IMPACTS OF IRRIGATION WATER QUALITY, ASSOCIATED SOILS CHARACTERISTICS AND ON-FARM PRACTICES ON PADDY YIELDS

Fridolin M. Mpanda

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Hydrology and Water Resource Engineering of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

July, 2022

ABSTRACT

In this study, the impacts of irrigation water quality, soil characteristics and on-farm practices on paddy yields were investigated. Standard spectroscopy and spectrometry methods were used to analyze irrigation water and irrigated soil samples. The irrigation water had sodium adsorption (SAR) values ranging from 0 to 3. The corresponding electrical conductivity (EC) values were between 0.2 and 0.7 dS/m and accounted for 14% of all samples hence posing slight to moderate infiltration problem. Neither sodium nor chloride levels were high enough to cause toxicity problems in the irrigation water. For boron, 54% of the samples was found to have moderate toxicity whereas ~14% of the samples indicated severe boron toxicity in the irrigation water. For bicarbonate, about 86 and 14% of the irrigation water indicated slight-to-moderate and severe potential detrimental effect to plant growth, respectively. The trace elements Fe^{2+}, Zn^{2+}, Cu^{2+}, Mn^{2+}, B, As, Cd, Cr^{2+}, Pb^{2+}, Ni^{2+}, and Al^{3+} in the irrigation water samples were too low to cause any harmful effect. Although soil EC (0.2 to 1.9dS/m), organic carbon (OC) (0.1 to 2.4%) and pH (6.0 to 8.5) indicated favorable levels, there were significant variations in soil Fe (2.6 to 169.5 mg/kg) and Zn (3.9 to 204.1 mg/kg). The mean value of Fe in soils was 19.8 mg/kg. Soils indicated signs of Fe-deficiency. High variabilities were also found in the total N (86 to 2155 mg/kg) content of the studied paddy soils. The levels of phosphorus (Olson P, mean 224.2 ± 149.4 mg/kg) were found to be too high compared to what is reported as normal in similar studies. There might be unsustainable and excessive application of P-containing inputs in the studied area. Furthermore, a low soil K content was observed in the analyzed soil samples. The present study recommends that regular control of irrigation water HCO_3^-, EC and controlling soil pH levels as well as adoption of standard on-farm practices following of crop calendar, proper application of fertilizers. Availability of extension officers to advice farmers is highly recommended.

DECLARATION

I, Fridolin M. Mpanda do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Fridolin M. Mpanda		20/07/2022
Candidate's Name	**Signature**	**Date**

The above declaration is confirmed by:

Dr. Mwemezi Rwiza		18/07/2022
(Supervisor 1)	**Signature**	**Date**

Prof. Kelvin Mtei		July 20th 2022
(Supervisor 2)	**Signature**	**Date**

COPYRIGHT

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology, a dissertation entitled, "Impacts of irrigation water quality, associated soils characteristics and on-farm practices on paddy yields in Tanzania" submitted in partial fulfillment for requirements for the Degree of Master's in Hydrology and Water Resource Engineering of Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania.

Dr. Mwemezi Rwiza 20th July 2022

(Supervisor 1) **Signature** **Date**

Prof. Kelvin Mtei 20th July 2022

(Supervisor 2) **Signature** **Date**

ACKNOWLEDGMENTS

All praise to God, the most generous, for giving me guidance, strength, wisdom and power to accomplish this work.

I would like to acknowledge my research supervisors, Dr. Mwemezi Rwiza and Prof. Kelvin Mtei of the Nelson Mandela African Institution of Science and Technology (NM-AIST) for supervision, mentorship, guidance and advice. I would also like to thank the NM-AIST laboratory staff for their technical assistance during sample collection and laboratory analysis. Also, I would like to express my thanks my employer, the district executive director (DED) for Moshi district and my colleagues in the Moshi District Council for their cooperation and support—especially Chikira Mcharo, Eng. Festo Massawe and Micdard Kessy for their advice and directives. Many thanks also to the AfDB project for the financial support which made my studies successful.

I would also like to thank all staff and officials especially Buzimi Mabula, Eng. Japhet Senyinah and Eng. Juma Omary Mdeke of National Irrigation Commission and the DED office for Mwanga district; Kivulini village Secretariat; Kivulini Irrigation Co-operative; and individual farmers for their assistance and cooperation during this study. Also, I extend my appreciation to my NM-AIST colleagues and fellow students for their friendly assistance.

