) in Obafemi Awolowo University Teaching and Research Farm, Nigeria recorded higher soil strength (0-15 cm) under NT compared to tillage under different moisture levels. Higher soil strength under NT was attributed to raindrop impact, surface sealing and crusting and soil compaction resulting from human traffic during weeding. Conversely, penetration resistance was 40% higher under CT contrary to NT in a study by Nebo *et al*. (2020) in Eastern Cape Province, South Africa attributed to soil crusting after 3 years of cropping.

The penetration resistance varied as the seasons progressed with significant interactions between tillage and time. This is likely due to changes and/or the extent of soil disturbance as well as crop growth and development. At the start of production, primary cultivation weakens the crust strength and then comes the first weeding and second weeding. Afterwards, the crops are left to continue growing without any disturbance. As crop roots continue expanding, they begin to bind soil particles together thus increasing crust strength, and tillage methods with hand hoe weeding tend to have the weakest crust strength (Miriti *et al*., 2013). In this case, all tillage methods exhibited the lowest penetration resistance values during both seasons after weeding. This is attributed to ploughing under DPH and HH as the control.

3.5.4 Effect of tillage methods on Bulk density and Porosity

Bulk density exhibited variations during long and short rains across the tillage methods. During the long rains, JP had the largest BD followed by DPH, HH, and R respectively despite tillage having insignificant effects on BD. Similarly, JP had the highest BD in the SR 2021, in both cases, this may have been attributed to the total non-inversion of soil in the treatment enhancing soil compaction. A study by Lampurlanés Castel and Cantero-Martínez (2003) at El Canós, Spain, recorded the largest BD (Mg m^{-3}) under no-tillage (1.34) contrary to the minimum (1.27) and subsoil (1.22) tillage methods. The study further noted that BD increases in no-tillage systems after the first years of introduction with no great limitations to root growth and expansion of well-structured soils. The high BD in DPH following JP in LR 2021 could be attributed to compaction by tractor wheels during harrowing (Karuma *et al.*, 2014b). Ripping had the lowest BD during the long rains which may be caused by the loosening of soil along ripped lines thus breaking down compacted layers. During the short rains, tillage significantly affected BD and DPH exhibited the lowest value, which may be due to the loosening of the soil during ploughing, harrowing and weeding. A study by Miriti *et al.* (2013) in Eastern Kenya equally observed that tillage significantly influenced BD.

Bulk density values (Mg m^{-3}) across both seasons ranged between 0.85 and 1.14 measured at the beginning of the season and harvest. This range was in line with a survey of the study site by (Mwendwa, 2021) who recorded a range of between 0.8 and 1.3 at 0-27cm soil depths. The range does not limit the growth of roots. Notably, variations in BD across the seasons were evident, for instance, while DPH exhibited high BD in LR 2021, it had the lowest value during SR 2021. Furthermore, DPH had the highest BD at 0-30cm which may be attributed to compaction during ploughing and harrowing; the lowest values at the same depth during SR 2021 could be due to soil loosening after tillage and weeding activities. These variations may have been attributed to the significance of tillage and time in SR 2021. In addition, variations may also result due to pan formation, topsoil composition (Alam *et al.*, 2014) raindrop impact (Miriti *et al.*, 2013) and slope (Mwendwa, 2021).

Porosity, which is a measure of the amount of open space or voids in the soil, is greatly influenced by the soil's bulk density. This is because it is calculated based on the relationship between the bulk density and particle density of the soil. While agricultural manipulations may not greatly alter the particle density of soil, they can greatly affect the bulk density, thereby changing the porosity of the soil (Karuma *et al.*, 2014b). Usually, porosity is inversely proportional to bulk density implying that an increase in BD results in a porosity decrease, this was observed in this study. Additionally, interactions between soil management, climate, and physical and mineral soil properties influence porosity (Mateo-Marín *et al.*, 2021).

As recorded in BD, tillage and time of measurement only significantly contributed to porosity during the short rains while interactions between tillage and time were significant during both seasons. In the long rains, R had the highest porosity, followed by HH, DPH, and JP respectively. During the short rains, the trend of porosity in decreasing order was DPH, R, HH, and JP. The trends were attributed to the changes in BD. Total porosity was observed in the range between 57% and 68% during both seasons.

3.5.5 Effect of tillage methods on Saturated hydraulic conductivity

Tillage had no significant effect on Ksat during both seasons as was recorded by Karuma *et al.* (2014b) and Miriti *et al*. (2013) in Eastern Kenya. Ripping and DPH exhibited highest Ksat va;ues during the long and short rains respectively. Loosening of soil during land preparation and low bulk densities in the tillage methods resulted in high Ksat values. High bulk density values result in low Ksat values (Miriti et al., 2013), however, this study recoreded variations in the relationship between bulk density and Ksat. Specifically, during the short rains, while ripping resulted in relatively low bulk density values, similary low Ksat values were observed under this method. Such variations are not uncommon and may be due to presence of roots, faunal channels, and stones in the soil (Mwendwa, 2021).

As noted during the LR 2021, low Ksat values observed under MT (subsoiling-ripping) have been linked to restricted lateral movement in unploughed sections in Eastern Kenya (Miriti et al., 2013). Conversely, in relations to the SR 2021 findings, Haruna et al. (2018) recorded higher Ksat values under CNT contrary to CT at Lincoln University's Freeman Center in the USA. In the study, CNT resulted in Ksat values that were 87% higher than no-tillage, attributed to a 32% increase in the proportion of coarse mesopores.

3.5.6 Effect of tillage methods on soil Nitrogen

Nitrogen is of great importance in crop production as a macronutrient. The method of tillage significantly affects the soil nitrogen component in the soil, especially in the upper layer of the soil, 0-30cm ((Hafif, 2014). Three aspects of soil nitrogen are critical when considering the effect of the various tillage methods on soil nitrogen, N-dynamic, mineralization, and emission. Total nitrogen was the focus of this study, as observed by Yuan *et al.* (2022) at Gansu Agricultural University, China, tillage significantly influenced soil nitrogen. The amount of total nitrogen present in soils can vary greatly, with some soils containing as little as 0.02% nitrogen, while others, such as peat soils, can have as much as 2.5% nitrogen (Hafif, 2014). This study recorded total nitrogen ranging from 0.3017% to 0.6293% at harvest.

R had the highest value during both LR 2021 and SR 2021, followed by JP. In comparison to the control, DPH had the lowest value during the long rains and higher during the short rains. The results are supported by a review by Hafif (2014) who points out that applications of CT methods in the long term provide a better contribution to total nitrogen than conventional methods. Similarly, the findings of Yuan *et al.* (2022) recorded higher total nitrogen values under CT in comparison to conventional tillage.

High values under R and JP could be explained by minimal and zero exposure to soil, respectively. The more the soil disturbance, the lower the level of soil nitrogen (Hafif, 2014; Yuan *et al*., 2022). Nitrogen mineralization increases with a decrease in intensity of tillage while soil disturbance as a result of CNT methods enhances losses of various forms of total nitrogen. The CNT methods can negatively impact soil fertility by disrupting the surface soil, damaging the structure of the plough layer, and resulting in reduced nutrient levels and a decline in soil organic matter *(Yuan et al*., 2022). Moreover, CT through reduced or no tillage preserves soil structure and organic matter which may contribute to total nitrogen.

