WATER RETENTION AND YIELD OF RICE CROP UNDER DIFFERENT LAND PREPARATION TECHNIQUES IN MAUGO SMALLHOLDER IRRIGATION SCHEME, HOMA BAY COUNTY, KENYA

BY

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A THESIS SUBMITTED TO THE SCHOOL OF ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL AND BIOSYSTEMS ENGINEERING, UNIVERSITY OF ELDORET, KENYA

AUGUST, 2021

DECLARATION

Declaration by the Candidate

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To my beloved wife Joyce; my daughters Trizer, Celestine, Helida, and my sons; Vincent, Joseph and David for their prayers and unwavering moral support during the writing of this thesis.

ABSTRACT

The area under rice cultivation in Kenya has been increasing but production and productivity are still low compared to demand due to inappropriate, poor and untimely land preparation and field water management. For this reason, therefore, a research experiment was conducted in a farmer's field in Maugo Irrigation Scheme, Homa Bay County, Kenya during July 2019-January 2020 crop season. The main purpose of the study was to determine the effect of land preparation techniques on water retention and yield of rice (*Oriza sativa L.,*) crop in the scheme. Treatments were arranged in Randomized Complete Block Design (RCBD) with four replicates. Four tillage treatments were used. The first one was conventional ox- ploughing practised by farmers where they first flood the field with water before ploughing. The other three treatments were ox- plough, hand- hoe and tractor plough and all were not flooded before ploughing. Data on the depth of ploughing and harrowing during ploughing, furrow slice sizes during ploughing and harrowing, water retention, number of tillers, yield and rooting were collected, recorded and analysed. The findings of the study indicated that tractor ploughing had the highest mean depth of ploughing of 42.00 ± 0.81 cm followed by conventional ox- ploughing with 17.75 ± 0.75 cm, ox-ploughing15.75 ± 0.62 cm and hand hoe ploughing had the lowest mean depth 15.50 ± 0.28 cm. Tractor ploughing had the largest mean furrow slice size of 62.00 ± 0.91cm followed by conventional ox-ploughing 32.25 ± 0.85 cm, ox- ploughing 30.25 ± 0.85 cm while hand- hoe ploughing had the smallest mean furrow slice of 16.5 ± 0.50 cm. The highest mean of retained water was recorded in week 4 in the paddy rice fields that were prepared using conventional ox ploughing (10.5 cm), ox ploughing (10 cm), hand hoe ploughing (11.5 cm) and tractor ploughing (11.5 cm) while the lowest was recorded in week 15 for conventional plots. There were significant differences in mean depths among the treatments during both ploughing and harrowing. Tractor ploughing means depths were significantly different from the other three treatments. The weekly mean water depths retained in the plots were more than 6 cm for the entire growing season of rice. The results also showed that conventional ox-ploughing consumed the highest amount of water to the tune of 1240 mm. The highest water use efficiency of 0.49 kg/m3 and highest milled yield of 5.7 tons/ha were observed in the hand hoe ploughing treatment. Use of the hand hoe ploughing technique was found increased rice yields by 20 per cent, as compared to the conventional ox-ploughing. Therefore, the use of water for ploughing is not necessary for the study area. Future research will be needed to see how farmers are adopting the study recommendations before scaling up to full mechanization, as partial mechanization was not profitable during this research.

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LIST OF ABBREVIATIONS

AfDB	African Development Bank
AgGDP	Agricultural Gross Domestic Product
ANOVA	Analysis of Variance
ASAL	Arid and Semi-Arid Land
ASTGS	Agricultural Sector Transformation and Growth Strategy
ATDC	Agricultural Technology Development Centre
CAADP	Comprehensive Africa Agricultural Development Programme
CGIAR	Consultative Group on International Agricultural Research
CIDP	County Integrated Development Plan
CoK	Constitution of Kenya
DAP	Di-Ammonium Phosphate
EAC	East African Community
ECARRN	Eastern and Central African Rice Research Network
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GoK	Government of the Republic of Kenya
IRRI	International Rice Research Institute
KARLO	Kenya Agricultural and Livestock Research Organization
MOALF&C	Ministry of Agriculture, Livestock, Fisheries and Cooperatives
NEPAD	New Partnership for Africa's Development
NERICA	New Rice for Africa
NIB	National Irrigation Board

NIA	National Irrigation Authority
NGOs	Non-Governmental Organizations
SDGs	Sustainable Development Goals
SRI	System of Rice Intensification
TARDA	Tana and Athi River Development Authority
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
WARDA	West African Rice Development Association
IWUA	Irrigation Water User's Association

ACKNOWLEDGEMENT

I am grateful to the following institutions and individuals who contributed a lot to the development of this thesis.

The academic staff members in the University of Eldoret, Agricultural and Biosystems Engineering Department deserve exceptional recognition for their valuable contributions in the course of my coursework that gave me the skills and capacity to carry out this work. My supervisors; Eng. Dr. Clement K. Kiptum, of the Civil and Structural Engineering Department and Prof. Eng. Japheth O.Onyando, Adjunct Professor of Agricultural and Biosystems Engineering Department, who were instrumental in their critique, guidance and encouragement which helped in maintaining the focus of the thesis.

Thanks also go to the Ministry of Agriculture, Livestock, Fisheries and Cooperatives for projecting me for MSc. studies, my colleagues at work in Homa Bay Agricultural Technology Development Centre (ATDC), for their support and Homa Bay County Department of Planning for generously providing useful information from its library.

My gratitude also goes to the Maugo Irrigation Scheme farmers, especially Mr. Elijah Akumu and Mr. Tom Aoch for availing their farms for the research and the research assistant Mr. Philip Ayata for remaining committed during the data collection exercise. Further appreciation goes to the African Development Bank (AfDB) for their sponsorship of this work.

Lastly, I express my gratitude to my dear wife and children for giving me time to accomplish this research.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Globally, the widely used cultivated rice (*Oriza sativa L.,*) is the second most popular cereal crop and staple food for many people (Prodhan *et al.,* 2020). Projections show that rice continues to be the world's most important staple food in the coming decades. Further, rice crop farming assists in improving food security, poverty alleviation, youth employment, and if a saving of scarce water resources is achieved in growing rice it will go a long way in mitigation of impacts on the climate. The total annual world production of rice is approximately 903.4 million tons with average productivity of 4 tons/ha (Srujana, *et al.,* 2017). China is the major producer of rice in the world with 212.1 million metric tons followed by India with 172.6 million tonnes (FAO, 2018).

Rice cultivation was first brought to Kenya in 1907 by Asians (Onyango, 2014). It is now occupying the third position in terms of importance after maize and wheat (Gitonga & Snipes, 2017). It is a commercial and food crop grown majorly by small-holder farmers. Rice is one of the food crops that help in the fight against hunger. Its demand is expected to rise with the increase in population and change in eating habits due to rapid urbanization. Whereas the area under cultivation of rice has considerably increased, rice production in Kenya is still low compared to the demand. This is a threat to food security and the yields of rice in the country. Improved rice farming can help address food insecurity in Kenya (Majiwa & Mugodo, 2018).

The productivity of rice and increase of yield is dependent on several parameters such as land preparation (also called tillage or cultivation) which is the practice of modifying soils to provide conditions suitable for good crop growth. It is necessary to make sure that the field is ready for planting through ploughing and other management practices. This helps in inverting and pulverizing the soil, removing all weeds, garbage and crop residues and burying them under the soil. Commonly recognized benefits of good soil preparation include the suppression of pests and weeds, the application of fertilizers, improvement of porosity and aeration, bringing up leached deposits and improvement of plant nutrient adsorption in the soil. (Musukwa, 2018).

Conventional land preparation usually takes place after ponding and flooding in paddy fields to allow puddling and air removal. This first ploughing is a lengthy and hard method for preparing one hectare of land with farm animals, which can take up to 25 days. Mechanization using tractor-powered implements could be swifter if there are hardpans close to the surface to avoid the tractor from sinking. Poor land preparation is a typical feature in most farms because of poor ploughing and rainfall periods, complicated landforms, ploughing machines and land management (Lal, 2015).

In addition to land preparation, it is important for rice farming to inundate paddy fields with a lot of water. Water worldwide is rapidly becoming scarce, with over one-third of the world's population suffering total water deficits by

2025 (Islam & Karim, 2019). The majority of Sub-saharan Africa nations currently have a high rate of population growth and live in cyclic poverty. The projected consumption of water and the demand for food is growing with the faster population increase in the affected areas (Serdeczny et al., 2017).

According to Kogo *et al.*, 2020, climate change will impact the availability of water resources in Kenya in both time and space wreaking havoc, on precipitation and runoff. Projections point to rainfall increase in the long rainy season and decrease in the short rainy season in most places in the country (Wainwright *et al.,* 2019). Thus, there will be significant effects on farming because of the rain-fed nature of Kenya's agriculture. The lower the agricultural productivity the higher the insecurities in food and nutrition. Crop yields in Kenya are projected to decline by up to 45 per cent by 2100 due to the effects of climate change. This is also expected to affect maize, rice, and, soybean crops. As water supplies become increasingly scarce, livestock numbers are also expected to decrease (Puzyreva & Roy, 2018).

Irrigation development is one of the most important practices that boost rural livelihoods by increasing agricultural and household food production. Irrigation expenditure is one way of enhancing smallholder farmers' crop yield and income and hence eradicating poverty (Domenech, 2015).

As regards policy, irrigation is described by major agricultural policy documents as a core factor in increasing the development and productivity of soil (Boulanger *et al.,* 2020). Agriculture is the highest consumer of freshwater resources accounting for 50% of water demand in Kenya (GoK, 2013b). About 97 % of staple food production is rain-fed in Sub-Saharan Africa and approximately 3% of the cultivated area is under irrigation (Jenkins, Gilbert & Nelson, 2017).

The potential for irrigable rice in Kenya is around 540,000 hectares and the land for rain-fed rice production is one million hectares. The existing irrigation capacity may be increased by 800, 000 ha by enhancing water harvesting, storage, use of aquatic tools and advanced management technology (Muthee, 2017).

Kenya's irrigation sector is classified into notable organizational types that include private or commercial, smallholder, centrally-managed or public schemes. Private irrigation schemes encompass those developed, owned and managed by farmers on themselves or companies and are operated commercially. Government agencies develop and manage centrally public schemes by giving farmers tenancy rights in the use of the irrigation facilities during the crop production season. Kenya has four major public rice irrigation schemes that are managed by NIA, namely: Bunyala, Ahero and West Kano and Mwea. Upland rice is in Migori, Kuria, Tana Delta and Msambweni Sub-Counties. Farmers, through irrigation water users' associations (IWUAs), cooperatives or self-help groups, own, operate and manage smallholder community irrigation schemes. The government cost-shares with communities and development partners in the development of these schemes hence they are demand-driven farmer-managed irrigation schemes (de Bont & Veldwisch, 2020).

There are about 3000 current irrigation systems for smallholders covering a total area of 51,903 ha with more than 2 million people operating them (Muema, 2018). The bulk of horticultural crops consumed in Kenya are produced in them and also most export crops, tubers, staples and grains. Their developments have been supported by the government, Non-Governmental Organizations (NGOs) and development partners. Some examples of these schemes include; Vanga, Mitunguu, Lower Nzoia, Jarajara, Chala, Alungo, Lower Kaya, Mukuria-Kyambogo, Ng'uuru-Gakirwe, Oluch-Kimira, Isiolo River, Maugo, Anyiko, Lari-Wendani, Malindi, Mukuria-Kyambogo, New Mutaro, Emening, Kipini, Lari-Wendani, New Mutaro, Isiolo River, Kore, Anyiko, Chiga, South West Kano, Wanjare, Gem-Rae, Shimoni, Kimorigo and Nyachoda, among others.

Irrigation farming in Kenya is still confronted by many challenges, such as exploitation by middlemen, poor management, unpredictable commodity prices, scarcity of water, marketing, and demand for more land for scheme expansion. Studies show that hunger and food shortages in the community have decreased in two to three years through well-coordinated irrigation, regardless of how poor farmers are, at first (Mati, 2008). For the sustainability of rice production, water-saving is critical. Rice grows well in soil, which during any of the entire period of forming is soaked or even submerged in water. Boulanger *et al.* in 2020 observed the scarcity of adequate water to replicate significant and complicated maintenance and procurement problems of large irrigation systems. Ingenious approaches have been built by smallholders of the rice farmers to resolve some of their problem areas (Altieri et al., 2017). Finda et al. in 2018 found that rural farmers have excellent informal knowledge acquired through trial and error practices that assists them to overcome possible failures which might befall their farming operations and consequently reduce yields.

Given that Kenya has a tremendous rice production potential, something needs to be done to place the sector at the forefront of food production. It is not well that it stays mostly untapped and its production responsibilities are only left to small-scale farmers. Furthermore, rice production and consumption promotions are projected to help eliminate over-dependence on maize as a staple food and thus increase the income and food security of rural and urban populations.

Amongst major challenges faced in rice production include unfavourable weather conditions and insufficient water to irrigate, acceptable variations, low and diminishing soil efficiency, high-income costs, weak facilities, machinery shortages, transboundary/regional problems and institutional capability with the most performing rain-fed rice scheme (Atera *et al.,* 2018). In general, considering low yields from farmers, rice processing systems are productive. Techniques for growing rice production on farms must be investigated for households producing rice to increase income and nutrition needs.

Farmers, particularly in the Mwea Region, have seen low water availability for irrigation as a restriction. The irrigation productivity in Kenya is very low in more than 80 per cent of smallholder irrigation schemes. Policies directed at smallholders' irrigation systems should be advocated as government schemes inevitably lead, alongside the issue of corruption and duplication, to inefficient distribution and use of money.

Generally, Maugo farmers do not practice recommended rice plant spacing and use higher seed densities hence influencing their production. This thesis explores the effect of different land preparation techniques on water retention and rice yield crop in Maugo Smallholder Irrigation Scheme with a view of recommending the most suitable technique in rice cultivation system for the study area.

1.2 Statement of the problem

Farmers in Maugo Smallholder Irrigation Scheme in Rangwe Sub-county of Homa Bay County, Kenya barely subsist as they are stuck in a poverty cycle. They face challenges such as low access to credit facilities, shortage of human labour and land preparation machinery, scarcity of irrigation water and adverse effects of climate change (FAO, 2016). As climate change is expected to reduce rice yields by 10% in the 21st century (Huang *et al., 2020*), farmers need to find methods of saving water for them to be able to cope with water challenges in the future. Also, farmers in the study area do not plough dry soil but they add some water to wet and soften them. Wetting the fields eases ploughing but does not aid in crop development. Tilling dry soil helps to save water but results in decreased yields (FAO, 2020). This calls for a study on water management at the farmers' fields to save water that is a priority for any rice farmer.

Saving water will address the water problem particularly in areas where canals are poorly maintained and low water flows in observed in rivers in the study area during dry months (RoK, 2013). This will further give information on the performance of dry-seeded rice (Arora *et al.,* 2018). Some literature (Materu *et al.,* 2018) has focused on the System of Rice Intensification (SRI) on large scale and not small-holder farmers, which are key to rice production in Kenya.

Land preparation techniques may influence water retention and yields of rice. Zero-tillage is considered to be the best alternative to ploughing and harrowing due to its effect on soil properties. Ploughing, harrowing and levelling increases rice yield and reduces weed density. Indeed, most developing countries such as Kenya have not benefitted from the awareness of zero-tillage (El-Shater *et al.,* 2020). Information on the effect of different land preparation techniques on water retention and rice yields in smallholder irrigation schemes such as Maugo Irrigation scheme is scanty. While many studies have proposed ways of improving water management, little is known about the performance of smallholder farmers' ploughing techniques and other ploughing practices in reducing water use in rice production. This research highlights the need for farmers to slowly learn new ways of improving their technical know-how on water management by setting up on-farm experiments near them.