Last but not least, I wish to give many thanks to my father, Ludovick H. Mpanda, my mother, Tarsisia L. Nzema and my lovely wife, Disila V. Mallya, for their love, prayers, support and encouragement.

DEDICATION

I dedicate this work to my loving parents, Ludovick H. Mpanda and Tarsisia L. Nzema, who raised and nurtured me. I also dedicate this work to my lovely wife, Disila V. Mallya and our children: Jesca, Priscila, Catherine, Christabella, Nadya and Nathan for their encouragement and patience. My brothers (Novatus Mpanda, Jerome Mpanda) and my sisters (Getrude Mpanda, Lydia Mpanda and Demetria Mpanda)—thank you!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

AAS	Atomic Absorption Spectrophotometer
Al^{3+}	Alminium Ion
As	Arsenic
B	Boron
Ca^{2+}	Calcium Ion
Cd	Cadmium
Cl^{-}	Chloride Ion
CO_3^{2-}	Carbonate Ion
Cr^{2+}	Chromium Ion
Cu^{2+}	Copper Ion
DO	Dissolved Oxygen
EC	Electrical Conductivity
Fe^{2+}	Iron Ion
HCO_3^{-}	Bicarbonate Ion
HNO3	Nitric Acid
K^{+}	Potassium Ion
Meq	Mill Equivalent
Mg^{2+}	Magnesium Ion
Mn^{2+}	Manganese Ion
Na^{+}	Sodium ion
Ni^{2+}	Nickel Ion
NM-AIST	Nelson Mandela African Institution of Science and Technology
NO_3^{-}	Nitrate Ion
OC	Organic Carbon
ORP	Oxidation Reduction Potential
Pb^{2+}	Lead Ion
pH	Measure of Degree of Acidity or Basicity
PO_4^{2-}	Phosphate Ion
SAR	Sodium Absorption Ratio
SO_4^{2-}	Sulfate Ion
SS	Soil Sample

TDS	Total Dissolved Salts
WS	Water Sample
Zn^{2+}	Zinc Ion

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Cultivated rice (*Oryza sativa*) is among the most important crops in the world serving as food to more than half of the world's population (Hu *et al.*, 2016; Oster *et al.*, 2016). In Tanzania, this crop is one of the widely grown crop and is the second most important crop (Kolleh *et al.*, 2017). Rice is both cash and food crop for majority of people and it is estimated that 60 percent of the population consumes rice each day (Achandi & Mujawamariya, 2016; Gowing *et al.*, 2018). The crop is grown under three major ecosystems namely; rain-fed, upland and irrigated (Nkuba *et al.*, 2016). The irrigated ecology is 20 percent of 21 million hectares suitable for rice production (Wilson & Lewis, 2015). The production of rice in this country is predominantly rain-fed ecology covering 72% with yield ranging from 1 ton/ha to 2 tons/ha while that of irrigated ecology have reported yields ranging from 2.5 to 4 tons per hectare (Tippe *et al.*, 2017; Mosha *et al.*, 2018a). The demand for this crop is growing rapidly day after day as food source in several countries of the world following wheat (Gale *et al.*, 2015). It was reported that there is projected increase in rice demand from 680 million tons in 2015 to 771 million tons in 2030 (Bruinsma, 2017).

Despite rice being an important cash and food crop in Tanzania, its production is lower than the yield potential of 10 tons/ha reported in Egypt and USA (Kadigi *et al.*, 2004). The low yield is reported to be due to rainfall, quality and quantity of irrigation water, soil nutrients, initial capital investment, genotypes, pest and diseases (Deng *et al.*, 2015; Alfarisy *et al.*, 2018; Shiba *et al.*, 2018). Among these challenges facing paddy production, quality of irrigation water, soils characteristics and agronomic practices are reported to significantly influence paddy yield (Thitisaksakul *et al.*, 2015; Singh *et al.*, 2016). For example, irrigation water containing sodium levels above 1300 ppm, calcium above 120 ppm, magnesium above 24 ppm, coupled with poor agronomic practices have been reported to negatively affect paddy production (Khaleghian *et al.*, 2015; Krishnamurthy *et al.*, 2016). Improved rice irrigation practices has been viewed as vital element in efforts to increase rice production in many areas (Shao *et al.*, 2015; Xuan, 2018).

As such, farmers in irrigated ecology are more technically allocative and economically efficient in rice production than farmers in the rain-fed ecology (Pede *et al.*, 2015; Bidzakin *et al.*, 2018).