Depth was a significant factor during the short rains. Studies by Dessureault-Rompré *et al*. (2016) in Western Canada and Qaswar *et al*. (2022) and Southern China recorded a decrease in nitrogen with increasing depth, however, this study recorded variations in total nitrogen with depth. This may be a result of variations in interactions between tillage, depth, soil microorganisms present, organic matter, erosion, climate, and soil compaction.

3.6 Conclusion

Tillage significantly influenced soil moisture and total nitrogen during both the long and short rains, with notable effects on SSR and bulk density observed specifically during the short rains. Ripping resulted in the highest soil moisture and total nitrogen contents. Disc ploughing and harrowing, along with the farmer's common practice of HH, recorded elevated SSR values, even though disc ploughing and harrowing (DPH) realized the lowest moisture values during the short rains. Jab planting (JP) recorded the highest bulk density and crust strength values across both seasons.

CHAPTER FOUR: EFFECT OF TILLAGE METHODS ON MAIZE GROWTH AND YIELD

4.1 Abstract

Maize is a staple food in Kenya and is adapted to diverse agroecological zones and is produced by a significant proportion of smallholder farmers. This crop has an important significant impact on the national food reserve. However, there is a decline in its production due to constraints on climate and soil factors. A trial was conducted to determine the effect of tillage on maize growth and maize yield parameters on the soils of the experimental fields of Upper Kabete Campus, University of Nairobi for two rainy seasons, long rains (LR) and short rains (SR) in 2021. The tillage methods used were Disc Ploughing and Harrowing (DPH), Ripping (R), Jab Planter (JP), and Hand Hoe (HH). The trial was laid on a Randomized Complete Block Design (RCBD) with four replicates., Maize height, maize leaf area (LA), maize leaf area index (LAI), and maize grain and biomass yields were all influenced by tillage methods. Ripping recorded the highest mean maize height during the long and short rains compared to DPH, JP and HH. Tillage influence on maize height was however statistically insignificant in this study, as was the case for LA and LAI. The average observed trend for both LA and LAI were DPH > JP > HH > R during LR 2021 and HH > DPH > R > JP during SR 2021. Maize grain yields were significantly affected by the tillage methods during LR 2021 and SR 2021 ($P<0.05$). The grain yield (Mg/ha) varied in decreasing order of R > DPH > JP > HH in LR 2021 and R > DPH > HH > JP in SR 2021 with the higher grain yields attained in SR 2021 irrespective of tillage. The effect of tillage on the maize biomass yields (Mg/ha) was statistically insignificant in this study, R and HH recorded the highest biomass yields during LR and SR 2021 respectively. Amongst the selected methods in this study, ripping is recommended as the best alternative for improved maize growth and better yields.

4.2 Introduction

Maize production in Kenya occurs under diverse climatic zones with smallholder farmers accounting for the largest share of its production estimated to be 70 % (Kang'ethe *et al.*, 2020). Despite the benefits enjoyed by the smallholder farmer due to its cultivation, the production per hectare in Kenya has declined and remains relatively low with an estimate of 1,440 kg to 1,836 kg relative to 5,751 kg globally and an estimate of 2,070 kg elsewhere in Africa (FAOSTAT, 2019; Kang'ethe *et al.*, 2020). The diminished productivity is linked to moisture stress and loss of soil fertility (Okalebo *et al.*, 2007; Otieno *et al.*, 2020). Water constraints are an important factor limiting crop production in many cropping zones (Kumar *et al.*, 2022). The decline in rainfall received has been a major challenge in the production of maize in Kenya coupled with an extended period of drought spell (Otieno *et al.*, 2020) or delayed rainfall that contribute to reduced grain yields. In reference to the relief web report (2023), this has been a contributor to chronic hunger and deaths, especially in the drier parts of the country.

There is a need to maximize the limited rainfall by increasing water use efficiency (Kumar *et al.*, 2022). Soil constraints have been significant in hindering maize production as explained by high soil fertility depletion *(Otieno et al.*, 2019, 2020) and the diminishing of soil health through degradation. To address such constraints, adoption of appropriate tillage methods that contribute to moisture and nutrient conservation is critical. These methods will in turn enable the realization of maximum grain yields. Adoption of good agronomic practices (GAP) is important for crop production (Otieno *et al.*, 2020), as such, there is a need to use a more sustainable and integrated approach in the conservation of soil towards the realization of improved yields. This includes no-tillage, proper residue management programs (Otieno *et al.*, 2019b), and reduced tillage methods. Soil tillage has been reported as among the factors that affect crop yields and is regarded to be the most important practice in land preparation that makes the soil physically, chemically and biologically suitable for germination and plant growth (Alam *et al.*, 2014).

Several studies have noted that indeed tillage methods significantly affect growth parameters (Bk & Shrestha, 2014), with variations between CT and CNT methods. Loss of soil organic matter that is crucial for crop growth is aggravated with the continuous use of CNT (Powlson *et al.*, 2012). A study by Ogega *et al.*, (2023) in Embu, Kenya notes that CT methods enhance improved crop yields relative to CNT methods. The study recorded higher maize and beans yields under CT, 4.18 tons/ha and 3.58 tons/ha, contrary to CNT, 1.98 tons/ha and 1.78 tons/ha respectively; with both methods interacting with NPK, Zn, B, Mg, Ca, and S nutrients. On the other hand, Sornpoon and Jayasuriya (2013) recorded higher grain yields under CNT methods relative to no-tillage in Phitsanulok Province, Thailand. According to the study, sufficient deep ploughing of maize fields was more effective in improving maize biomass yields than shallow ploughing. This can be attributed to improved root penetration into the lower horizons to exploit leached nutrients. This study aimed to evaluate the implication of tillage methods on the growth and yields of maize and to give a recommendation of the appropriate tillage methods to produce maize.

4.3 Materials and Methods

The study site, experimental design and layout, and field management were described in sections 3.3.1, 3.3.2 and 3.3.3 in the order.

4.3.1 Measurement of crop growth and, yield parameters

Several maize parameters were considered to assess crop growth: maize height, leaf area, leaf area index, maize stover yield, and maize grain yield. Maize height (cm) was measured using a measuring tape from the base of the plant to the top-most extended leaf, and also to the uppermost part of the tassel once the tasseling process began (Karuma et al., 2016). To determine the leaf area, the leaf length was taken, as well as the widest part of the leaf using a measuring tape. After that, the area was multiplied by a factor of 0.75, which is set as the maize calibration factor (Musa & Usman, 2016). The formula used was:

$$\text{Single leaf area} = \text{L x W x K}$$

Where, L = Leaf length (cm), W = Maximum leaf width (cm), K = Coefficient

To establish the leaf area index (LAI), the total leaf area of a plant was taken, divided by the ground area of the plant. The parameters were assessed throughout the growing seasons. 3 randomly selected plants per plot were monitored for plant height, leaf area, and leaf area index throughout the season.