1.3 Research objectives

1.3.1 Broad objective

To determine the effect of land preparation techniques on water retention and yield of rice crop in Maugo Smallholder Irrigation Scheme, Homa Bay County, Kenya.

1.3.2 Specific objectives

1. To determine the effect of land ploughing techniques on depths and furrow slices during ploughing and harrowing.
2. To determine the effect of land ploughing techniques on water retention in paddy rice fields.
3. To determine the effect of land ploughing techniques on yield, rooting depth and tillers of rice crops.

1.4 Research questions

The study sought answers to the following questions:

1. How do land ploughing techniques affect ploughing and harrowing depth as well as furrow slices?
2. How do land ploughing techniques affect water retention in paddy rice fields?
3. How do land ploughing techniques affect tillers, straw and grain yield, and rooting depth of rice crops?

1.5 Justification of the study

The UN Sustainable Development Goals (SDGs) emphasizes on poverty and hunger eradication, sustainable agriculture, sustainable availability of water and sanitation management ,food and nutrition security for everyone by the year 2030 (Perez, 2017). As a big drought mitigation measure, Kenya recognizes the importance of irrigation development as laid down in Vision 2030. Given the 9.2 million untapped acres of Arid and Semi-Arid land (ASALs), the irrigation industry is Kenya's future promise as defined in the Agricultural Sector Growth and Transformation Strategy (ASTGS), for 2019 to 2029 (Oremo,2020). The goal is also to increase rice production from 70,000 tons per annum in 2018 to 406,456 tons in 2022 (GoK, 2018b). This growth can be achieved by extending the production areas of the crop, improving access to quality inputs, irrigation, mechanization and post-harvest management. Rice production needs to be expanded to keep up with increasing populations and rice prices and high import bill (Chirchir, 2019).

In addition, several agricultural studies have been undertaken in Kenya on on-farm productivity assessment, but most have not analyzed the study for irrigated rice production (Van Ittersum *et al*., 2013). For Kenya to attain its long-term food security aim, irrigational research and innovation are necessary. The core challenges and opportunities identified in Maugo Smallholder Irrigation Scheme can serve as a benchmark for improving rice production in other current or potential areas beyond existing NIA schemes. Extension of non-farming sectors must integrate productive water use in water administration to enable current and potential irrigation extensions if fair portion of existing water is to be received (Pervez *et al.,* 2020).There is need to develop methodologies for improved water use efficiency in the production of rice to save water for other productive uses (Alexander *et al.,* 2018).

Finally, this research helps farmers, Maugo Rice Cooperative Society, national and county governments to come up with suitable steps to meet the challenges of small scale rice farming with guidelines on the right method of land preparation. Improved rice production in smallholder community irrigation schemes in Kenya is actually the most significant contribution of this study .Also this study reinforces issues in the Constitutional of Kenya 2010 and Irrigation Act 2019(Okumu, 2020).

1.6 Scope and limitations of the research study

The research was confined to rice cultivation in a farmer's plot in Powo B sub-block of Maugo Smallholder Irrigation Scheme in one season, from July 2019 to January 2020. It involved four ploughing techniques namely: conventional ox, ox, hand hoe and tractor. Also, soil fertility and water quality were assumed constant.

Inadequate funding limited the number of variables considered during the study. The absence of adequate secondary data and published literature on the performance of the scheme further limited the work. It was also not possible to get irrigation efficiencies due to poor maintenance of the canals as a result of weak farmers' water users association. Also, Maugo River is seasonal with unpredictable night flooding hence making the scheme sometimes inaccessible for taking measurements.

CHAPTER TWO

LITERATURE REVIEW

2.1 Kenya’s economy and agriculture

Kenya's economy is largely dependent on the performance of the agricultural sector. It has four major sub-sectors that include crops, livestock, fisheries and forestry of which the crops sub-sector is the largest. The sector is key in providing food for an ever-increasing population, wealth creation, poverty elimination and management of degraded natural resource base (GoK, 2017). The sector gives a direct contribution of about 25% to the country's GDP and about 27% indirectly via agro-industries and services. It contributes above 65% exports, occupies about 75% of the total employment and 80% of the rural population in the country. The size of the Agricultural Gross Domestic Product (AgGDP) from the crops sub-sector is about 77.6% and it encompasses industrial, food and horticultural crops. Cereals, pulses, roots and tubers, fruits and vegetables are the major food crops and together they give about 32% of the AgGDP and 0.5% of earnings from export. Most crops have recorded a significant decline in production in the recent past due to insufficient rainfall that has limited agricultural production. However, the agriculture sector realized a modest increase in the production of rice in 2019 (KNBS, 2020).

2.2 Kenya’s water position

According to World Bank, 2000, Taft, 2015 and GoK, 2018c, Kenya is a water-scarce country with 647 cubic metres (m3) per capita water availability which is lower than the global average benchmark of 1,000 m3. With increased extreme weather events due to climate change, scarcity of water will increase and hence more investment in good management and conservation of water resources is paramount (GoK, 2018a). Thus, this country has to devise water harvesting and conservation technologies that are innovative and safe for use by the Kenyan population for domestic, industrial and agricultural purposes.

In the world, agriculture consumes an average of 71% of freshwater making it the major user of earth's water with huge regional variations ranging from Africa's 88% to Europe's less than 50%. Irrigated agriculture, in Kenya, is one of the largest sectors that use water. Wang *et al*.,2016 indicates that high competition for water affects the availability of irrigation water for crops such as lowland rice which is exaggerated by climate change.

2.3 Irrigation laws in Kenya

The government repealed the Irrigation Act, Chapter 347 Laws of Kenya with the Irrigation Act, 2019 in 2019 for it to be in tandem with the Constitution of Kenya 2010 (Kashindi, 2021). The act provides for the development, regulation and management of the irrigation sector for food security and socio-economic development in Kenya (RoK, 2019a). In addition, it defines the functions and duties of the national government and county governments on matters of irrigation and creates the National Irrigation Authority (NIA) to succeed the National Irrigation Board (NIB). This piece of legislation has widened the mandate of NIA to include the development and improvement of irrigation infrastructure for public schemes and supporting private medium and smallholder schemes. In addition, subject to constraints of water including other resources with consultation from the county governments, and other stakeholders provide adequate and quality water for irrigation in the country. Further, it ensures that the design of national irrigation schemes and others puts into consideration other users of irrigation water such as livestock and fish farmers and the impacts of irrigation schemes on the environment. Furthermore, the act also allows for the formation of irrigation water users associations by community-based irrigation schemes in the country for purposes of the development and management of the concerned scheme associations and also provide for dispute resolution mechanisms (Munyua, 2020). Therefore, the full implementation of this new piece of legislation may assist in the government's focus on smallholder irrigation schemes hence contributing to the expansion of land under irrigation in Kenya (Nakawuka *et al.*,2018).

2.4 Rice production

Rice (*Oriza sativa L.*,) is the second-largest cereal crop and staple food produced for supporting more than half of the world's population (Msangya *et al.,* 2016). In most parts of Asia and Africa, rice is the most commonly consumed staple food. It is the third-highest agricultural product in the world (Tigga *et al.,* 2017). The major producer of rice in this world is China with 212.1 million tons followed by India with172.6 million tons. The area under rice cultivation is predicted to increase by 1.5% and yields by about to 1%. The development of rice, thus, allows decreasing the size of food-insecure populations in the world

Rice cultivation was brought to Kenya in 1907 by Asians. Langat *et al.,* 2019 classifies Kenya's irrigation sector into three organizational types, namely: smallholder schemes, private or commercial schemes and public schemes. Namu *et al.,* 2018 indicates rice as the third significant cereal crop after maize and wheat. It is produced majorly by small-scale farmers for food and commercial purposes. About 80% of Kenya's rice is mostly produced in irrigation schemes managed by the state-owned National Irrigation Authority (NIA). Rice production systems are grouped as per ecology in terms of water as irrigated, System of Rice Intensification (SRI), rain-fed lowland and deep water and upland (Muchira, 2019). The most common irrigated rice variety grown in the country is the Sindano and Basmati types. Both the GoK and county governments are also promoting the production of New Rice for Africa (NERICA) which is an improved, rain-fed, upland rice variety. NIA, to increase the area under cultivation of rice, is expanding and rehabilitating irrigation schemes under their management (Obura *et al.,* 2017).

The total rice coverage area grew by 17.9% on 32.3 000 hectares, up 11.8% to 15.7 000 hectares in terms of landholders. Generally, paddy rice increased to 42.6 per cent from 112.6 billion tons in 2018 to 160.6 billion tons. In 2019, paddy irrigated production grew by 34.5% to 121 million tons, which represented 75.3% of paddy's total rice production. All other systems reported a 1.5% decrease in paddy production, apart from Bunyala, due to a decrease in cultivated areas (KNBS, 2020).

Through the Big Four Agenda, the Government of Kenya has purposed to improve rice production from 70,000 tons annually in 2018 to 406,456 tons annually by the year 2022 (GoK, 2018b). It has targeted to achieve this by expanding production areas, increasing access to quality farm inputs, improving irrigation techniques, mechanizing and managing post-harvest issues in production. Increased rice production enhances food security and income for smallholder farmers' households, job creation for the rural population and decreases rice import bills.

Traditionally, the cultivation of rice has always been done by flooding the field after preparing the seedlings. This involves proper planning and conveyance of water. It reduced the growth of weed and pest plants that have no submerged growth state. Other techniques of rice production through irrigation may be used to improve crop growth. However, these may be costly in terms of weed and pest control as well as fertilizer management (Mahajan *et al*., 2017).

2.4.1 Rice growth stages

Cui *et al.*, 2018 has indicated the stages of rice growth and development so that farmers can employ appropriate management practices at the right time Usually, a distinction is made between the four growth stages as follows. Firstly, the nursery stage covers from sowing to transplanting with a duration of about one month. Secondly, the vegetative stage is from transplanting to panicle initiation with a duration that varies from one and a half to three months. It also includes tillering whereby several stems develop on one plant. In broadcasted rice, the two stages combined are referred to as the vegetative stage. Thirdly, the mid-season or reproductive stage starts from panicle initiation to flowering for approximately one month and includes stem elongation, panicle extension and flowering with the likelihood of die late tillers dying. Lastly is the late-season or ripening stage that begins from flowering, grain growth up to full crop maturity for approximately one month.

2.5 Effect of ploughing techniques on depths and furrow slices during ploughing and harrowing

Land preparation involves ploughing and harrowing using an ox-drawn implement, hand tools or tractors. Ploughing involves cutting followed by turning over the soil furrow slices. This can be done by tractor, animal traction, power tillers, or by using a hand hoe. Proper land preparation for sowing is achieved via tractors. The land preparation method is one of the most important factors controlling the suitability of the physical conditions of the soil. Some tillage techniques of land preparation have been evaluated as a way to reduce land preparation costs without sacrificing rice grain yields (Shemahonge, 2013).

According to Upadhaya & Kishor,2019, the physical manipulation of soils to support plant growth is known as tillage. It includes the application of human, animal, or mechanical power in working with soils to get conditions suitable for growing plants. Also, the selection of the most appropriate tillage method depends on several physical factors, namely: soil properties, compaction and erosion, climate, drainage, crop rooting depth, local cropping systems, farm sizes and inputs availability (Lawrence *et al.*, 2020). In addition, the use of proper tillage techniques may lead to higher crop yields and profit margins, soil fertility increase and conservation, control of weeds and optimum utilization of water (Ozturk, 2019).

There are two major tillage systems, namely, conventional and conservation tillage. Conventional tillage system involves intense mechanical soil manipulations and inversions. It is used to prepare the seedbed to improve seed-soil contact to facilitate regular, unvarying early plant emergence (Bangura, 2015). It involves the use of mouldboard or disc plough followed by no disc harrowing, one or two-disc harrowing. Conventional cultivation includes ploughing or reversal of soil, secondary cultivation using discs and tertiary production, farm work and harrowers (Bangura, 2015). These tools are commonly drawn by animals or tractors or by other mechanically powered devices.

These practices, however, pose some serious global concerns. These may include high energy usage and the need for more time, risks of soil erosion, soil compaction, and soil structure degradation (Lal, 2015). On the other hand, conventional tillage systems have been found to improve soil physical properties and increase crop performance. According to studies conducted on the effect of different tillage practices on soil physical properties under wheat in a semi-arid environment, the study indicated that conventional tillage practices performed better than conservation tillage practices, as conventional tillage improved crop performance and soil physical properties (Raiesi & Kabiri, 2016). Furthermore, EL-Din *et al.,* 2008 studied the effect of the tilling and planting practices on the yield of rice and the technical characteristics of the milling quality also showed that the highest total yield of grain was obtained from traditional tillage compared to conservation tillage. Also, the results showed that higher yield values were achieved with traditional tillage compared to the same planting method under conservation tillage practices. Other authors have also reported better crop performance on conventional tillage compared with conservation tillage practices (Ujoh and Ujoh, 2014).

Tillage depth depends on the crop and soil features and also on the source of power or energy available. As per Carter (2017), tractor ploughing operations pose some serious concerns internationally such as high fuel and time requirements, increasing the possibility of soil compaction thus significantly increasing the depth and deterioration of soil structure.

Zhang *et al.,* 2019 demonstrated the effect of five land preparation systems of rice on grain yield. They found that the grain yield of rice did not vary significantly among land preparation systems. Tomar *et al.,* 2018 investigated the impact of seedbed preparation and planting methods on rice yield. The relevant factors were considered for the form and depth of ploughing. Because of its improved soil reversal capacity and consequently weed killing, rice yielded highly with mouldboard plough. Rice yield improved in all treatments by the depth of ploughing.

Other studies done on land preparation using zero, traditional and minimum tillage treatments concluded that conventional tillage increased grain yields and tiller quantities, followed by minimum and zero tillage respectively (El-Din *et al.,* 2008).

2.6 Effect of ploughing techniques on water retention in paddy rice fields

Globally, the rice crop is one of the largest water consumers (Hanafiah *et al.*, 2019). Each stage of rice growth and development needs some amount of water to meet its crop growth requirements. Its production needs a threshold rainfall of about 200 mm/month to 600 mm/month for a particular crop season and this is dependent on the climatic conditions (Dharmappa *et al.,* 2019).

The soil bulk density is a measure of compaction and mass of soil and has a major effect on soil structure, aeration, water retention, drainage, porosity, and plant nutrient accessibility which affects the growth of plant roots and activities of soil micro-organisms. The finer the soil the lower the bulk density. The magnitude of bulk density for ideal agricultural soils usually ranges between 1.1 to 1.6 g/cm3(Nosalewiczhepic, 2014). When densities start to exceed the ideal, root growth and microbial activity are affected. Bulk density is almost always altered by tillage operations (Bangura *et al.,* 2015). Rashidi & Keshavarzpour (2011) reported that when compared to reduced and traditional tillage, zero tillage raises soil bulk density.

Further, Alam *et al.*, 2014 found that bulk density differed significantly across tillage practices after four years of Wheat-Mungbean-Rice cropping. When comparing zero tillage to traditional tillage, they discovered that zero tillage decreased bulk density the most.

In rain-fed agriculture, tillage is important for preserving soil moisture at various depths. Modifying the mechanical impedance to penetration, hydraulic conductivity and water holding capacity will also help to improve soil condition (Birkas *et al.*, 2006).

Tillage operations are commonly used to break up and pulverize the soil, as well as to promote the movement of air and water, to encourage plant growth. The seedbed ecosystem has a major effect on the success or failure of crop production systems that are surrounded by other factors. Tillage increases the water storage ability and other physical properties of the soil in general. In a crop production method, tillage implements have a direct effect on soil moisture content and physical properties. As a result, crop production and yields are supported by tillage techniques that preserve moisture (Busari *et al.,* 2015).