The formula for LAI:

$$\mathrm{LAI} = \frac{\text{Leaf area} \quad (\mathrm{m}^2)}{\text{Ground area2} \ (\mathrm{m}^2)}$$

Sampling for above-ground biomass (AGB) and grain yield was done from 3 rows by 3m (4.5 m^{-2}) at the centre of each plot during harvest. Sampled plants were harvested by cutting at ground level (Munyao *et al*., 2019). Maize ears were manually separated from husks and samples were weighed at the field. Subsamples for stover were then collected, weighed, and taken to the laboratory for further analysis for dry weight. The subsamples placed in labelled khaki bags were oven dried to a constant weight at 60 °C for 72 hours (Muigai *et al*., 2021). Dry weight was determined upon drying. Grain yield was determined at a moisture content of 12% and a shelling percentage of 80% (Tandzi & Mutengwa, 2019). Biomass and grain yields were calculated according to the net experimental plot and later adjusted to metric tons per hectare (tonnes per hectare=Mg ha^{-1}). The following formulae were used for AGB (Bell & Fischer, 1994):

$$\mathrm{DWS} = \mathrm{DWSS} + \frac{\mathrm{FWS}}{\mathrm{FWSS}}$$

Where DWS= Total dry weight (g), DWSS= Subsample dry weight (g), FWS= total sample fresh weight (g), FWSS= subsample fresh weight (g).

$$\mathrm{TDW} = \frac{\mathrm{DWS}}{\mathrm{A}}$$

Where, TDW= Standing biomass (g) and A=plot area m^{-2}

Grain yield was calculated as follows (Tandzi & Mutengwa, 2019):

$$\mathrm{GY} = \frac{\mathrm{Fwt\ x\ (100 - MC)\ x\ 0.8\ x\ 10}}{\mathrm{100 - adjusted\ MC\ x\ Plot\ area}}$$

Where GY is grain yield (t/ha), Fwt is fresh ear weight in Kg, MC is the moisture content of grains at harvest, and adjusted MC is adjusted moisture content of 12.5% (Karuma *et al.*, 2016; Kebede, 2019) and 0.8 is the shelling coefficient (Tandzi & Mutengwa, 2019).

4.4 Results

4.4.1 Effect of tillage methods on maize height

The maze height increased progressively throughout the season within all the treatments during both the LR 2021 and SR 2021 (Figures 4.1 and 4.2). Tillage had no significant effects on the heights. Time (WAP) however had significant effects on the height at P< 0.001 (Table 4.1). The average observed trend of the parameter during the LR 2021 in decreasing order was R > DPH > JP > HH; during the SR 2021, the trend was R > DPH > HH > JP.

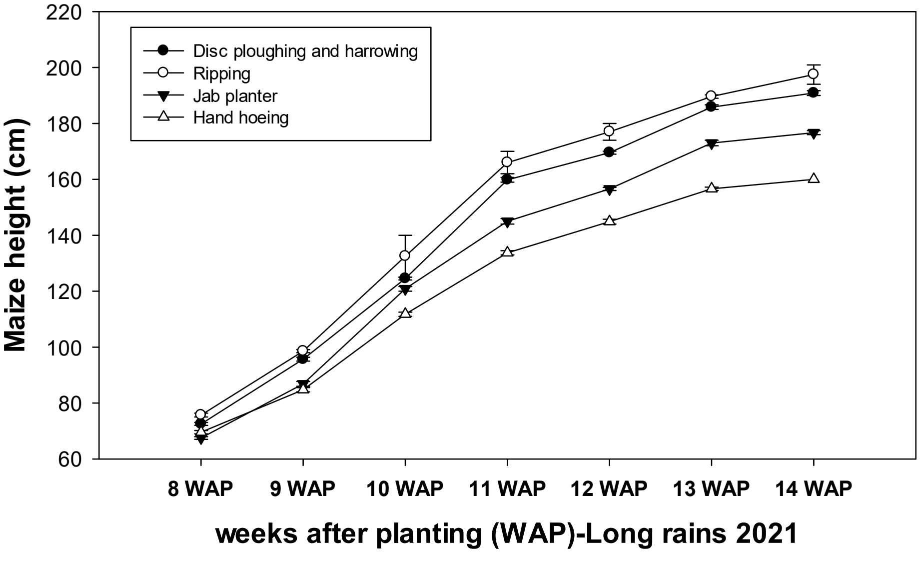

Figure 4.1: Maize height (cm) as influenced by tillage and time of measurement during LR 2021

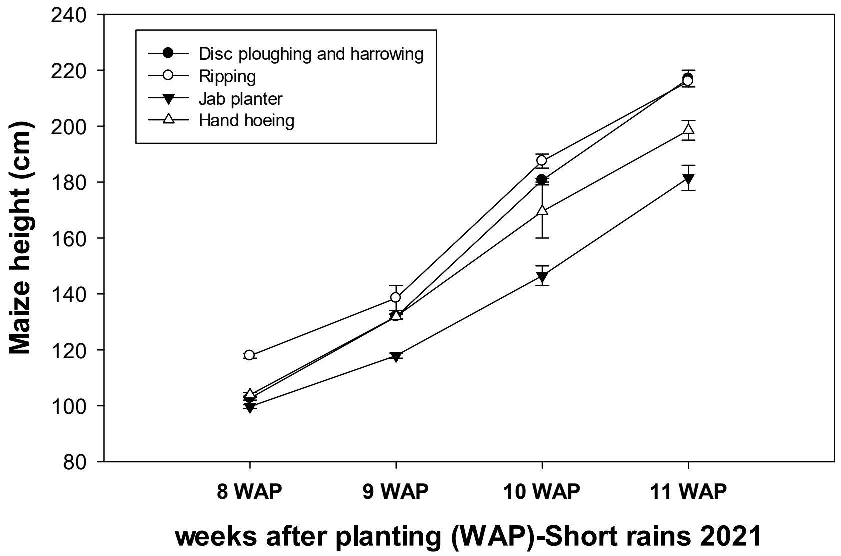

Figure 4.2: Maize height (cm) as influenced by tillage and time of measurement during SR 2021

Table 4.1: Maize height (cm) as influenced by tillage and time of measurement

Tillage method	**Long rains 2021**	**Short rains 2021**
DPH	143.36a	158.32a
R	146.68a	161.42a
JP	133.13a	137.83a
HH	123.7a	155.28a
Significant levels		
Tillage	0.1693	0.3457
Time	**<0.001**	**<0.001**
Tillage*Time	0.8037	0.0892

Tillage: DPH: disc ploughing and harrowing, R: ripping, JP: jab planter, HH: hand hoeing. Different letters down the columns indicate significant differences at a 5% probability level. Bold *P*-values are significant at P < 0.05.

4.4.2 Effect of tillage on maize leaf area (LA) and leaf area index (LAI)

Tillage exhibited no significant effects on LA and LAI during both seasons, LR 2021 and SR 2021 (Tables 4.2 and 4.3). The average observed trend for both parameters in the LR 2021 was DPH > JP > HH > R; the observed trend during the SR 2021 was HH > DPH > R > JP. Time of measurement significantly affected LA and LAI during both seasons ($P < 0.001$).