According to Khurshid *et al.,* 2006, tillage methods have a significant effect on the physical properties of soils. They discovered that conventional tillage yielded higher soil moisture content than conservation tillage.

2.7 Effect of ploughing techniques on yield, rooting depth and tillers of rice crop.

Various studies have been done to find the optimal yield of rice crops under combined land preparation methods with different field conditions. According to Usman *et al.,* 2014, there was a statistically different number of tillers per plant between the tillage methods. At nine weeks after planting, the disc ploughing followed by disc harrowing treatment presented the highest number of tillers per plant while the smallest number of tillers per plant was found in the mouldboard ploughing.

Kadziene *et al.,* 2011 research on the effects of seedbed preparation on root characteristics including root length. As a result, they discovered that tillage intensity increased as well as root volume. That could be due to increased aeration in tilled treatments. The increased root volume means increased nutrient absorption by the root hence this explained why tilled treatments yielded more grain than untilled treatments. Aikins *et al.,* 2012 found that disc ploughing yielded more grain in plots on sandy loam in Kumasi, Ghana's semi-deciduous agro-ecological region. Further, El-Din *et al.,* 2008 found in traditional tillage, more grains per panicle. Besides, it had a higher 1000-grain weight than that in conservation tillage. They also observed that tillage treatments had a major effect on the number of filled grains per panicle, weight of 1000 grains, and yield. Also, they found that increased tillage practices did not substantially increase both manual transplanting and broadcasting systems. On the other hand, mechanical drilling devices had a significant rise for both varieties. Generally, disc ploughing followed by disc harrowing produced significantly higher yields than no-tillage treatment. This was in agreement with research conducted by Aikins *et al.*, (2010) and Ujoh (2014).

2.8 Water requirements for rice crop growth

The estimated water requirements for rice crop growth emanates from crop evapotranspiration or the crop water use that is the product of the reference evapotranspiration (ETo) and the crop coefficient (Kc) as indicated in Equations 2.1 and 2.2 below.

According to Allen *et al.*, 1998, Karanja, 2006 and Samejima et al., 2020, the FAO Penman-Monteith method is applied in the estimation of the reference evapotranspiration (ETo) by use of local climatic data.

$$ET_{crop} = K_c \times ET_o \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Equation\ (2.1)$$

where,

ET_{crop} = Crop Evapotranspiration (mm)

K_c = Crop Coefficient

ET_o = Reference Evapotranspiration

The value of ETcrop in Equation (2.1) is calculated from crops growing in optimal management and environmental conditions. More often than not, crops are not grown optimally, thus, ETcrop is computed from either a water stress coefficient or by adjusting Kc under various stress and environmental constraints (Equation 2.2).

$$ET_a = K_s \times ET_{crop} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Equation\ (2.2)$$

where:

ET_a = ET_{crop} actual = Actual Crop Evapotranspiration

K_s = Water stress coefficient

Any deficiencies in water requirement in either full or water stress levels lower crop yields and its effects are estimated by equating the relative decrease in yield to the relative deficit in evapotranspiration through a yield response factor (Ky):

$$1 - \frac{\mathrm{Ya}}{\mathrm{Ymax}} = K_y \left[1 - \frac{\mathrm{ETa}}{\mathrm{ETm}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ (2.3)$$

where:

Y_a = Actual yield

Y_m = Maximum/potential yield

K_y = Yield response factor

ET_m = Maximum/potential evapotranspiration.

ET_m = ET_{crop}

1-Y_a/Y_{max} = the fractional yield reduction as a result of the decrease in evaporation rate (1 - ET_a/ET_m)

Equations (2.2) and (2.3) are combined to get the solution for the water stress factor (K_s) as follows:

$$K_s = \frac{1}{K_y}\left[1 - \frac{\text{Ya}}{\text{Ymax}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Equation\ (2.4)$$

2.9 Optimization of rice production

Optimization is simply maximizing profits as a result of high rice yields or minimizing losses in agriculture. It helps in improving productivity by enabling the researcher to adopt a technique that increases income for farmers and hence agricultural sustainability which is a challenge to many smallholder farmers like the ones in Maugo Smallholder Irrigation Scheme.

Optimization models can be divided into three major components. First is the decision variable or rather the decision to be made which is the size of land to be cultivated. Second is the objective which is the measure to be optimized or the profit that the farmer will gain if they cultivate land with different ploughing techniques. Lastly, the constraint is any logical restriction on a potential solution and for this case, the land allocation was not to exceed one hectare. Also, other constraints were that the plots for different treatments had to be greater than zero.

The fertilizers, seeds, decision making on the allocation of land depended on many factors that included the water used, weeding and labour from both machine and human powers. Thus, for the farmer to use land efficiently, there was a need for a single decision-making mechanism and land was indicated for this study. The decisions were made by the farmer at the beginning of the crop season. Land optimization-based models are used to determine the effect of each decision made on the designed objective and for farmers, it is usually profit margin maximization.

Linear programming is one way of doing optimization and is applied in agriculture for the optimal allocation of land for different crops. Linear programming in this study was used to optimize the allocation of a plot for different ploughing techniques. A Linear programming model has three main parts. First, the objective function can be maximized or minimized and for this study, a combination that maximizes profit to a landowner was required (Kiprotich *et al.,* 2013).

2.10 Conceptual framework

Nazari *et al.*, 2015 defined conceptual framework as the diagrammatic illustration of various variables in a research study, their operational definitions and interactions. Lamichhane *et al.*, 2018 put it that conceptual framework shows how the independent variables affect the dependent variable in the study. The growing of rice in the Maugo Irrigation Scheme had various components illustrated in Figure 2.1. Farmers are using conventional ploughing means that involves wetting the land using water. At the time of ploughing, normally it is just before the onset of the rains and the water flows in the river is normally. It is expected that this water will reduce due to climate change in future over and above the pollution of water upstream. Therefore, farmers need to be aware of new techniques to improve yield which will consequently improve their economic status and overall development of the county. Another component is population, population is expected to affect the size of land and subsequently the yields from the farms. The following conceptual framework illustrates the possible interrelationship among various factors that influence rice production by small scale farmers in the scheme.

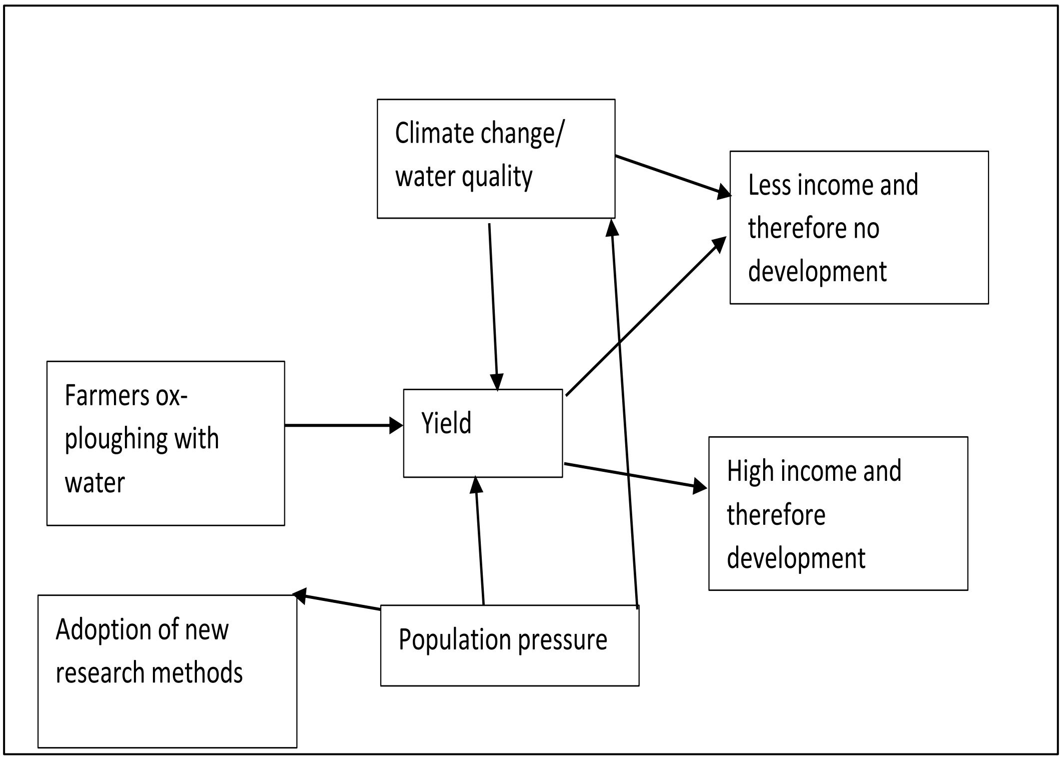


Figure 2.1: Conceptual framework for the research

CHAPTER THREE

METHODOLOGY

3.1 Description of the study area

This study was conducted on a farmer's field in Powo B sub-block of Maugo Irrigation Scheme during July 2019–January 2020 rice cropping season. The experimental site was located in the vicinity of Olare Shopping Centre, Kamenya Sub-location, Kochia East Location, Kochia Ward, Rangwe Sub-County, Homa Bay County, Nyanza Region, Kenya at geographical co-ordinates 0°30′S and 34°30′E (Figure 3.1)

The area has an altitude that varies from 1145 to 1190 m above sea level. Agro-ecologically, the area is sub-humid, lower midland (LM3) or the cotton zone, suitable for growing maize, sorghum, cowpeas, groundnuts, beans, soya, sweet potatoes, sunflower, sesame, green grams, rice and vegetables. The mean annual rainfall ranges from 800 mm to 1200 mm with a long season whose peak is between April and May and the season that peaks between November and December. The annual mean maximum and minimum temperatures are 31 °C and 18 °C, respectively. Relative humidity varies between 60% and 75% and potential evapotranspiration of 1744 mm/annum

(RoK,2018). From the 2019 Kenya Population Census, the study area is 10,193 persons with 4,803 male and 5,390 female in 2,406 households living in a land area of 26.9 square kilometres giving a population density of 378 persons per square kilometre (RoK, 2019b).

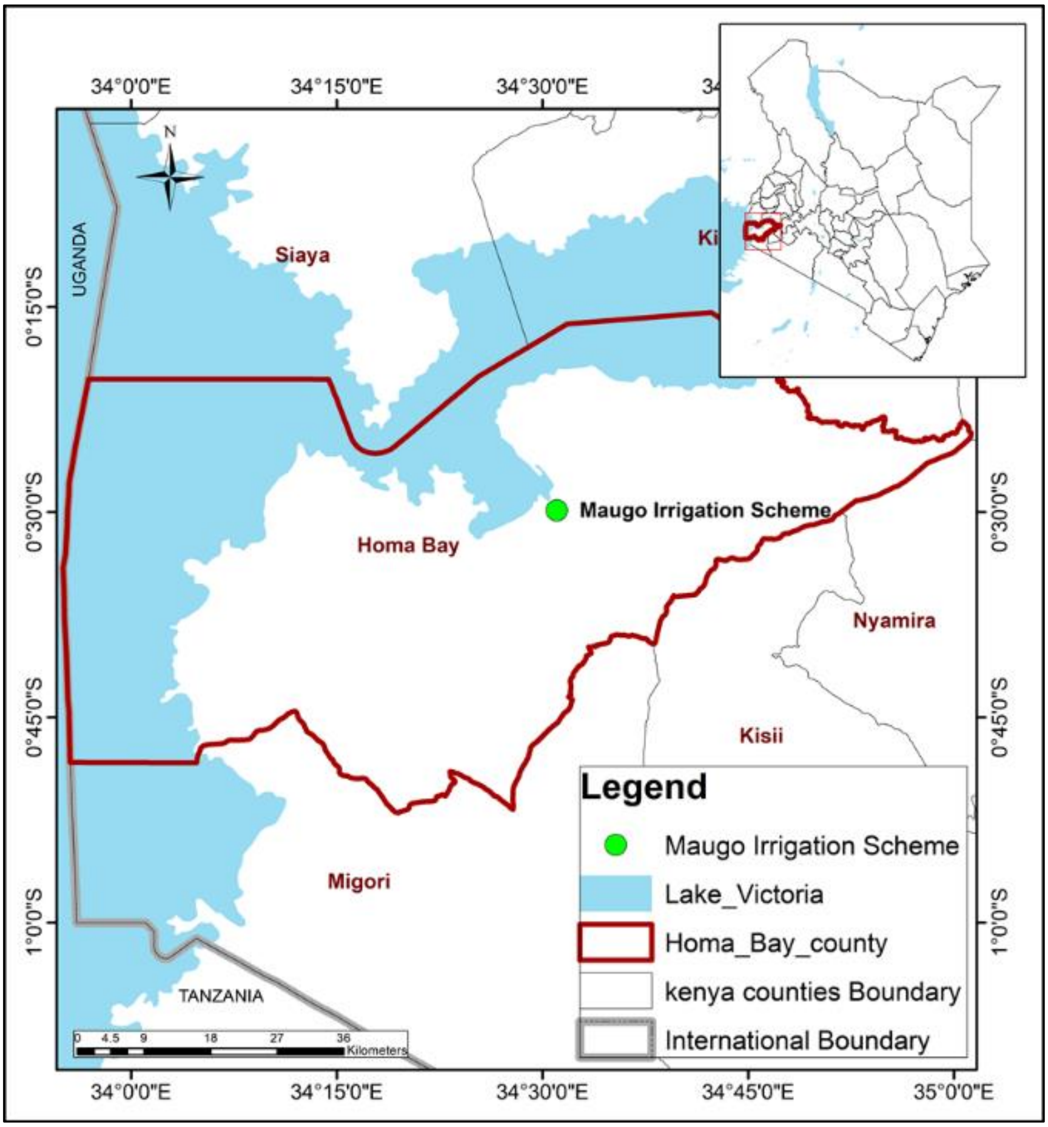


Figure 3.1: Map showing the study area (Source : Author, 2019)

The study area is situated on the lowland alluvial plains. Soils in the study area are clayey with more than 40% clay content with a bulk density of 1.15 g/cm3 and penetration resistance of 2.0 bars (M'Marete, 1991). Soils in this area are fertile because they emanate from nutrient-rich alluvial deposits but are highly erodible due to high silt content as compared to clay content and also other areas have (vertisols) and montmorillonite (black cotton soils) that swell when wet and crack when dry.

The source of water for irrigation in the scheme is Maugo River, which is a seasonal tributary of River Tende with a base flow of 0.5 m3/s and its catchment extends to Kisii hills, the tail end of the catchment area of 1700 km2, with a flood return period of 5 years carrying 79–90 m3/s. The area is a seasonal swamp prone to flooding during heavy rains (FAO, 2020). It is the only large scale gravity-operated system rice irrigation scheme in Homa Bay County. It was started by farmer's initiatives in the year 1962 using floodwater from River Maugo. It was for subsistence farming until 1980 when the Japanese Government came in to form Maugo Rice Co-operative Society. In 1986, the Ministry of Agriculture secured funds from the European Union to implement a conventional gravity system to cover 280ha.The scheme initially consisted of five blocks(9 sub-blocks), as shown in the sketch in Annex 1, each with independent water abstraction point named after branch canals : BC-1[Gem (10ha,68 farmers), Powo A (90ha,140 farmers) and Powo B(80ha,138 farmers) sub-blocks] , BC-2 [Diko(102ha,230 farmers) sub-block] , BC-3[Rachar A(87ha,128 farmers) and Rachar B(68ha,110 farmers) sub-blocks] ,BC-4 [Kanyadenyo(37ha,60 farmers),Amuono(71ha,115 farmers) and Koinga(50ha,82 farmers)sub-blocks], and BC-5[Wakunja(85ha,60 farmers) and Adhiambo(98ha,60 farmers) sub-blocks]. The first phase took six years and saw the implementation works, by the Ministry of Agriculture, in only two blocks i.e. BC3 and BC4 bringing into command 87ha. Due to multiparty politics in 1990, the donor withdrew from the project as preparations were being done to implement blocks 1 and 2.

3.2 Effect of land ploughing techniques on depths and furrow slices during ploughing and harrowing

3.2.1 Land preparation techniques

Land preparation normally starts in May in the downstream blocks. It consists of 15% tractors and 85% ox implements. Land sizes in the scheme measure 40m by 100m. Rotavation is done under wet conditions and ox-drawn implements are used for puddling and levelling. Levelling is done using hands by moving soil from higher places to fill the lower places. The study period covered the months of July 2019 to January 2020, when rice was sown and harvested.

The following combinations of land preparation techniques were applied (Annex 2. a-c); tractor ploughing followed by hand harrowing then hand levelling. Ox ploughing then hands harrowing then hand levelling. Hand ploughing then hand harrowing then hand levelling. Conventional ox ploughing then hand harrowing followed by hand levelling.

3.2.2 Experimental design

The layout of the experiment was a Randomized Complete Block Design (RCBD) with four ploughing techniques and four replicates, as shown in Figure 3.2. A total of 16 plots of 10 m by 9 m each (90 m2) were measured using a tape measure with a total area for the research farm as 1440 m2 (0.144 ha). The plots were pegged for easy identification of the boundaries of the plots during ploughing and random allocation of treatments to them.

3.3 Effect of land ploughing techniques on water retention in paddy rice fields

3.3.1 Separation of plots

Each plot was ploughed using the identified land preparation technique, separated and guarded by using mud bunds. Inlets and outlets were made for the measurement of water inflows and outflows. Bunds of 0.25 m high and 0.25 m wide were made by heaping soil to separate plots. Bunds destroyed by floods were quickly sealed. The bunds to control the water and separate the plots were made before ploughing and those for harrowing were made later. Earthen water inlets and outlets were made to facilitate the measurement of water inflows and outflows.

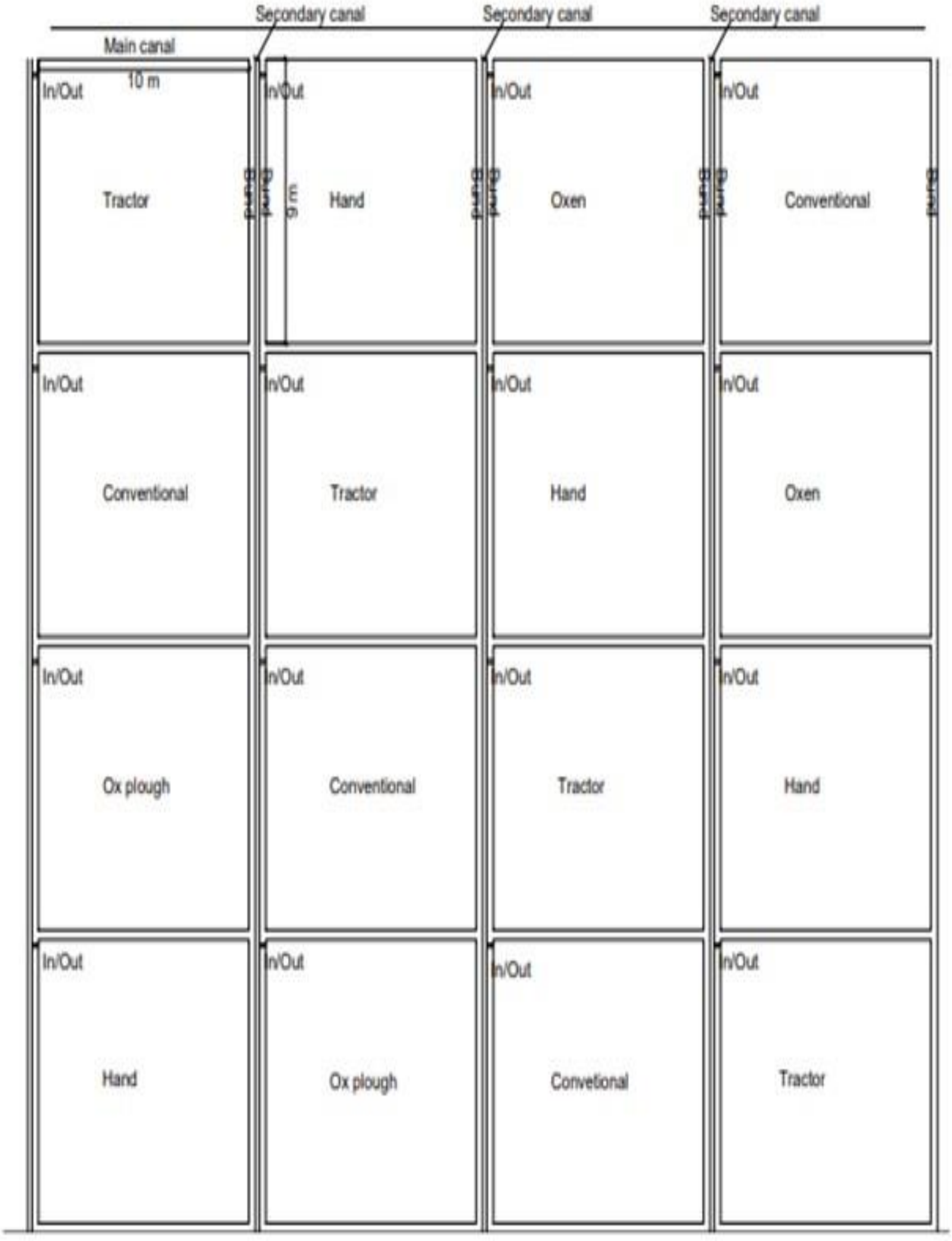


Figure 3.2: Layout of plots in the field (Source: Author, 2019)

3. 4 Effect of land ploughing techniques on yield, rooting depth and tillers of rice crop

3.4.1 Rice variety

Hybrid rice seed Arize 6444 Gold from Bayer Company was selected based on high yield potential, resistance to shattering and diseases, high milling yield, good eating qualities and suitability for the market. High-quality seed reduces the required seeding rate and produces strong, healthy seedlings, resulting in a more uniform crop with higher yields. The seeds were soaked in water for 24 h to break dormancy and then removed and spread in an open area to sprout. The sizes of seedbeds were 28 m2 in these areas. They were ready in three weeks (about 21 days plus one day) for transplanting.

3.4.2 Crop management at nursery and in the field

A nursery site was selected and prepared by ploughing and harrowing twice. Each experimental plot was harrowed and levelled underwater by hand hoe to allow uniform water ponding. The plots were harrowed twice at an interval of three days to ensure proper soil-water mixture. Transplanting was done in lines into puddled and water-covered fields after 20–30 days of germination in all the treatments on 5th and 6th September 2019. Fertilizer was broadcasted, then left for 2–3 h to dissolve before transplanting. Row planting was used (0.15 m by 0.20 m). Fertilizer was broadcasted at a rate of 50 kg per acre for Di-ammonium phosphate (DAP). Top-dressing at the rate of 50 kg per acre was done using Sulphate of Ammonia (SA). Weeding was done within the first 20–50 days after crop establishment and the field was maintained weed-free throughout the growing season. Harvesting was carried out using sickles and put in tarpaulins the same day and threshed immediately in the field. This was done to avoid theft and destruction by floods at night if left in the field. Water was drained 1–2 weeks before harvesting. Threshing was done by manual labour. Straw was left on the farm as animal feed. Grains were dried for two sunny days for all the treatments, as practised by farmers and stored for 2–3 months before milling to determine the yield.

3.4.3 Optimization of land allocation

Linear programming was achieved using the Microsoft Excel® solver tool. A piece of one hectare of land was assumed. The purpose of linear programming was to assist a farmer to apportion the land to different techniques. The price of preparing land for all the treatments is given as follows. The selling price of 1 Kg of rice was taken as Ksh. 100. The ploughing cost was used in determining the cost. The cost of the tractor was Ksh. 11250/hectare, ox Ksh. 7500/hectare, the hand was Ksh. 6250 /hectare. Seeds cost Ksh. 15000/hectare and fertilizers Ksh. 8250/ acre. The cost of weeding and pest control was taken as Ksh. 6000 /hectare. For One-hectare it means a farmer needs to employ someone to do the work of opening water and this was assumed as Ksh. 3000 per hectare.

3.4.4 Optimization procedure

First, the objective function was determined:

$$Profit = \sum_{Coventional} (Yield \times price - production\ cost - ploughing\ water) + \sum_{oxen} (Yield \times price - production\ cost) + \sum_{hand} (Yield \times price - production\ cost) + \sum_{tractor} (Yield \times price - production\ cost)$$

Equation 3.1

Secondly, variable cells to be changed were identified for the four ploughing techniques.

Third, the constraints were set as follows.

$$Land_{conventional} + Land_{oxen} + Land_{hoe} + Land_{tractor} \leq 1.0 \qquad \text{Equation 3.2}$$

$$Land_{conventional} \geq 0, Land_{oxen} \geq 0, Land_{hoe} \geq 0 \text{ and } Land_{tractor} \geq 0 \qquad \text{Equation 3.3}$$

Lastly solving the linear programming equation was done by pressing the solve button.

3.5 Data collection and analysis

Data collected included depth during ploughing and harrowing. The size of the furrow slice during ploughing and harrowing was also measured. The depth of water in millimetres (mm) entering and leaving each plot was measured weekly for the determination of the amount of water retained. During crop growth, rice tillers were counted individually and recorded. Rooting depth was measured using a transparent one-meter ruler after harvesting. This was achieved by digging the ground to expose the roots. After harvesting the grain yields from each plot, they were measured and recorded for comparison purposes. The yields per plot (kg/ 90m2) were then scaled to tons/hectare. Data on yield (milled) and water used was used to calculate Water Use Efficiency (WUE). Yield divided by water used resulted in WUE. Data were analyzed in Microsoft Excel®. Statistical significance was done at $\alpha = 0.05$ based on F tests that are normally used to compare variances. Separation of means was done using Fisher's least significant difference (LSD)-tests at $\alpha = 0.05$.

CHAPTER FOUR

RESULTS

4.1: Effect of land ploughing and harrowing techniques on depth and furrow slices

4.1.1 Land ploughing techniques on depth and furrow slices during ploughing

Tractor ploughing had the highest mean depth of ploughing of 42.00 ± 0.81 cm followed by conventional- ox ploughing with 17.75 ± 0.75 cm, ox ploughing15.75 ± 0.62 cm and hand hoe ploughing had the lowest mean depth 15.50 ± 0.28 cm. Results show that when harrowing, hand hoe ploughing had the greatest mean depth of 14.50 ± 0.05 cm followed by that of tractor ploughing 13.75 ± 1.03 cm while conventional-ox ploughing had a mean depth of 11.55 ± 0.26 cm, and ox- ploughing had the least mean depth of 11.25 ± 0.75 cm as shown in Figure 4.1 Also, hand hoe cannot go deeper than the size of the hoe so larger ploughing depths cannot be reached by use of hoe in the tractor or ox-ploughed plots. There was a significant difference in mean depths during both ploughing and harrowing as shown in Table 4.1 at $\alpha = 0.05$. There was no significant difference between conventional ox plough and the ox plough and also no significant difference between ox plough and hand hoe ploughing. However, there was a significant difference in depth between tractor ploughing and all the other methods during ploughing as shown in Figure 4.1.

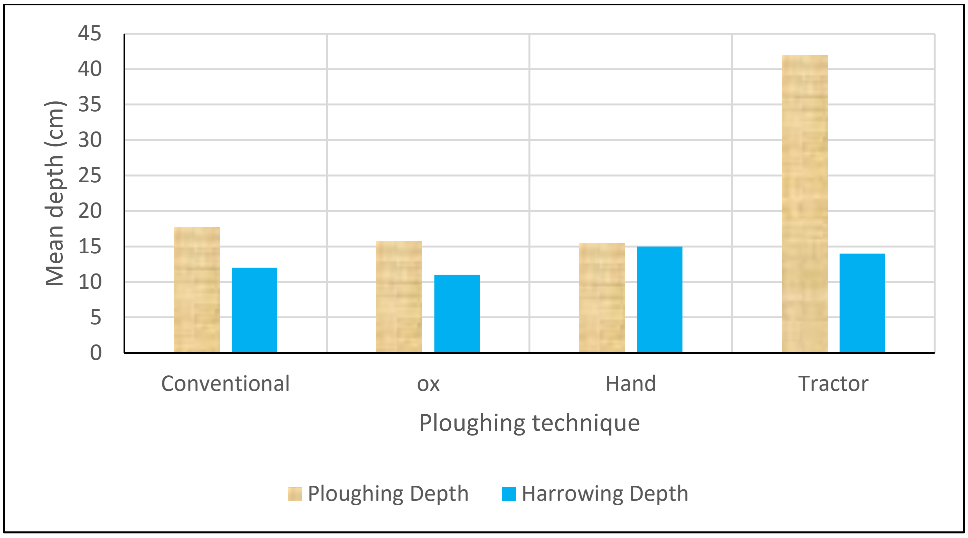


Figure 4.1: Mean ploughing depths for different ploughing techniques

4.1.2 Land ploughing techniques on depth and furrow slices during harrowing

Tractor ploughing had the largest mean furrow slice of 62.00 ± 0.91cm followed by conventional- ox ploughing 32.25 ± 0.85 cm, ox ploughing 30.25 ± 0.85 cm while hand hoe ploughing had the smallest mean furrow slice of 16.5 ± 0.50 cm. The mean size of furrow slice after harrowing was high in tractor ploughing 9.75 ± 1.03 cm followed by that of ox-ploughing 6.00 ± 0.40 cm then conventional ox plough 5.50 ± 0.90 cm while hand hoe ploughing had the least size of 5.25 ± 0.48 cm as portrayed in Figure 4.2.

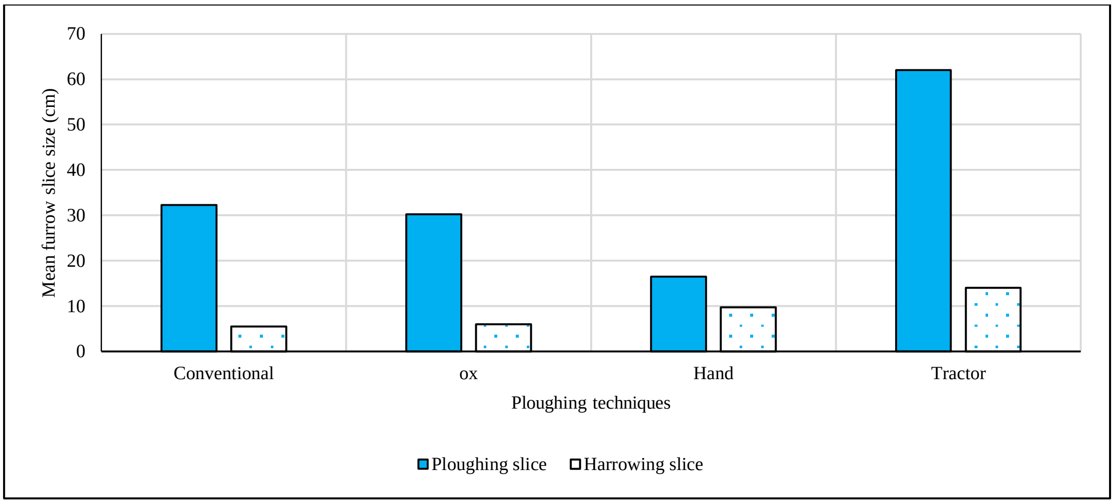


Figure 4.2: Mean furrow slice for different ploughing techniques

There was a significant difference in mean furrow slices during both ploughing and harrowing as shown in Table 4.1 with a significant difference observed between tractor ploughing and all the other techniques.