Table 4.2: Maize leaf area (m^2) as influenced by tillage methods and time of measurement during long and short rains 2021

Tillage method	Long rains 2021								Short rains 2021				
	8WAP	9WAP	10WAP	11WAP	12WAP	13WAP	14WAP	Mean	8WAP	9WAP	10WAP	11WAP	Mean
DPH	0.0375a	0.0475a	0.0575a	0.0525a	0.0525a	0.0525a	0.045a	0.0493a	0.055b	0.0675ab	0.0725a	0.0675ab	0.0656a
R	0.0325b	0.0475ab	0.05a	0.0475ab	0.0475ab	0.0450ab	0.045ab	0.045a	0.0575a	0.06a	0.0675a	0.065a	0.0625a
JP	0.0275b	0.0475a	0.0575a	0.055a	0.0525a	0.0525a	0.0475a	0.0486a	0.055a	0.0625a	0.065a	0.06a	0.0606a
HH	0.093b	0.045ab	0.07a	0.05ab	0.0475ab	0.045ab	0.0475ab	0.0479a	0.055a	0.0775a	0.07a	0.065a	0.0669a
Significant level													
Tillage					0.4876						0.355		
Time					**<0.001**						**<0.01**		
Tillage*Time					0.2453						0.6492		

Tillage: DPH: disc ploughing and harrowing, R: ripping, JP: jab planter, HH: hand hoeing. Different letters down the columns indicate significant differences at a 5% probability level. Bold P-values are significant at $P < 0.05$.

Table 4.3: Maize leaf area index as influenced by tillage methods and time of measurement during long and short rains 2021

Tillage method	Long rains 2021								Short rains 2021				
	8WAP	9WAP	10WAP	11WAP	12WAP	13WAP	14WAP	Mean	8WAP	9WAP	10WAP	11WAP	Mean
DPH	0.1775a	0.2325a	0.265a	0.2575a	0.25a	0.25a	0.2425a	0.2393a	0.27b	0.32ab	0.34a	0.325ab	0.3138a
R	0.1575b	0.2225ab	0.245a	0.2325ab	0.23ab	0.2275ab	0.215ab	0.2186a	0.275a	0.2875a	0.3275a	0.315a	0.3013a
JP	0.1325b	0.215a	0.275a	0.25a	0.2525a	0.2525a	0.2375a	0.2307a	0.27a	0.2975a	0.3075a	0.2975a	0.2931a
HH	0.145b	0.205ab	0.3175a	0.23ab	0.2275ab	0.2175ab	0.21ab	0.2218a	0.275a	0.3755a	0.3225a	0.305a	0.3188a
Significant level													
Tillage	0.4175								0.4684				
Time	**<0.001**								<0.01				
Tillage*Time	0.5072								0.5827				

Tillage: DPH: disc ploughing and harrowing, R: ripping, JP: jab planter, HH: hand hoeing. Different letters down the columns indicate significant differences at a 5% probability level. Bold P-values are significant at $P < 0.05$.

4.4.3 Effect of tillage methods on maize grain and biomass yields

Tillage significantly affected maize grain yields, P< 0.0284 and P < 0.01, during the LR 2021 and SR 2021 (Figure 4.3). The average observed trend during the LR 2021 was R > DPH > JP > HH, while the trend was R > DPH > HH > JP. Grain yields were higher during SR 2021

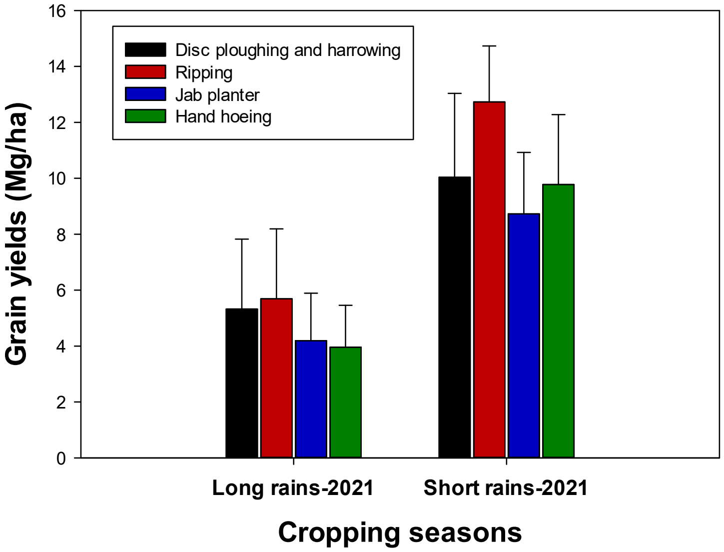

Figure 4.3: Maize grain yields as influenced by tillage

Maize biomass yields were not significantly affected by tillage: LR 2021 P = 0.1593 and SR 2021 P= 0.7928 (Figure 4.4). The average observed trend of biomass yields according to tillage treatments was R > DPH > JP > HH during the LR 2021 and HH > R > DPH > JP during the SR 2021.

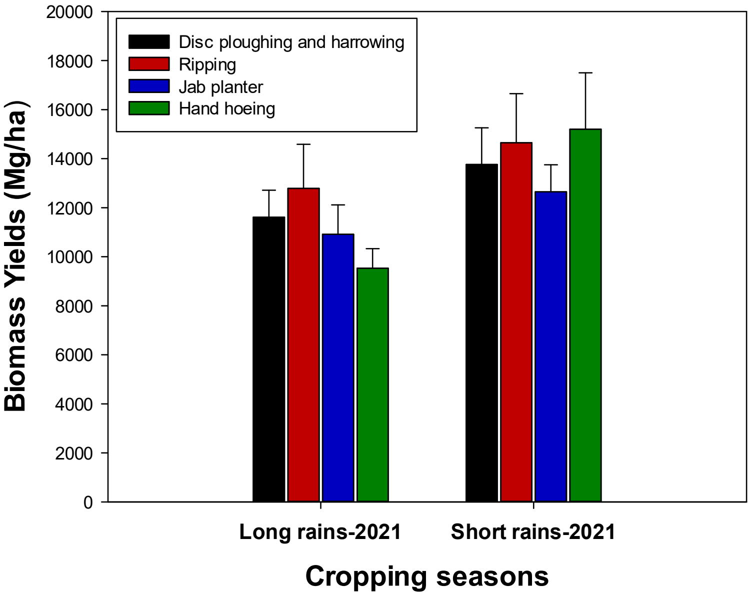

Figure 4.4: Maize biomass yields as influenced by tillage

4.5 Discussion

4.5.1 Effect of tillage methods on maize height

Ripping had the tallest plant height followed by DPH in both seasons. In comparison with HH as the control, JP ex had the shortest height during the short rains. High moisture values under R (LR and SR) and DPH (LR) contributed to the crop heights. During the SR 2021, tall plant heights under DPH could be due to low bulk density and high Ksat values enhancing water availability for root uptake. In this case, minimum tillage had better results than tillage and no-tillage methods. Similarly, minimum tillage recorded higher plant heights in comparison with NT and CNT under green gram production in Katumani and Mwea areas of Kenya (Hakim *et al.*, 2022). Contrarily, the study by Karuma *et al.* (2016) recorded higher values under DPH as compared to disc ploughing, ox-ploughing, subsoiling-ripping, hand hoeing with tied ridges, and hand hoeing.