Table 4.1: Analysis of Variance for depths and furrow slices during ploughing and harrowing

Description	Significance (α = 0.05)	Ploughing Calculated F	Harrowing Calculated F	Critical F
Ploughing depth	Significant (P = <0.05)	388	5.3	3.5
Furrow slice	Significant (P = <0.05)	577	8.0	3.5

4.2 Effect of land ploughing techniques on water retention in paddy rice fields

The water retention during weeks 1, 2, 3, 4, 5, 10, 12 and 14 in the paddy rice fields for the four ploughing techniques did not differ significantly as represented in Table 4.2, however, in weeks 6, 8, 9, 11, 13 and 15 they differed significantly. The highest mean water retention was observed in tractor treatment whereas the least was observed in the conventional one using ox plough. It is worth noting that the water retention for tractor ploughing was close to that of hand hoe ploughing. This means that the extra depth during tractor ploughing did not contribute much to water retention. The highest mean of retained water was recorded in week 4 in paddy rice fields prepared using conventional- ox ploughing (10.5 cm), ox ploughing (10 cm), hand hoe ploughing (11.5 cm) and tractor ploughing (11.5 cm) while the lowest was recorded in week 15.

Table 4.2: ANOVA of weekly water retained (cm) in different ploughing techniques

	Conventional-Ox Ploughing	Ox Ploughing	Hand hoe Ploughing	Tractor Ploughing	F-Ratio	Critical F
Week 1	8.50±0.27	8.25±0.20	8.83±0.34	8.38±0.05	1.06	3.49
Week 2	6.70±0.45	6.95±0.41	7.18±0.36	8.03±0.41	1.99	3.49
Week 3	8.35±0.21	7.28±0.26	7.70±0.20	7.40±0.76	1.25	3.49
Week 4	10.50±0.65	10.00±0.00	11.50±0.65	11.50±0.29	2.45	3.49
Week 5	9.25±0.85	10.25±1.18	9.50±0.29	11.00±0.71	0.92	3.49
Week 6	4.20±0.51	4.35±0.49	5.30±0.27	6.28±0.47	4.62	3.49
Week 8	3.68±0.32	3.73±0.26	4.75±0.19	6.23±0.38	16.27	3.49
Week 9	7.80±0.31	8.20±0.43	7.75±0.31	3.88±.50	26.26	3.49
Week10	5.25±0.49	5.33±0.50	6.75±0.23	5.68±0.09	3.41	3.49
Week 11	8.25±0.37	7.63±0.11	7.85±0.28	9.03±0.31	4.76	3.49
Week 12	4.65±0.13	5.35±1.29	7.88±0.80	7.13±0.72	3.18	3.49
Week 13	3.88±0.10	3.90±0.19	5.33±0.13	7.15±0.23	84.26	3.49
Week 14	3.58±0.28	4.05±0.15	3.28±0.10	4.08±0.43	2.00	3.49
Week 15	1.60±0.93	4.15±0.54	3.85±0.50	3.75±0.25	3.75	3.49
Average	6.160±0.71	6.39±0.61	6.96±0.61	7.11±0.64		

Based on Spearman's rank-order correlation Table (4.3); conventional- ox ploughing was positively correlated with ox ploughing (r = 0.93), hand hoe ploughing (r = 0.91) and tractor ploughing (r = 0.83). Looking at the average depths it was found out that the mean depths were more than 6 cm for the entire growing period with tractor ploughing having higher depths.

Table 4.3: Spearman's rank correlation coefficient for the trend of water retention

	Conventional-Ox Ploughing	Ox Ploughing	Hand hoe Ploughing	Tractor Ploughing
Conventional- Ox Ploughing				
Ox Ploughing	0.9341 *-14* 0.0008			
Hand hoe Ploughing	0.9121 *-14* 0.001	0.8989 *-14* 0.0012		
Tractor Ploughing	0.833 *-14* 0.0027	0.7099 *-14* 0.0105	0.8154 *-14* 0.0033	

4.3 Effect of land ploughing techniques on yield, rooting depth and tillers of rice crop

4.3.1 Number of tillers

The mean number of tillers per ploughing technique was established. Both hand hoe ploughing 24.00 ± 0.41 with a coefficient of variation of 3.40 and tractor ploughing (24.00±0.58SE with a coefficient of variation of 4.81) constituted the highest mean number of tillers insignificantly different (F0.05 (3, 12) = 0.8481, P=0.4938) from Conventional- Ox Ploughing (23.49±0.64) and Ox ploughing (22.75±0.85SE) as portrayed in Figure 4.3. There was no significant difference between the numbers of tillers for all four treatments.

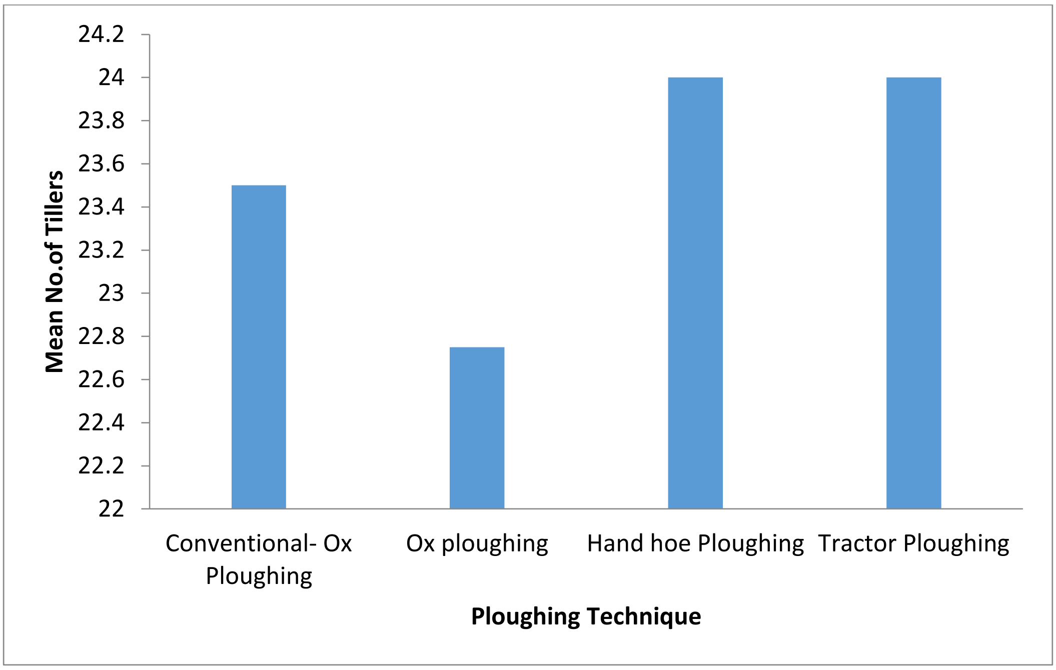


Figure 4.3: Number of tillers

Comparison of grain weight to the number of tillers in respect to the ploughing technique was determined. For conventional ox ploughing, grain weight increased as the number of tillers increased. The simple regression analysis shows that the tillering rate has a positive insignificant impact on yield (F0.05 (1, 2) = 1.67, P=0.3252) as portrayed in Figure 4.5 with R2 being 0.4553.

*Grain weight (kg) = 46.29 + 2.81*No.of tillers*

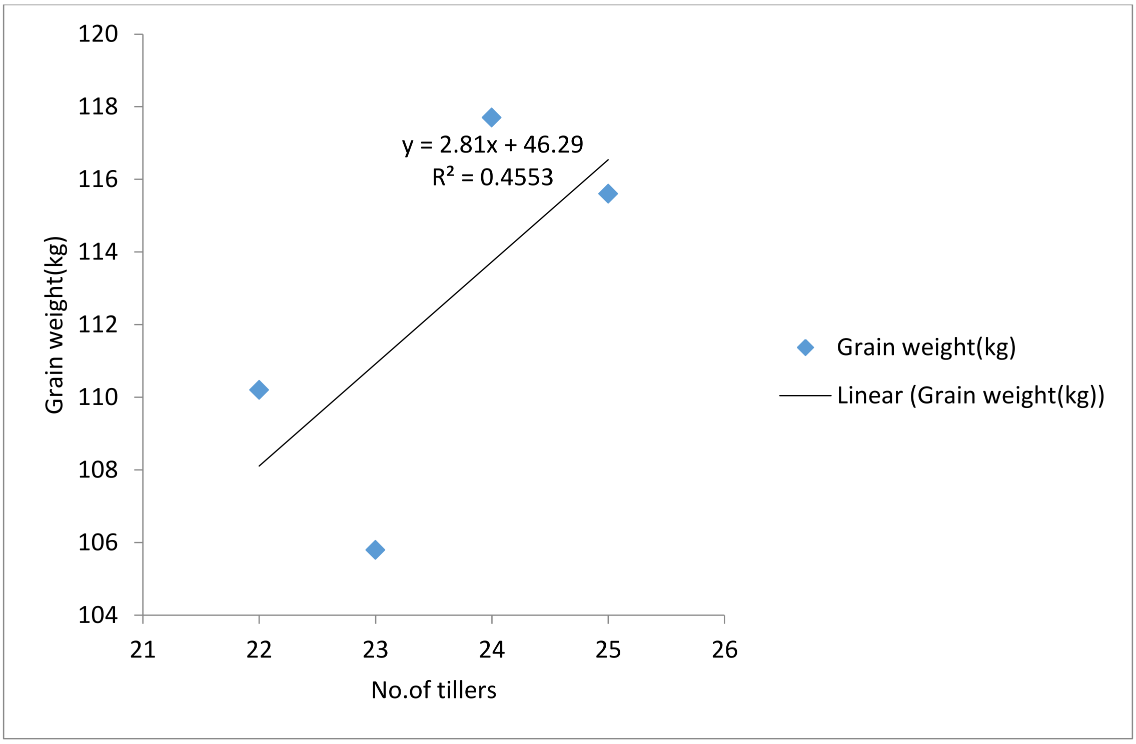


Figure 4.4: Grain yield versus number of tillers for conventional- ox ploughing

For ox ploughing, the increased number of tillers led to reduced grain weight as portrayed in a simple linear regression line (Figure 4.5) with an equation of

*Grain weight (kg) = 138.14 - 0.717143*No.of tillers* and R2= 0.1088.

with statistically insignificant relationship between the variables at the 95.0% or higher (F0.05 (1, 2) = 1.67, P=0.3252).

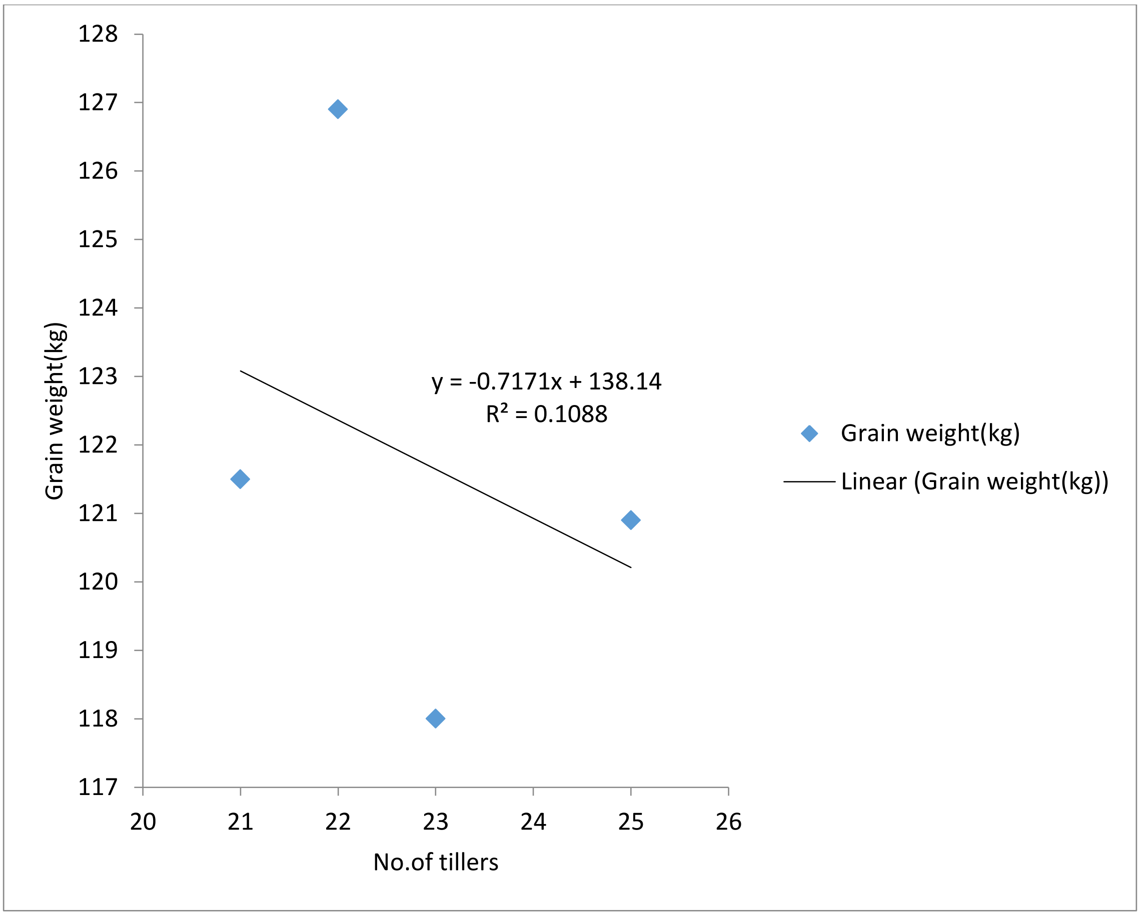


Figure 4.5: Grain yield versus number of tillers for ox ploughing

For hand hoe ploughing, the result indicated that grain weight insignificantly increased with the reduced number of tillers (F0.05 (1, 2) = 6.53, P=0.1235). This gave a regression equation of:

*Grain weight (kg) = 145.2 - 0.65*No.of tillers*

with R2=0.7682 as portrayed in Figure 4.6.

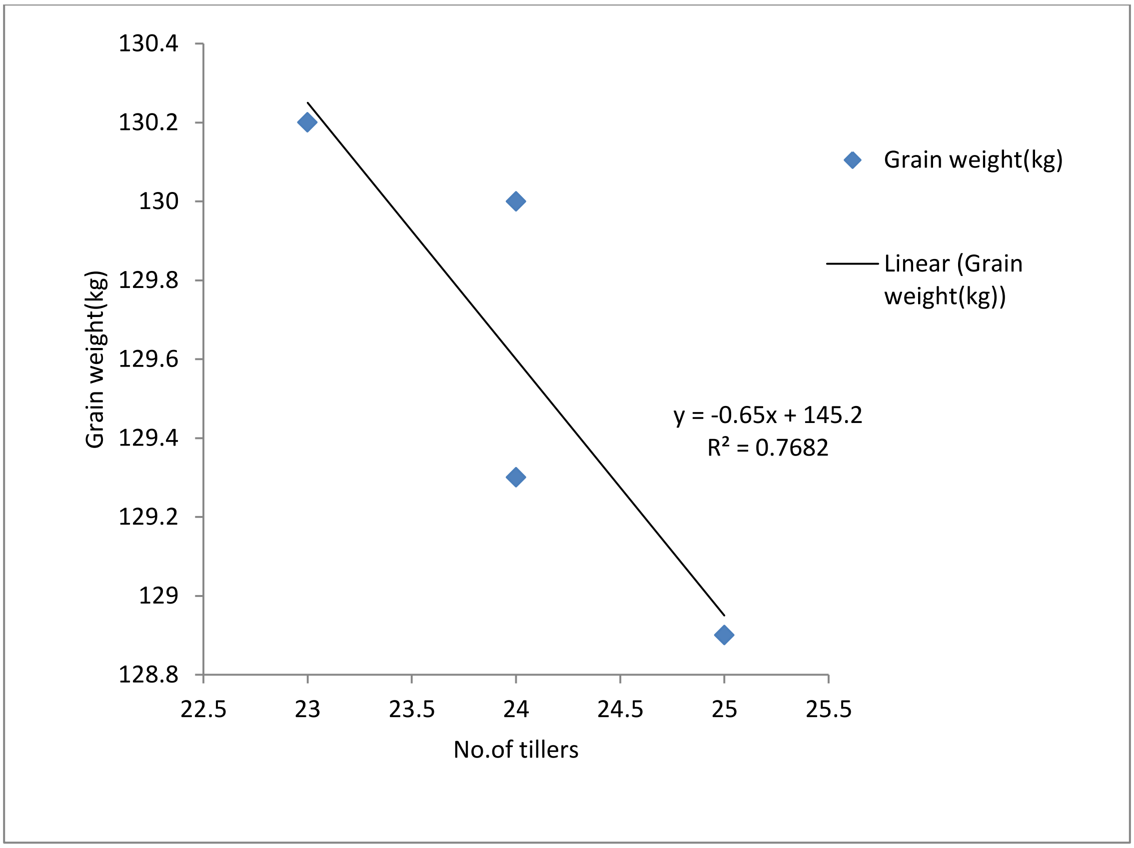


Figure 4.6: Grain yield versus number of tillers for hand hoe ploughing

An increase in the number of tillers resulted in an insignificant increase in grain weight for tractor ploughing ($F_{0.05}$ (1, 2) = 0.43, P=0.5778) as portrayed in Figure 4.7 with a regression equation of;

*Grain weight (kg) = 110.1 + 1.0*No.of tillers* (R2=0.1783)

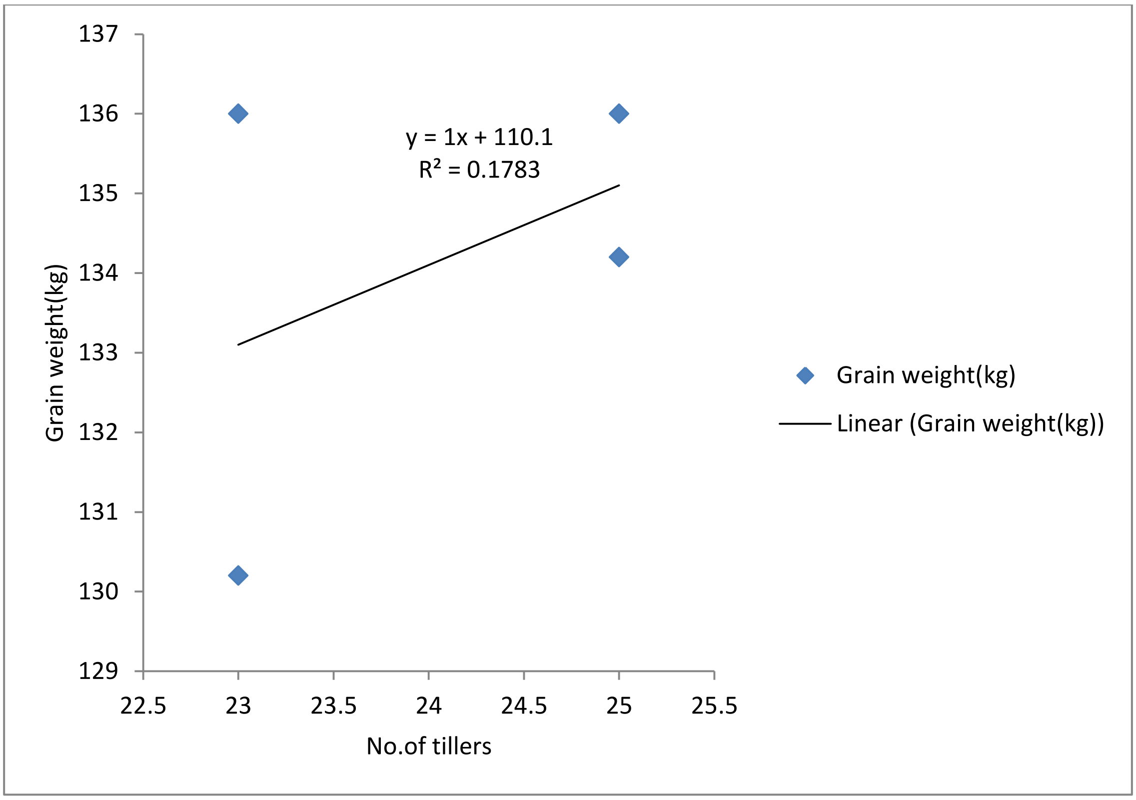


Figure 4.7: Grain yield versus Number of tillers for Tractor ploughing

4.3.2 Rooting depth

Mean rooting depth of paddy rice was established. The mean rooting depth was high in paddy rice field prepared using tractor ploughing (51.25±1.10SE) followed by that prepared using hand hoe ploughing (48.25±0.85SE). Paddy rice field prepared using ox ploughing resulted in a lower mean rooting depth of 45.50±0.64SE which was significantly different from other rooting depths in paddy rice fields prepared using other ploughing techniques ($F_{0.05}$ (3, 12) = 10.37, P=0.0012) as portrayed in Figure 4.8.

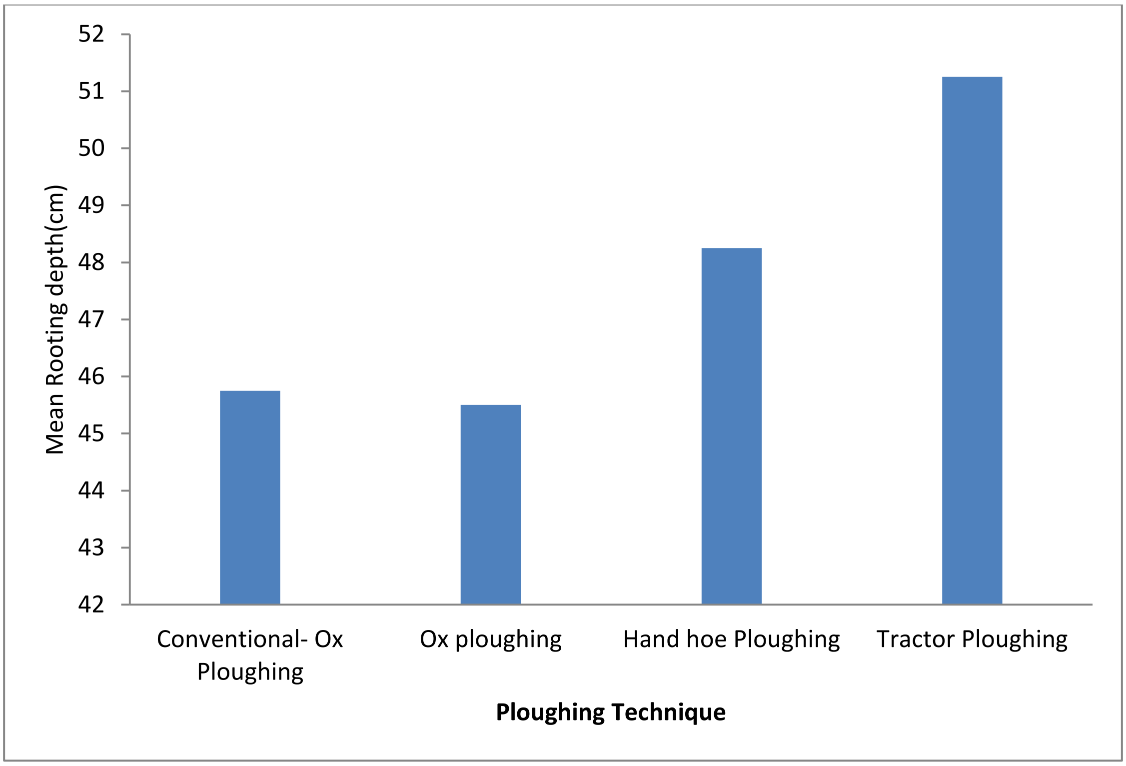


Figure 4.8: Mean rooting depth

4.3.3 Straw and grain yield

Straw yield in kilogram from paddy rice field prepared using tractor plough was highest with a mean of 61.00 ± 0.41SE followed by that of field prepared using hand hoe ploughing with a mean of 59.00±1.12SE while ox ploughing of paddy rice field resulted in a straw yield of 41.75±3.75SE as portrayed in Table 4.4. Straw weight in kg differed significantly from paddy rice fields prepared using the four ploughing techniques ($F_{0.05\ (3,\ 12)} = 19.80$, $P<0.0001$).

Paddy rice field prepared using tractor ploughing resulted in a significantly higher mean wet grain weight of 134.10±1.37SE followed by preparation using hand hoe Ploughing (129.60±0.30SE) while conventional- ox ploughing resulted in significantly lower wet grain weight in kg as portrayed in table 4.4 ($F_{0.05\ (3,\ 12)} = 28.85$, $P<0.0001$).

Dry grain weight in kilogram from paddy rice field prepared using tractor plough was higher (100.58±1.03SE), followed by that of field prepared using Hand hoe Ploughing

(97.20±0.23SE) while Conventional- Ox Ploughing of paddy rice field resulted to low dry grain yield in kg of 84.25±2.02SE significantly lower from all others ploughing techniques ($F_{0.05}$ (3, 12) = 28.87, $P<0.0001$).

Milled grain weight in kilograms was also established. Paddy rice field prepared using Hand hoe Ploughing resulted in a significantly higher mean milled grain weight of 51.07±2.38SE followed by paddy rice field prepared using Tractor Ploughing (50.29±0.51SE) while Conventional- Ox Ploughing resulted to significantly lower mean milled grain weight in kg as portrayed in Table 4.4 ($F_{0.05}$ (3, 12) = 8.75, $P<0.0001$).

Table 4.4: Rice Yield in kilogram resulting from different ploughing techniques

Ploughing Technique	Weight of straw (Kg)	Grain weight (Kg) Wet	Grain weight (Kg) Dry	Grain weight (Kg) Milled
Conventional-Ox Ploughing	48.50±1.04	112.33±2.69	84.25±2.02	42.13±1.01
Ox ploughing	41.75±3.75	121.83±1.86	91.37±1.39	46.30±0.90
Hand hoe Ploughing	59.00±1.12	129.60±0.30	97.20±0.23	51.07±2.38
Tractor Ploughing	61.00±0.41	134.10±1.37	100.58±1.03	50.29±0.51
Df	3.00	3.00	3.00	3.00

F-Ratio	19.80	28.85	28.87	8.75
P-Value	<0.0001	<0.0001	<0.0001	<0.0001

4.4 Optimization results

The results showed that all the one hectare be apportioned to hand hoe ploughing as it maximizes the profit. The profit of one hectare was found to be KSHS. 417, 500 (Table 4.5). This was because of the high yield. Thus farmers should apportion much of their land to hand hoe ploughing.

Table 4.5: Optimization results

	Kg	100000			Profit
Ploughing technique	Conventional	Ox	Hand hoe	Tractor	417500
Land apportioning	0	0	1	0	1
Ploughing	7500	7500	6250	11250	
water	3000	0	0	0	
Seeds	15000	15000	15000	15000	
Fertilizer	8250	8250	8250	8250	
Weeding	5000	5000	5000	5000	
Diseases	1000	1000	1000	1000	
Yield	4.2	5.1	5.7	5.6	

CHAPTER FIVE

DISCUSSION

5.1 Effect of land ploughing techniques on depth and furrow slices

Tractor ploughing had the highest mean depth of ploughing. The depth of tractor ploughing was twice the 20 cm observed by Kareem and Sven, (2019). It was also one and half times the 30 cm observed in India. Tractor ploughing had the largest mean furrow slice. Tractor furrow slice was twice 30 cm observed by TNAU Agritech, (2016).

5.2 Effect of land ploughing techniques on water retention in paddy rice fields

Water retention in paddy rice fields prepared using tractor plough was higher as compared to the other three. The highest water retention in week 4 was attributed to rainfall received during that week. It is interesting to note that water retention increased in those weeks when rainfall was experienced for example in weeks 3, 9 and 11. Water retention decreased whenever there was no rainfall. Therefore, water retention fluctuated according to rainfall. Higher moisture retention for tractor ploughed fields was similar to that observed in Ghana by Bashagaluke *et al.*, (2019) who reported higher soil moisture content in tractor ploughing when compared to other techniques.

The amount of water used during land preparation was close to 360 mm observed by Singh *et al.* 2001. The highest consumption of water in a conventional way was attributed to the water that was used to wet the fields before ploughing. The second highest value for tractor ploughing was linked to deeper depths of ploughing when tractors were used. The observed least amount of water consumed by ox-plough without wetting was linked to shallow depths of ploughing because the soils were hard to plough. From the results, farmers were able to appreciate the need for not wetting the field, thus avoiding wastage of scarce water resources. The labour that would have been used during wetting the field before ploughing could be used elsewhere.

5.3 Effect of land ploughing techniques on yield, rooting depth and tillers of rice crop

Tractor ploughed plots had the highest number of tillers owing to their greater depths. The slow increase of tillers between week 2 and week 11 for hand ploughed fields could be attributed to shallow depths for hand hoe ploughing. The maximum number of tillers observed on day 77 was consistent with modern-day rice varieties that have 20–25 tillers (Pawar *et al.,* 2016). Tractor ploughing had the highest depth due to the increasing intensity of tillage. This means that, with greater depths, layers of soil loosened leading to adequate aeration for the growth of rice. An increase in root volume means an increase in nutrient uptake by the root, which led to high yields. All the rooting depths were higher than 45 cm observed for well-watered rice varieties in Malaysia (Zulkarnain *et al.,* 2009) and more than double what was observed in Taiwan (Pascual & Wang, 2017).

Conventional ox-ploughing resulted in a significantly lower mean milled yield of 4.7 tons/ha. This agrees with Huang *et al., 2020* study that found that deep tillage had more yield than shallow tillage. Use of the hand hoe ploughing technique increased yields by 20 per cent of the conventional ox-ploughing. Yields for tractor ploughing and hand hoe ploughing were also close to 5.5 tons/ha observed by FAO (2020). All the yields were well above the average of 3.84 tons/ha (Zingore *et al.,* 2014), but they were half of the potential yields of 10 to 11 tons/ha for low-land rice when water is not limiting. Furthermore, the observed yields were below 7.4 tons/ha for the USA, however, the yields were closer to 6.19 tons/ha in China (GYGA, 2020). This shows that there is still a need for improvement in rice production in the area of study. These

WUE were similar to rice production in Pakistan, which has a WUE of less than 0.45 kg/m3 (Soomro *et al.*, 2015).