The height progressively increased with time which was a significant factor ($P< 0.001$) in both seasons. Although obvious that crops get taller with time, there are instances where crops may experience stunted growth for one reason or another including for nutritional reasons. When all other factors remain constant, time is of the essence because it enables a farmer to keep their records and know when to expect to carry out various agronomic practices such as first weeding and other activities at different times of the season.

4.5.2 Effect of tillage methods on maize leaf area (LA) and leaf area index (LAI)

Tillage had insignificant effects on LA and LAI. Excluding the control treatment, DPH had the highest values for both seasons, while R and JP had in LR 2021 and SR 2021 respectively. These findings collaborate with those recorded by Abagandura *et al*. (2017) in Jabal al Akhdar, Libya, (Aikins & Afuakwa, 2012) in Kumasi, Ghana, and Otieno *et al.* (2020) in Alupe, Embu, and Kirinyaga areas of Kenya, which show the highest LA and LAI under conventional tillage and the lowest values of the same under zero tillage methods.

There was a variation in the maize LA and LAI in the two seasons. This variation may have been attributed to factors such as individual maize root spread and the ability to sufficiently have access to and uptake soil moisture, an observation also made by (Karuma *et al*., 2016) in Mwala Sub County, Kenya. Ploughing and other forms of deep tillage can damage LA and LAI, as they can disrupt the root system and result in reduced plant growth. Conversely, reduced tillage methods such as minimum tillage or no-till can increase LA and LAI by promoting root growth and allowing the plants to devote more energy to leaf development. In addition to the direct effects on maize plant growth, tillage practices can also affect LA and LAI indirectly by altering soil properties such as water retention and nutrient availability. For example, no-till practices can enhance soil structure and increase water retention, leading to increased plant growth and higher LA and LAI (Malekian *et al*., 2012). Overall, the effect of tillage practices on maize LA and LAI is complex and depends on a variety of factors such as soil type, climate, and crop management practices.

4.5.3 Effect of tillage methods on maize grain and biomass yields

Similar trends were recorded for both grain and biomass yield across the two seasons, long and short rains. Apart from the control, R had the highest yields followed by DPH and JP respectively. The high yields under R could be attributed to the high soil moisture and nitrogen contents. In line with the lowest yields in JP, a study by Abagandura *et al*. (2017) at Jabal al Akhdar, Libya, recorded the lowest yields under zero tillage in comparison with ridge and conventional tillage methods attributed to lack of loosening the soil thereby limited favourable conditions for crop growth and yields. During both seasons, JP had relatively high total nitrogen contents and sufficient moisture during the second season. However, the method exhibited high bulk density values limiting available water capacity, soil porosity, nutrient availability for plant use and soil microbial activity essential for crop growth and development. Owing to the former reason, farmers' common practiced of HH recorded better yields than JP. A study by Otieno *et al*. (2020) in Kenya indicated variations in conventional and no-tillage methods: conventional tillage, 4.9 Mg ha^{-1} and 3.5 Mg ha^{-1} recorded higher yields than zero tillage, 4.3 Mg ha$^{-1,}$ and 3.2 Mg ha^{-1}, at Kirinyaga and Alupe respectively, while at Embu zero tillage (5.4 Mg ha^{-1}) exhibited higher yields than conventional tillage (5.0 Mg ha^{-1}). Additionally, Karuma *et al*. (2016) recorded the highest yields under DPH as compared to disc ploughing, ox-ploughing, subsoiling–ripping, hand hoeing with tied ridges, and hand hoeing at Machakos, Kenya.

The effect of tillage on maize yields is not always consistent and can be influenced by various factors such as soil type, rainfall, season, and crop management practices. The higher grain yields during SR 2021 contrary to LR 2021 were because of higher rainfall (Appendix 2) and improved soil conditions. In addition, reduced tillage practices in drylands may be less effective at improving maize yields due to lower water availability (Karuma *et al*., 2014a). In certain soil types, reduced tillage practices may also be less effective at increasing maize yields due to lower nutrient availability. On the other hand, deep tillage practices like ploughing can damage root systems and decrease plant growth, resulting in lower yields. Reduced and no-till methods, on the other hand, can improve maize yields by promoting root growth and enabling plants to allocate more energy to grain and biomass production (Wang *et al*., 2015; You *et al*., 2017).

4.6 Conclusion

This study aimed to establish the effects of DPH, R and JP against the farmer's practice of HH on maize height, LA, LAI and grain and biomass yields. The crop height, leaf area and leaf area index were insignificantly influenced by tillage. Ripping recorded the tallest plant heights, while DPH had the greatest LA and LAI across the two cropping seasons. Tillage significantly influenced grain yields with R recording the highest during both seasons.

CHAPTER FIVE: EFFECT OF TILLAGE METHODS ON FINANCIAL RETURNS OF MAIZE

5.1 Abstract

Maize is the most important food crop in Kenya with a net capital consumption of over 98 kg per year and 85% of the Kenyan population depends on it directly or indirectly. The productivity of this food crop remains low, and this can be attributed to the high cost of production, including farm inputs, land preparation and other important inputs used for successful production. A study was conducted to ascertain the financial returns of maize production under different tillage methods: Disc Ploughing and Harrowing (DPH), Ripping (R), Jab Planter (JP), and Hand Hoe (HH). The experiment was conducted during the long rains (LR) and short rains (SR) of 2021 on the experimental fields of Upper Kabete Campus, University of Nairobi, and the trial was set up on a Randomized Complete Block Design (RCBD) with four replicates. The financial performance was evaluated using partial budgeting and marginal analysis which factored in the direct costs of production. In each tillage method, the grain yield was reduced by 10% to reflect the loss of grains at the farm level during the farmer's practice. The actual costs of production considered were maize seeds, fertilizers, pre-emergent and post-emergent herbicides, and labour in both seasons. Results from this study indicated that the production of maize in USD was the cheapest under JP in the LR 2021 and HH in the SR 2021. Net benefits in decreasing order were R > DPH > JP > HH in LR 2021 and R > DPH > HH > JP in SR 2021. In this study, ripping proved to be the most profitable tillage method for maize production.

5.2 Introduction

The maize crop is the most significant in Kenya with a capital consumption of 98 Kg per year (Kang'ethe *et al*., 2020), and failure to produce this crop results in a significant loss in the Kenyan food reserve. Maize is a staple food in Kenya and is mainly produced by small holder farmers (Muui *et al.*, 2010). Despite the importance of this crop for both the Kenyan economy and population, its productivity remains low with an estimate of below 1 t/ha and more below that in some producing zones (Otieno *et al*., 2020). The low productivity is attributed largely to high input costs which automatically contributes to higher production cost, soil fertility limitations (Otieno *et al*., 2018), and socio-economic barriers.

The constraint of low soil fertility in most production zones is attributed to the inefficient use of fertilizers (Otieno e*t al*., 2019) and the inability to use production inputs such as fertilizers is brought about by the rising cost of the inputs across the country and coupled with the use of the traditional tillage method (ReliefWeb, 2023). The traditional tillage methods disrupt the soil structure and it is labor intensive and requires more production inputs that are capital intensive (Otieno *et al*., 2019). Conservation agriculture has been associated with economic benefits that improve production efficiency (Shrestha *et al*., 2020). Research in Eastern Kenya by Micheni *et al*. (2015) recorded higher costs of production in maize-legume systems under CNT relative to CT, leading to higher net benefits with a 12% income increase under CT. Further, (Otieno *et al*., 2019) recorded KES 29,569 higher NB under no-till with crop residue retention relative to CNT without crop residue retention. Conservation tillage improves yields of different crops hence farmers gain huge profit margins as a result of increased better agronomic management (Shrestha *et al*., 2020). To absorb the high production cost farmers are required to maximize the yields and one of the major constraints experienced in the production of maize is the long periods of drought or rainfall variability. Water stress is a major cause of the poor yields in maize and CT has the potential to address the challenge (Bk & Shrestha, 2014; (Otieno, *et al*., 2019). Other studies note that CNT methods are more profitable than CT methods. A study in Western Kenya by Kihara *et al*., (2011) recorded lower yields and revenue under reduced tillage relative to CNT.

A sustainable approach is needed to alleviate the financial constraint in maize production and a cost-effective tillage method needs to be adopted. Adopting a tillage method that improves soil health, contributes to good residue management, results in minimal disturbance of the soil, and uses organic farm inputs is critical (Giller *et al.*, 2011; Vanlauwe *et al.*, 2010). Before promoting the adoption of any new production technology financial benefits need to be determined as an assurance of the return to investments, hence, an experiment was carried out to determine the economic benefits of maize production under the different tillage methods.

5.3 Materials and Methods

The study site, experimental design and layout, and field management were described in sections 3.3.1, 3.3.2 and 3.3.3 in the order.

5.3.1 Financial returns analysis

Gross margin analysis was done to assess maize performance under the different tillage methods. Partial budgeting was done using methodology as outlined by CIMMYT (1988). The budgeting was done on a hectare basis in US dollars (USD). Average costs of production per treatment were used as recorded in Tables 5.1 and 5.2. Actual costs of production were considered throughout the growing season. Direct costs of establishing and management of the plots included land preparation, labour costs, and purchase of inputs including seed, fertilizer as well as herbicides. These were summed up as total variable costs (TVC).

Table 5.1: Average cost of production (in USD) for maize under different tillage methods long rains 2021 season

Variable costs (USD)	DPH	R	JP	HH
Labour costs				
Land preparation	129.75	95.95	56.72	113.43
Planting and fertilizer application	56.72	56.72	56.72	56.72
Pre-emergent herbicide application	0	28.36	28.36	0
Post-emergent herbicide application	0	28.36	28.36	0
First weeding	56.72	0	0	56.72
Second weeding	56.72	0	0	56.72
Harvesting	56.72	56.72	56.72	56.72
Total labour costs	356.63	266.11	226.88	340.31
Input costs				
Maize seed SC Duma 43	50.15	50.15	50.15	50.15
Pre-emergent herbicide (Primagram gold 660Sc)	0	49.24	49.24	0
Post-emergent herbicide	0	49.24	49.24	0
DAP	202.79	202.79	202.79	202.79
Total inputs costs	252.94	351.42	351.42	252.94
Total variable costs (labour + input costs)	609.57	617.53	578.3	593.25

DPH = Disc ploughing and harrowing, R = Ripping, JP = Jab planter, HH = Hand hoeing, average exchange rate 2021 1 USD = KES 109.67

Table 5.2: Average cost of production (in USD) for maize under different tillage methods short rains 2021 season

Variable costs (USD)	DPH	R	JP	HH
Labour costs				
Land preparation	101.39	67.6	56.72	85.07
Planting and fertilizer application	56.72	56.72	56.72	56.72
Pre-emergent herbicide application	0	28.36	28.36	0
Post-emergent herbicide application	0	28.36	28.36	0
First weeding	56.72	0	0	56.72
Second weeding	56.72	0	0	56.72
Harvesting	56.72	56.72	56.72	56.72
Total labour costs	328.27	237.76	226.88	311.95
Input costs				
Maize seed SC Duma 43	54.71	54.71	54.71	54.71
Pre-emergent herbicide (Primagram gold 660Sc)	0	49.24	49.24	0
Post-emergent herbicide	0	49.24	49.24	0
DAP	225.32	225.32	225.32	225.32
CAN	202.79	202.79	202.79	202.79
Total input costs	482.82	581.3	581.3	482.82
Total variable costs (labour + input costs)	811.09	819.06	808.18	794.77

DPH = Disc ploughing and harrowing, R = Ripping, JP = Jab planter, HH = Hand hoeing, average exchange rate 2021 1 USD = KES 109.67

Financial returns were based on yields of maize under the treatments according to the prevailing market cost. The yields as computed were adjusted downwards by 10% to account for field and post-harvest losses (CIMMYT, 1988; Karuma *et al*., 2020). Total variable costs were computed as a sum of input and labour costs. Gross benefit (GB) was established by multiplying adjusted grain yields with the market price at harvest. Net benefits were obtained by subtracting TVC from GB.

To compare the costs and benefits of the different tillage methods, a marginal analysis was conducted through dominance analysis and calculating the marginal rate of return (MRR) for non-dominated tillage methods. The dominance analysis involves arranging the tillage methods in increasing order of total variable costs and identifying those systems as dominated if their net benefits were equal to or less than the preceding systems (CIMMYT, 1988).

MRR of non-dominated methods was calculated using the formula (CIMMYT, 1988):

$$\text{MRR} = \frac{\text{Net benefit}}{\text{Net cost}}$$

Lastly, the benefit-cost ratio (BCR) was computed through the formula:

$$\text{BCR} = \frac{\text{Net benefit}}{\text{Total variable cost}}$$

5.4 Results

Financial analysis, done on a hectare basis in US dollars (USD) included average costs of production per treatment as recorded in Tables 4.8 and 4.12. Prevailing market prices for inputs at planting and output at harvest were used in calculations. Input costs varied across the seasons, being higher during the short rains contrary to the long rains. Maize seed cost USD 5.02 and USD 5.47 per 2 kg packet, DAP fertilizer cost USD 41.03 and USD 45.59 per 50 kg bag during the long and short rains respectively. CAN, applied during short rains only, was USD 41.03. Primagram Gold 660 SC, a pre-emergent herbicide, costs 16.43 USD per litre while the post-emergence herbicide, Innovate 240 SC was 164.13 USD per litre. The daily wage rate was 5.67 USD for all activities in the seasons.