Another way of increasing yields and water use efficiency can be done by using biochar, as was observed in China (Yang *et al.*, 2018). The reason why hand hoe performed better than all the other techniques could be attributed to the reason that hand levelling and harrowing was done by hand. While hand hoe had the highest WUE, it is a laborious job and time-consuming. Hand hoe ploughing is impractical for larger fields, but since farmers have small pieces of land, they are recommended because they create jobs for youth and do not pollute the environment like tractors. The engine of tractors uses diesel, fossil fuel, which produces carbon dioxide when the tractor is ploughing. Carbon dioxide is one of the greenhouse gases that contribute to global warming, as observed by Mamona *et al.*, 2021. This is welcome as the County Government of Homa Bay in the area has a labour force that is 48% of the population. This could assist in alleviating the rate of unemployment in the county, which stood at 73% (FAO, 2020). The study looked at reducing the usage of irrigation water, which is a scarce resource in the world (Salins *et al.*, 2021) and this renewable resource is expected to reduce in future and not water quality (Khalilian & Shahvari, 2019). Environmental degradation in the area means high morbidity of water pollutants (FAO, 2020). Since the water for irrigation comes from the river, it is suspected as having some heavy metals, as seen in the Yangtze River in China (Liu *et al.*, 2016) or emerging pollutants in drinking water resources Wu *et al.*, 2019), which can pose serious health risks and needs more research in the future.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The highest water retained was observed in both hand hoe and tractor ploughed plots. There was a strong correlation between the weekly amounts of water between different treatments. The greatest correlation occurred between conventional ox plough (with water) and ox plough (without water).

6.1.1 Effect of land ploughing techniques on depths and furrow slices during ploughing and harrowing

Use of the hand hoe ploughing technique increased yields by 20 per cent of the conventional ox-ploughing. Use of water before ploughing does not add value to paddy rice production if hand ploughing is used during harrowing and levelling. Hand ploughing, harrowing and levelling resulted in the highest milled yield of 5.7 tons/hectare and water use efficiency of 0.49 kg/m3.

6.1.2 Effect of land ploughing techniques on water retention in paddy rice fields

The highest water retained was observed in both hand hoe and tractor ploughed plots. There was a strong correlation between the weekly amounts of water between different treatments. The greatest correlation occurred between conventional ox plough (with water) and ox plough (without water).

6.1.3 Effect of land ploughing techniques on yield, rooting depth and tillers of rice crop

Use of the hand hoe ploughing technique increased yields by 20 percent of the conventional ox-ploughing. Use of water before ploughing does not add value to paddy rice production if hand ploughing is used during harrowing and levelling. Hand ploughing, harrowing and levelling resulted in the highest milled yield of 5.7 tons/hectare and water use efficiency of 0.49 kg/m^3.

6.2 Recommendations

Thus this thesis makes the recommendations below:

6.2.1Effect of land ploughing techniques on depths and furrow slices during ploughing and harrowing

1. Hand hoe ploughing is recommended as there were no benefits in using tractor ploughing followed by subsequent harrowing and levelling manually.
2. The National Government and County Government of Homa Bay and the private sector should capacity-build the Maugo Rice Cooperative Society in terms of land preparation machinery.

6.2.2 Effect of land ploughing techniques on water retention in paddy rice fields

1. More capacity building of farmers is needed through training to help improve efficiency in the use of irrigation water in the scheme.
2. The main canal needs to be lined and maintained well to improve availability and ensure proper depth of irrigation water.

6.2.3 Effect of land ploughing techniques on yield, rooting depth and tillers of rice crop

1. It is recommended that farmers drain the field 7-10 days before harvesting, to harden the soil for good harvesting and also to quicken the drying and ripening of the rice.

2. Farmers in the scheme are advised to transplant rice seedlings in straight rows and avoid random planting to get the optimum tiller number for a good grain harvest.
3. The National Government and County Government of Homa Bay should capacity-build the Maugo Rice Cooperative Society in terms of rice harvesting and threshing technologies.

6.3 Suggestions for further studies

The following are the suggested areas for further research:

1. This research was conducted for one season and there is a need for further study to capture any climatic related conditions.
2. If the research findings are adopted satisfactorily, another combination of farmer's conventional method of ploughing and harrowing using tractors should be done before moving to full mechanization.
3. Since the research was based on continuous flooding(CF) then future work should explore investigations on alternate wetting and drying under the System of Rice Intensification (SRI)

REFERENCES

Aikins, S. H. M., & Afuakwa, J. J. (2010). Effect of four different tillage practices on cowpea performance. *World Journal of Agricultural Sciences*, *6*(6), 644-651.

Aikins, S. H. M., Afuakwa, J. J., & Owusu-Akuoko, O. (2012). Effect of four different tillage practices on maize performance under rainfed conditions. *Carbon*, *1*, 1-51.

Alam, M., Islam, M., Salahin, N., & Hasanuzzaman, M. (2014). Effect of tillage practices on soil properties and crop productivity in wheat-mungbean-rice cropping system under subtropical climatic conditions. *The Scientific World Journal*, *2014*.

Alexander, K. S., Parry, L., Thammavong, P., Sacklokham, S., Pasouvang, S., Connell, J. G. & Case, P. (2018). Rice farming systems in Southern Lao PDR: Interpreting farmers' agricultural production decisions using Q methodology. *Agricultural Systems*, *160*, 1-10.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome*, *300*(9), D05109.

Altieri, M. A., Nicholls, C. I., & Montalba, R. (2017). Technological approaches to sustainable agriculture at a crossroads: an agroecological perspective. *Sustainability*, *9*(3), 349.

Arora, V.K.; Joshi, R.; Singh, C.S (*2018*). Irrigation and Deep Tillage Effects on Productivity of Rice in a Subtropical Environment. *Agricultural Resources*, *7*, 416–423.

Atera, E. A., Onyancha, F. N., & Majiwa, E. B. (2018). Production and marketing of rice in Kenya: Challenges and opportunities. *Journal of Development and Agricultural Economics*, *10*(3), 64-70.

Bangura, K. (2015). *Effects of tillage and weeding frequency on rice performance and soil physical properties*, Doctoral dissertation, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi.

Bashagaluke, J. B., Logah, V., Opoku, A., Tuffour, H. O., Sarkodie-Addo, J., & Quansah, C. (2019). Soil loss and run-off characteristics under different soil amendments and cropping systems in the semi-deciduous forest zone of Ghana. *Soil Use and Management*, *35*(4), 617-629.

Birkás, M., Dexter, A., Kalmár, T., & Bottlik, L. (2006). Soil quality–soil condition–production stability. *Cereal Research Communications*, *34*(1), 135-138.

Boulanger, P., Dudu, H., Ferrari, E., Mainar-Causapé, A. J., & Ramos, M. P. (2020). Effectiveness of fertilizer policy reforms to enhance food security in Kenya: a macro–micro simulation analysis. *Applied Economics*, 1-21.

Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, *3*(2), 119-129.

Carter, M. R. (2017). *Conservation tillage in temperate agroecosystems*. CRC Press.

Chirchir, J. (2019). Evaluation of varietal purity of certified basmati 370 and bw 196 from two rice seed sources in Mwea and the response of rice varying n, p and k fertilizer regimes.

Cui, Z., Zhang, H., Chen, X., Zhang, C., Ma, W., Huang, C., & Dou, Z. (2018). Pursuing sustainable productivity with millions of smallholder farmers. *Nature*, *555*(7696), 363-366.

De Bont, C., & Veldwisch, G. J. (2020). State engagement with farmer-led irrigation development: Symbolic irrigation modernisation and disturbed development trajectories in Tanzania. *The Journal of Development Studies*, *56*(12), 2154-2168.

Dharmappa, P. M., Doddaraju, P., Malagondanahalli, M. V., Rangappa, R. B., Mallikarjuna, N. M., Rajendrareddy, S. H., ... & Sheshshayee, S. M. (2019). Introgression of root and water use efficiency traits enhances water productivity: An evidence for physiological breeding in rice (Oryza sativa L.). *Rice*, *12*(1), 1-14.

Domènech, L. (2015). Improving irrigation access to combat food insecurity and undernutrition: A review. *Global Food Security*, *6*, 24-33.

EL-Din, A. Z., EI-Abedin, T. Z., El-Hesawy, A. A., & Abd EI-Hameed, R. G. (2008). Effect of tillage and planting practices on rice yield and engineering characteristics of milling quality. *Misr Journal of Agricultural Engineering 25*(3), 778-803.

El-Shater, T.; Mugera, A.; Yigezu, Y.A (2020). Implications of Adoption of Zero Tillage (ZT) on Productive Efficiency and Production Risk of Wheat Production. *Sustainability*, *12,* 3640.

FAO (2016). *Planning, Implementing and Evaluating Climate Smart Agriculture in Smallholder farming systems. The Experience of the MICCA Pilot Projects in Kenya and the United Republic of Tanzania*; FAO: Rome, Italy, pp. 3–112.

FAO (2018) FAOSTAT database from http://faostat.fao.org/).

FAO (2020). Available online: http://www.fao.org/3/T7202E/t7202e00.htm#dataContent (accessed on 29 September 2020).

Finda B. Jenkins, Kanu A.S.,Mahmood N.,Gborie M., Bangura K.,Kargbo H.M.S(2018**):** An Assessment of rice-based farmers' indigenous land preparation, crop establishment and soil fertility maintenance practices in Sierra Leone. *IOSR Journal of Humanities and Social Science (IOSR-JHSS).23(1),* 74-82

Gitonga, K., & Snipes, K. (2017). Grain and Feed Annual: 2017 Kenya Corn, Wheat and Rice Report. *Gain Report, Global Agricultural Information Network*.

Glinski, J. (2018). *Soil physical conditions and plant roots*. CRC press.

Global Yield Gap Atlas (GYGA) (2020).Availlable online: http://www.yieldgap.org/gygamaps/app/index.html (accessed on 5th October 2020).

Kogo, B. K., Kumar, L., & Koech, R. (2020). Climate change and variability in Kenya: a review of impacts on agriculture and food security. *Environment, Development and Sustainability*, 1-21.

Government of Kenya. (2013b). National Water Master Plan 2030 in the Republic of Kenya final report volume -v sectoral report (2/3), Nairobi, Kenya.

Government of Kenya (2017): Kenya Climate Smart Agriculture Strategy-2017-2026; Ministry of Agriculture,Livestock and Fisheries,Nairobi,Kenya.

Government of Kenya (2018a): Kenya National Climate Change Action Plan, 2018-2022. Volume I. Pre-publication version approved by NCCAP Task Force. Nairobi: Ministry of Environment and Forestry.

Government of Kenya (2018b): Third Medium Term Plan 2018-2022: Transforming lives: Advancing socio-economic development through the "Big Four" .National Treasury and Planning, Nairobi, Kenya.

Government of Kenya (2018c): Kenya Climate Smart Implementation Framework-2018-2027; Ministry of Agriculture, Livestock and Fisheries, Nairobi, Kenya.

Hanafiah, M.M., Ghazali, N.F., Harun, S.N., AbdulHasan,M.J.,& Kamarudin, M. K. A. (2019). Assessing water scarcity in Malaysia: a case study of rice production. *Desalination Water Treatment*, *149*, 274-287.

Huang, C.; Li, N.; Zhang, Z.; Liu, Y.; Chen, X.; Wang, F.; Chen, Q. (2020). What Is the Consensus from Multiple Conclusions of Future Crop Yield Changes Affected by Climate Change in China? *International Journal of Environmental and Resources and Public Health*, *17*, 9241.

Islam, S. F., & Karim, Z. (2019). Sustainable Agricultural Management Practices and Enterprise Development for Coping with Global Climate Change. In *Sustainable Management Practices*. IntechOpen.

Jenkins, B., Gilbert, R., & Nelson, J. (2017). The 2030 Water Resources Group: Collaboration and Country Leadership to Strengthen Water Security.

Kadžienė, G., Munkholm, L. J., & Mutegi, J. K. (2011). Root growth conditions in the topsoil as affected by tillage intensity. *Geoderma*, *166*(1), 66-73.

Kashindi, G. (2021). Local agricultural production in Kenya: legal framework, obstacles and challenges. *KAS African Law Study Library*, *7*(4), 581-593.

Karanja, F. K. (2006). CROPWAT model analysis of crop water use in six districts in Kenya. *CEEPA DP35, University of Pretoria, South Africa*.

Kareem KI, and Sven P.2019. Effect of Ploughing Depth, Tractor forward speed, and plough types on the fuel consumption and tractor performance. Polytechnic Journal, 9,43-49.

Khalilian, S.; Shahvari, N. A. (2019). SWAT Evaluation of the Effects of Climate Change on Renewable Water Resources in Salt Lake Sub-Basin, Iran. *AgriEngineering*, *1*, 44–57.

Khurshid, K. A. S. H. I. F., Iqbal, M., Arif, M. S., & Nawaz, A. (2006). Effect of tillage and mulch on soil physical properties and growth of maize. *International Journal of Agriculture and Biology*, *8*(5), 593-596.

Kiprotich, K. C., Kipkorir, E. C., & Munyao, T. M. (2013). Optimization of Benefits from Cabbage Farming by Staggering Transplanting Dates during the Dry season in Keiyo Highlands, Kenya. *Resource Journal of Chemistry and Environmental Science 1*(3), 56-62.

KNBS (2020): Economic Survey 2020; Kenya National Bureau of Statistics,Nairobi,Kenya. Available on line at http://www.knbs.or.ke.

Kogo, B. K., Kumar, L., & Koech, R. (2020). Climate change and variability in Kenya: a review of impacts on agriculture and food security. *Environment, Development and Sustainability*, 1-21.

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, *7*(5), 5875-5895.

Lamichhane, J. R., Debaeke, P., Steinberg, C., You, M. P., Barbetti, M. J., & Aubertot, J. N. (2018). Abiotic and biotic factors affecting crop seed germination and seedling emergence: a conceptual framework. *Plant and soil*, *432*(1), 1-28.

Langat, P. K., Kumar, L., Koech, R., & Ghosh, M. K. (2019). Monitoring of land use/land-cover dynamics using remote sensing: a case of Tana River Basin, Kenya. *Geocarto International*, 1-19.

Lawrence, B., Alexandrina, A., Sam, W., Godfrey, S., & Morris, O. S. (2020). Evaluation of maize (Zea mays L.) performance under minimum and conventional tillage practice in two distinct agroecological zones of Uganda. *African Journal of Agricultural Research*, *16*(5), 600-605.

Liu, Z.; Zhang, Q.; Han, T.; Ding, Y.; Sun, J.; Wang, F.; Zhu, C. (2016). Heavy Metal Pollution in a Soil-Rice System in the Yangtze River Region of China. *International Journal Environmental Resources and Public Health*, *13*, 63.

Mahajan, G., Kumar, V., & Chauhan, B. S. (2017). Rice production in India. In *Rice production worldwide* (pp. 53-91). Springer, Cham.

Majiwa, E., & Mugodo, C. (2018). Technical efficiency and technology gap ratios among rice farmers in Kenya.

Mamona, H.; Hafiz, M.T.; Zhan, J.; Xia, J.; Zhou, Y.; Zhou, H.; Du, J.; Sultan, M. (2021). Experimental Investigation of Traction Power Transfer Indices of Farm-Tractors for

Efficient Energy Utilization in Soil Tillage and Cultivation Operations. *Agronomy 11*, 168.

Materu, S.T.; Sanjay, S.; Sishodia, R.S.; Tarimo, A.; Tumbo, D.S. (2018) Water Use and Rice Productivity for Irrigation Management Alternatives in Tanzania. *Water, 10, 1018.*

Mati, B. M. (2008). Capacity development for smallholder irrigation in Kenya. *Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage*, *57*(3), 332-340.

M'Marete CK. 1991. The bearing capacity of the soils of Ahero irrigated rice fields under exposure to land preparation traffic. MSc Thesis, Department of Agricultural Engineering, University of Nairobi, Nairobi, Kenya.