Total variable costs in USD in LR 2021 were in the order of R (617.53) > DPH (609.57) > HH (592.25) > JP (578.30). Similar trends in USD were observed (R > DPH > JP > HH) in gross benefits (4201.70 > 3930.88 > 3093.83 >2129.49), net benefits (3584.17 > 3321.31 > 2515.53 > 2328.24), and benefit-cost ratios (5.8 > 5.45 > 4.35 > 3.92) indicated in the partial budget (Table 5.3). Dominance analysis led to the elimination of HH (Table 5.4). Calculation of the marginal rate of return was done using the remaining non-dominated treatments. MRR between JP and DPH was 2577% while between DPH and R it was 3302% (Table 5.5).

Table 5.3: Partial budget and BCR of maize under different tillage methods during the LR 2021 season

	DPH	R	JP	HH
Grain yields (t/ha)	5.32	5.69	4.19	3.96
Adjusted grain yields (t/ha)	4.79	5.12	3.77	3.56
Gross Benefits (USD)	3930.88	4201.7	3093.83	2921.49
Total Variable Costs (USD)	609.57	617.53	578.3	593.25
Net Benefits (USD)	3321.31	3584.17	2515.53	2328.24
Benefit Cost Ratio	5.45	5.8	4.35	3.92

DPH = Disc ploughing and harrowing, R = Ripping, JP = Jab planter, HH = Hand hoeing, average exchange rate 2021 1 USD = KES 109.67

Table 5.4: Dominance analysis during the LR 2021 season

Treatment	Total Variable Costs (USD)	Net Benefits (USD)
JP	578.3	2515.53
HH	593.25	2328.24 D
DPH	609.57	3321.31
R	617.53	3584.17

DHP = Disc ploughing and harrowing, R = Ripping, JP = Jab planter, HH = Hand hoeing, average exchange rate 2021 1 USD= KES 109.67

Table 5.5: Financial returns of non-dominated tillage treatments during the LR 2021 season

Tillage	Grain yield	Adjusted grain yield	Total gross income (USD)	TVC (USD)	NB (USD)	MC	MB	MRR	BCR
JP	4.19 t/ha	3.77 t/ha	3093.83	578.3	2515.53				4.35
DPH	5.32 t/ha	4.79 t/ha	3930.88	609.57	3321.31	31.27	805.79	2577%	5.45
R	5.69 t/ha	5.12 t/ha	4201.7	617.53	3584.17	7.96	262.85	3302%	5.8

DPH = Disc ploughing and harrowing, R = Ripping, JP = Jab planter, HH = Hand hoeing TVC = Total Variable Cost, NB = Net Benefit, MC = Marginal Cost, MB = Marginal Benefit, MRR = Marginal Rate of Return USD = US Dollars, average exchange rate 2021 1 USD = KES 109.67

During the short rains, TVCs were in the order R (819.06) > DPH (811.09) > JP (808.18) > HH (794.77) captured in the partial budget (Table 5.6). Corresponding trends in USD were recorded (R > DPH > HH > JP) in gross benefits (9402.12 > 7415.34 > 7223.31 > 6447.80), net benefits (8583.06 > 6604.25 > 6428.54 > 5639.62) and benefit cost ratios (10.48 > 8.14 > 8.09 > 6.98) according to the partial budget. Dominance analysis led to the elimination of JP (Table 5.7). MRR between HH and DPH was 1077% while between DPH and R was 24828% (Table 5.8).

Table 5.6: Partial budget and BCR of maize under different tillage methods during the SR 2021 season

	DPH	R	JP	HH
Grain grains (t/ha)	10.04	12.73	8.73	9.78
Adjusted grain yields (t/ha)	9.04	11.46	7.86	8.8
Gross Benefits (USD)	7415.34	9402.12	6447.8	7223.31
Total Variable Costs (USD)	811.09	819.06	808.18	794.77
Net Benefits (USD)	6604.25	8583.06	5639.62	6428.54
Benefit Cost Ratio	8.14	10.48	6.98	8.09

DPH = Disc ploughing and harrowing, R = Ripping, JP = Jab planter, HH = Hand hoeing, average exchange rate 2021 1 USD = KES 109.67

Table 5.7: Dominance analysis during the SR 2021 season

Treatment	Total Variable Costs (USD)	Net Benefits (USD)
HH	794.77	6428.54
JP	808.18	5639.62 D
DPH	811.09	6604.25
R	819.06	8583.06

DHP = Disc ploughing and harrowing, R = Ripping, JP = Jab planter, HH = Hand hoeing, average exchange rate 2021 1 USD = KES 109.67

Table 5.8: Financial returns of non-dominated tillage treatments during the SR 2021 season

Tillage	Grain yield	Adjusted grain yield	Total gross income (USD)	TVC (USD)	NB (USD)	MC	MB	% MRR	BCR
HH	9.78	8.8	7223.31	794.77	6428.54				8.09
DPH	10.04	9.04	7415.34	811.09	6604.25	16.32	175.71	1077%	8.14
R	12.73	11.46	9402.12	819.06	8583.06	7.97	1978.81	24828%	10.48

DPH = Disc ploughing and harrowing, R = Ripping, JP = Jab planter, TVC = Total Variable Cost, NB = Net Benefit, MC = Marginal Cost, MB =Marginal Benefit, MRR = Marginal Rate of Return USD = US Dollars, average exchange rate 2021 1 USD = KES 109.67

5.5 Discussion

Financial analysis is usually used for evaluating the viability of different agricultural production systems. During both LR 2021 and SR 2021, R exhibited the highest total variable costs and net benefits, followed by DPH. In comparison to the 2 methods, JP had the least TVC and NB. These findings were attributed to high yields in R and DPH during both seasons. Marginal analysis performed to determine the most profitable tillage method resulted in the elimination of HH and JP as dominated treatments during LR 2021 and SR 2021 respectively through dominance analysis. This was attributed to their higher variable costs, with lower net benefits (CIMMYT, 1988). Non-dominated treatments included DPH, R, and JP during LR 2021 and DPH, R and HH during SR 2021.

One important aspect of the marginal rate of returns (MRR) is that it could give a deeper insight into financial analysis and treatment viability. Computation of MRR established that adopting DPH over JP and HH implied 2577% and 1077% rates of return during long and short rains respectively. Consecutively, adopting R over DPH implied 3302% and 24828% rates of return during the seasons respectively. Despite the adoption of R recording higher MRR, changing from farmers' traditional method of HH to either R or DPH accounted for MRR of more than 100%, which is the minimum acceptable value by farmers (Buah *et al.*, 2017; Karuma *et al.*, 2020). In support of the findings, a study by Mihertie *et al.* (2021) implemented in Guder Catchment, a highland in Northwestern Ethiopia, found that reduced tillage was more profitable than conventional tillage due to higher net benefits. This was attributed to the lower cost of labour for ploughing and greater yields under reduced tillage. For broadcast sowing and soil trampling in teff production, introducing reduced tillage resulted in a 3504% rate of return while conventional tillage resulted in a -297% rate of return. Likewise, in Tigray, Ethiopia, reduced tillage contrary to no-tillage resulted in 374% and 705% MRR for two cropping seasons respectively under maize monoculture (Tsegay *et al.*, 2018).