Msangya B., Yihuan W. (2016): Challenges for Small-Scale Rice Farmers: A Case Study of Ulanga District-Morogoro, Tanzania; *International Journal of Science Research and Innovative Technology*,3(6).

Muchira, C. W. (2019). Effect of Direct Seeding and Transplanting On Growth and Yield of Selected Rice (Oryza Sativa L.) Varieties On Rain-Fed and Irrigated Lowlands of Kenya (Doctoral dissertation, University of Nairobi).

Muema, F. M. (2018). *Comparative Performance Evaluation of Public Rice Irrigation Schemes in Western Kenya Using Benchmarking Process* (Doctoral dissertation, JKUAT-PAUSTI).

Munyua, J. M. (2020). Mwea Irrigation Scheme in Kenya. *Jumuga Journal of Education, Oral Studies, and Human Sciences (JJEOSHS), 3*(1), 1-11.

Musukwa, G. (2018). Effect of Conservation Agriculture on Physical Quality of Soil from Medium Rainfall Areas of Zambia (Doctoral Dissertation, Ghent University).

Muthee, F. (2017). Modelling the Impact of National Development Strategies for the East African Rice Sector.

Namu, J., Karuri, H., Alakonya, A., Nyaga, J., & Njeri, E. (2018). Distribution of parasitic nematodes in Kenyan rice fields and their relation to edaphic factors, rainfall and temperature. *Tropical Plant Pathology*, *43*(2), 128-137.

Nakawuka, P., Langan, S., Schmitter, P., & Barron, J. (2018). A review of trends, constraints and opportunities of smallholder irrigation in East Africa. *Global food security*, *17*, 196-212.

Nazari, S., Rad, G. P., Sedighi, H., & Azadi, H. (2015). Vulnerability of wheat farmers: Toward a conceptual framework. *Ecological indicators*, *52*, 517-532.

Nosalewicz, A., & Lipiec, J. (2014). The effect of compacted soil layers on vertical root distribution and water uptake by wheat. *Plant and soil*, *375*(1), 229-240.

Obura, J., Ombok, B. O., & Omugah, G. (2017). Analysis of rice supply chain in Kenya. *International Journal of Managerial Studies and Research (IJMSR)*, vol5, no.8.

Okumu, M. N. (2020). *The role of women in irrigation: a case study of the Ahero Irrigation Scheme in Kenya* (Doctoral dissertation), University of Nairobi.

Onyango, A. O. (2014). Exploring options for improving rice production to reduce hunger and poverty in Kenya. *World Environment*, *4*(4), 172-179.

Oremo, F. O. (2020). *Enhancing Governance of Water Resources for Improved Uptake of on-farm Water Storage Technology among Smallholder Irrigators in Tsavo Sub-catchment, Kenya*,Doctoral thesis,University of Nairobi.

Öztürk, F. (2019). Effects of tillage systems on second crop sesame (sesamum indicum L.) yield and weed density. *International Journal of Agriculture Environment and Food Sciences*, *3*(1), 29-33.

Pascual, J.V.; Wang, Y.M. (2017). Impact of Water Management on Rice Varieties, Yield, and Water Productivity under the System of Rice Intensification in Southern Taiwan. *Water*, *9*, 3.

Pawar, S.Y.; Radhakrishnan, V.V.; Mohanan, K.V. (2016). The importance of Optimum Tillering in rice-an overview. *South Indian Journal of. Biological Sciences 2*, 125–127.

Pérez-Escamilla, R. (2017). Food security and the 2015–2030 sustainable development goals: From human to planetary health: Perspectives and opinions. *Current developments in Nutrition*, *1*(7), e000513.

Pervez Bharucha, Z., Attwood, S., Badiger, S., Balamatti, A., Bawden, R., Bentley, J. W., & Pretty, J. (2020). The Top 100 questions for the sustainable intensification of agriculture in India's rainfed drylands. *International Journal of Agricultural Sustainability*, 1-22.

Prodhan, Z.H., & Qingyao, S.H.U. (2020). Rice Aroma: ANatural Gift Comes with Price and the Way Forward. *Rice Science,* 27(2), 86-100

Puzyreva, M., & Roy, D. (2018). *Adaptive and Inclusive Watershed Management*. International Institute for Sustainable Development.

Raiesi, F., & Kabiri, V. (2016). Identification of soil quality indicators for assessing the effect of different tillage practices through a soil quality index in a semi-arid environment. *Ecological Indicators*, *71*, 198-207.

Rashidi, M., & Keshavarzpour, F. (2011). Effect of different tillage methods on some physical and mechanical properties of soil in the arid lands of Iran. *World Applied Sciences Journal*, *14*(10), 1555-1558.

Republic of Kenya (2013).Homabay County Government;Second County Integrated Development Plan (2013-2017); Government Printer: Nairobi, Kenya, p. 4.Available online at http://www.homabay.go.ke.

Republic of Kenya (2018); Homabay County Government;Second County Integrated Development Plan (2018-2022); Government Printer: Nairobi, Kenya, p. 4-6.Retrieved from http://www.homabay.go.ke on 17th January 2021.

Republic of Kenya (2019a).Kenya Gazette Suppliment No.136 (Acts No.14) Special Issue).Government Printer, Nairobi.1-28.Retrieved from https://irrigation.go.ke/resources on 9th march 2021.

Republic of Kenya (2019b).*2019* Kenya Population and Housing Census Volume II:Distribution of Population by Administrative Units. Kenya National Bureau of Statistics, Nairobi, Kenya. pp. 230.Retrieved from http://www.knbs.or.ke on 8th March 2021.

Salins, S.S.; Siddiqui, S.A.; Reddy, S.V.K.; Kumar, S. (2021). Experimental Investigation on the Performance parameters of a helical coil dehumidifier test rig. *Energy Sources Part A Recovery Util. and Environ. 43*, 35–53.

Samejima, H., Katsura, K., Kikuta, M., Njinju, S. M., Kimani, J. M., Yamauchi, A., & Makihara, D. (2020). Analysis of rice yield response to various cropping seasons to develop optimal cropping calendars in Mwea, Kenya. *Plant Production Science*, *23*(3), 297-305.

Srujana, G., Suresh, B. G., Lavanya, G. R., Ram, B. J., & Sumanth, V. (2017). Studies on Genetic Variability, Heritability and Genetic advance for yield and quality components in rice (Oryza sativa L.). *Journal of pharmacognosy and phytochemistry*, *6*(4), 564-566.

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., & Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, *17*(6), 1585-1600.

Singh, S.; Sharma, S.N.; Rajendra, P. (2001). The Effect of Seedling and Tillage Methods on Productivity of Rice-Wheat Cropping Systems. *Soil Tillage Res. 61*, 125–131.

Shemahonge, M. I. (2013). *Improving upland rice (oryza sativa L.) perfomance through enhanced soil fertility and water conservation methods at Ukiriguru Mwanza, Tanzania* (Doctoral dissertation, Sokoine University of Agriculture).

Soomro, Z.A.; Arshad, M.D.; Ejaz, K.; Ashraf, M. (2015). *Rice Cultivation on Beds-An Efficient and Viable Irrigation Practice*; Pakistan Council of Research in Water Resources (PCRWR): Islamabad, Pakistan, p. 24.

Srujana, G., Suresh, B. G., Lavanya, G. R., Ram, B. J., & Sumanth, V. (2017). Studies on Genetic Variability, Heritability and Genetic advance for yield and quality components in rice (Oryza sativa L.). *Journal of pharmacognosy and phytochemistry*, *6*(4), 564-566.

Taft, H. L. (2015). Water scarcity: global challenges for agriculture. In *Food, Energy, and Water*,395-429, Elsevier.

Tigga, V., Kumar, A., Khan, H. H., Singh, P., Sahu, H. N., & Ghongade, D. S. (2017). Effect of different insecticides on Coccinellid and Spider in rice field in district Allahabad, UP.

TNAU AGRITEC, 2016. Agriculture. Available from http://agritech.tnau.ac.in/agriculture/agric_tillageimplements.html [Accessed on 11 September 2020].

Tomar, R., Singh, N. B., Singh, V., & Kumar, D. (2018). Effect of planting methods and integrated nutrient management on growth parameters, yield and economics of rice. *J. Pharmacogn. Phytochem*, *7*(2), 520-527.

Ujoh, F. T., & Ujoh, F. (2014). Effects of different tillage operations on rice yield at Yandev, Central Nigeria. *Agriculture Science Developments*, *ISSN*, 2306-7527.

Upadhaya, B., & Kishor, K. (2019). Chapter-7 Soil Tillage. *Chief Editor Dr. Neeraj Kumar*, 151.

Usman, Y. M., Hussaini, M., Baba-Musami, B., & Sheriff, B. (2014). Effect of Different Tillage Methods on the Growth and Yield of Pearl Millet under Rainfed Conditions. *The International Journal of Science and Technoledge*, *2*(11), 62.

Van Ittersum, M. K., Cassman, K. G., Grassini, P., Wolf, J., Tittonell, P., & Hochman, Z. (2013). Yield gap analysis with local to global relevance—a review. *Field Crops Research*, *143*, 4-17.

Wainwright, C. M., Marsham, J. H., Keane, R. J., Rowell, D. P., Finney, D. L., Black, E., & Allan, R. P. (2019). 'Eastern African Paradox'rainfall decline due to shorter not less intense Long Rains. *npj Climate and Atmospheric Science*, *2*(1), 1-9.

Wang Y., Ren, T., Lu, J., Ming, R., Li, P., Hussain, S., & Li, X. (2016). Heterogeneity in rice tillers yield associated with tillers formation and nitrogen fertilizer. *Agronomy Journal*, *108*(4), 1717-1725.

World Bank (2000): World Development Report 2000/2001: Attacking Poverty.The World Bank,Washington,D.C.

Wu, D.; Zhou, Y.; Lu, G.; Hu, K.; Yao, J.; Shen, X.; Wei, L. (2019). The Occurrence and Risks of Selected Emerging Pollutants in Drinking Water Source Areas in Henan, China. *Int. J. Environ. Res. Public Health*, *16*, 4109.

Yang, S.; Jiang, Z.; Sun, X.; Ding, J.; Xu, J. (2018). Effects of Biochar Amendment on CO_2 Emissions from Paddy Fields under Water-Saving Irrigation. *International Journal of Environmental Resources and Public Health 15*, 2580.

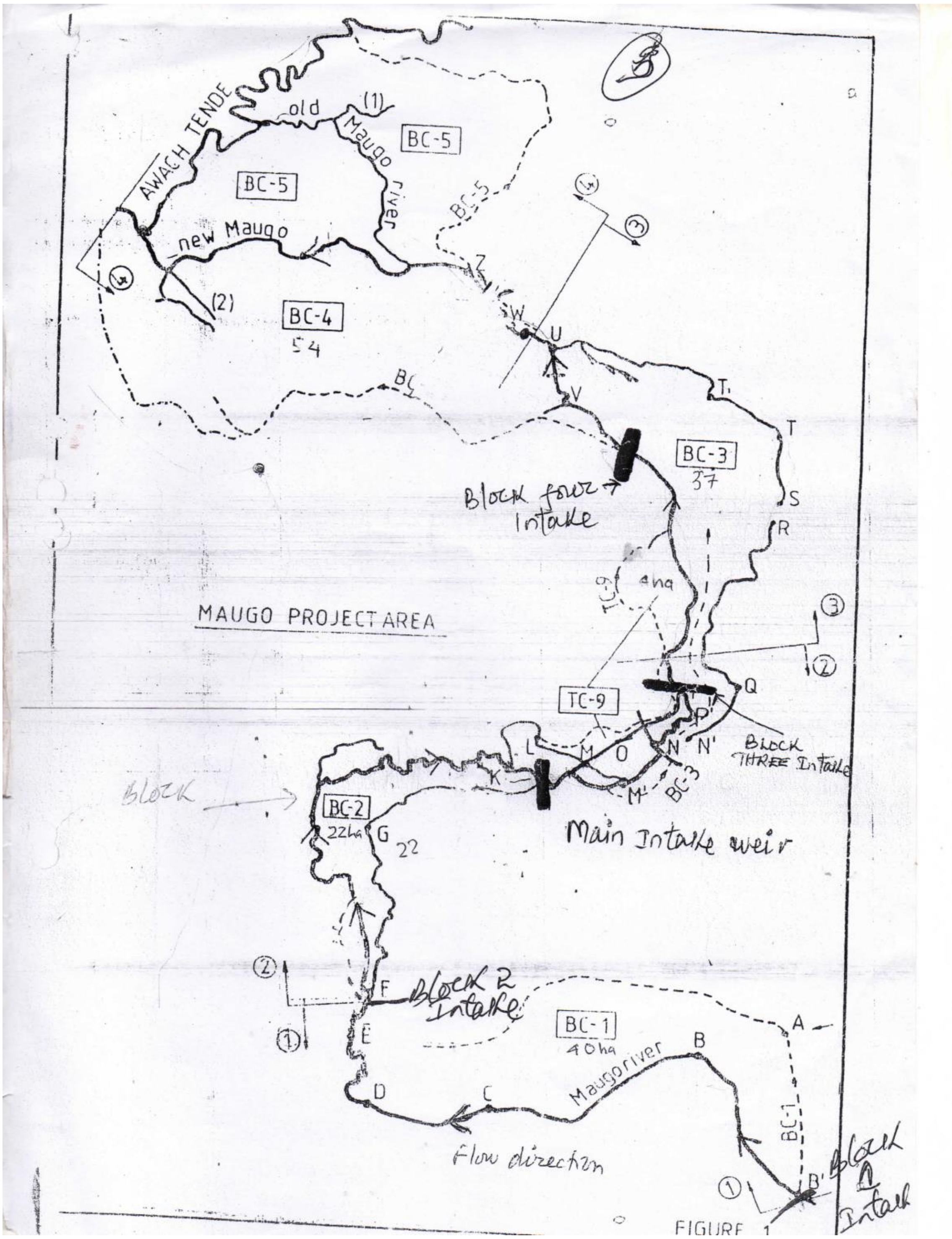
Zhang, J., Zhou, S., Sun, H., Lü, F., & He, P. (2019). Three-year rice grain yield responses to coastal mudflat soil properties amended with straw biochar. *Journal of environmental management*, *239*, 23-29.

Zingore, S.; Wairegi, L.; Ndiaye, M.K. *Rice Systems Cropping Guide*; African Soil Health Consortium: Nairobi, Kenya, 2014,1–64.

Zulkarnain, W.Z.; Ismail, M.R.; Ashrafuzzaman, M.; Saud, H.M.; Haroun, I.C. (2009). Growth, Physiological and Biochemical Responses of Malaysia Rice Cultivars to Water Stress. *Pertanika Journal of Tropical Agricultural Sciences 32*, 323–333.

APPENDICES

Appendix I: A sketch of Maugo Smallholder Irrigation Scheme



Appendix II: Project activities pictures and ploughing techniques

Site visit

Plot measurement and pegging

Nursery

a

b

c

Ploughing techniques (a-oxen, b-hand and c- tractor)

(Source: Author,2019)

Flooding

Transplanting

Puddling/Levelling

New rice

Appendix III: Similarity report

PG/ABE/005/14

ORIGINALITY REPORT

17%	15%	5%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	doaj.org Internet Source	3%
2	www.mdpi.com Internet Source	2%
3	ir-library.ku.ac.ke Internet Source	1%
4	www.ceepa.co.za Internet Source	1%
5	mdpi.com Internet Source	<1%
6	Submitted to University of Witwatersrand Student Paper	<1%
7	ir.mu.ac.ke:8080 Internet Source	<1%
8	www.coursehero.com Internet Source	<1%
9	dspace.knust.edu.gh Internet Source	<1%

In Abstract it is from our paper in Turjaf and Agneng. Kindly remove

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