Conversely, a study by Karuma *et al.* (2020) in Eastern Kenya recorded the highest MRR under conventional tillage methods, ox-ploughing (2887%) disc ploughing and harrowing (1775%), and disc ploughing (457%), compared to reduced tillage, subsoiling-ripping (220%). High MRR values (above 1000%) are not uncommon in tillage studies; comparatively high MRR results have been reported in literature (Biya & Gurmu, 2021; Ehsanullah *et al*., 2015; Karuma *et al*., 2020; Khaliq *et al*., 2014; Mihertie *et al*., 2021; Wasaya *et al*., 2018), and this could be attributed to high net returns at low costs of production. Thus, both conventional and reduced tillage methods could be adopted by farmers having MRR of more than 100%.

Jab planter exhibited the lowest values of the net benefits as well as benefit cost ratios (BCR) in this study. On the contrary, a studies by Buah *et al*. (2017) in Lwara District, Ghana, and Ahmed *et al*. (2007) in Islamabad, Pakistan recorded higher net benefits for no-tillage relative to conventional tillage due to grain yield increases. The BCR values of this study were within the range of 4 and 7 in LR 2021, and 7 and 12 in SR 2021, where R recorded the highest BCR, In line with this study, Jabran (2015) in Pakistan recorded higher BCR under reduced tillage (1.94) as compared to conventional tillage (1.72). Despite that, Jabran's study recorded the highest value under zero tillage (2.02). This was also supported by Fatumah et al. (2021) in Mukono District, Uganda. In terms of the BCR, all alternative tillage treatments (DPH, R and JP) were viable during the two seasons.

5.6 Conclusion

Attributed to high yields, ripping recorded highest TVC and NB followed by DPH across both seasons. Zero tillage, JP, resulted in the least TVC and NB apart from the farmers' practice of HH. Ripping and DPH yielded MRR above 100% during both seasons.

CHAPTER SIX: GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

The effect of tillage on the selected soil properties, maize parameters and yields, and financial returns of maize productions proved to be complex. Variations were evident and factored in interactions between tillage, time of measurement (WAP) and sampling depth. Tillage significantly contributed to soil moisture and total nitrogen, with ripping recording the greatest enhancements in the parameters. Maize grain yields were substantially influenced by tillage with highest yields attained under R. The grain yields and costs of production influenced financial returns of maize across the different tillage methods. The highest net benefits and marginal rates of returns were recorded under ripping.

6.2 RECOMMENDATIONS

Ripping yielded better results in terms of soil quality, and maize production and productivity. The method is viable for enhanced soil conservation and productivity, better yields, and improved financial returns in Upper Kabete. Disc ploughing and harrowing exhibited high moisture contents and grain yields after ripping. Nevertheless, adoption of sustainable tillage methods is critical taking into consideration the current challenges of rainfall variability and delays, and soil degradation including soil fertility depletion. For these reasons, R proved to be the most viable.

Following this study, some recommendations for potential future research in Upper Kabete include:

- Effect of tillage methods on root growth and development
- The risk of herbicides application to humans and environment
- Examining the interactions between different tillage methods and microorganisms, and how they may impact soil properties and maize growth.
- Evaluating the long-term effects of different tillage methods on soil properties and maize growth in Kabete.

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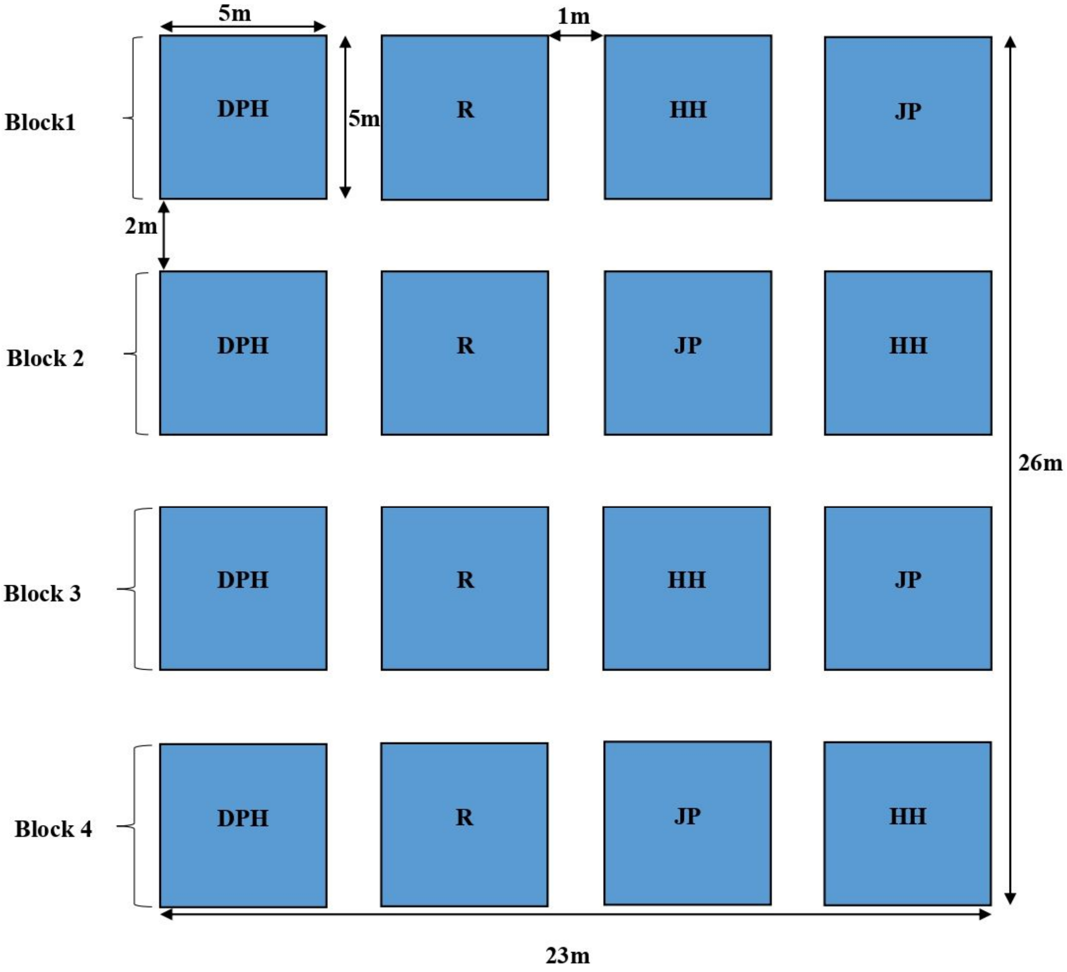
APPENDICES

Appendix 1: Experimental design layout



Appendix 2: Monthly average rainfall data (mm) for the cropping seasons

Season 1		Season 2	
May 2021	157.2	November 2021	114.1
June 2021	3.1	December 2021	104.3
July 2021	7.3	January 2022	64.4
August 2021	19.7	February 2022	79.4
September 2021	12.8	March 2022	29.8