Irrigated rice ecology provides readily available water. This accessibility of irrigation water coupled with high solar radiation and low incidence of pest and diseases results in higher paddy (Deng *et al.*, 2015; Carrijo *et al.*, 2017). Therefore, analysis of water quality for irrigation, soil characteristic and agronomic practices is important due to the declining soil fertility, water resources, low rice yields and water competition from other uses (Assouline *et al.*, 2015; Cao & Yin, 2015; Rehman *et al.*, 2016)

This study, therefore, attempted to find causes of low paddy production in irrigated rice ecology by assessing the irrigation water quality, soil physicochemical properties and farmers' on-farm practices. The information gathered will help in improving irrigation water practices, soil fertility management and will provide readily available reference on proper agronomic practices that will improve paddy production in the future.

1.2 Statement of the problem

Like many other developing countries, Tanzania has been making effort to improve its rice yields due to increased rice demand which is expected to triple by 2020 (Wilson & Lewis, 2015). The Government initiated a Rice Development Strategy which aimed at increasing rice production for domestic use and export through improved irrigation (Mosha *et al.*, 2018b). Despite these efforts by the government, rice production in the irrigated rice ecology has faced increased challenges resulting to continued low rice yields (Atera *et al.*, 2018). Current rice yields in irrigated ecology range from approx. 2.5 to approx. 4 tons/ha which is lower compared to the average rice yields of 10 tons/ha reported in some other countries (Kadigi *et al*., 2004)

It has been reported that low paddy yields are associated with predominantly poor water quality, poor water management, limited adoption of technology, poor agronomic practices, unavailability of improved cultivars as well as the low use of fertilizers (Liu *et al.*, 2016b). It was also reported that water quality has direct effect on growth and performance of plants, soil and the environment (Liu *et al.*, 2018). The extensive use of fertilizers and pesticides to support plant growth has caused serious public health and environmental damages worldwide, particularly in developing countries (He *et al.*, 2018). Moreover, it has been reported that decline in soil fertility is one of the most serious agricultural problems of the world especially in tropical cropland that is causing dwindled yields (Islam *et al.*, 2016). In summary, it could be argued that paddy yields are influenced by fertility status of the soil, on-farm practices and the quality of water used to irrigate the crop (Kumar *et al.*, 2017). At Kivulini Irrigation Scheme of Kilimanjaro, Tanzania, where this study was conducted, there have been experiences of low and highly varied paddy yields. We purposely conducted this research in an attempt to address problems related to paddy yields and the quality of irrigation water.

1.3 Rationale of the study

In many areas where rice is grown, irrigated rice ecology is reported to be an important solution in increasing rice yields compared to rain-fed ecology (Watto & Mugera, 2014; Mosha *et al.*, 2018a). This agrees with the findings by Ugalahi *et al.* (2016), who reported that institution of irrigation in rice farming led to rice self-sufficiency. Under this ecology in the USA and Egypt, the average yield of rice is approx. 10 tons/ha whereas that of Tanzania is ranging from 2.5 to 4 tons/ha (Fageria *et al.*, 2003;Wilson & Lewis, 2015; Elmoghazy & Elshenawy, 2019). This implies that irrigated rice ecology in Tanzania needs improvement. It is reported that for improved paddy production under irrigated ecology, understanding changes within the irrigation project are necessary for long term productivity and sustainability of yield (Li *et al.*, 2016; Mosha *et al.*, 2018a). So, knowledge of irrigation water quality, soil characteristics and the impact of agronomic practices is critical. This study, therefore, was designed in such a way that it would provide baseline information on the causes of low and varied paddy production. Moreover, the information generated from the present study will be useful to agricultural practitioners and extension service providers in attempts to improve paddy productivity in irrigated paddy farms across the country.

1.4 Research objectives

1.4.1 General objective

The objective of this study is to assess the impacts of irrigation water, soil characteristics and on-farm practices on paddy productivity.

1.4.2 Specific objectives

The specific objectives are:

(i) To determine irrigation water quality in the study area.

(ii) To determine physicochemical properties of soils in the study area.

(iii) To assess farmer’s common agro-irrigation practices in the study area.

1.5 Research questions

(i) How is irrigation at the study site loaded with nutrients and pollutants?

(ii) What are the physical and chemical qualities of the irrigated soils at the study site?

(iii) How are farming practices at the study site affecting paddy yields?

1.6 Significance of the research

Tanzania is a highly rice-dependent country because rice is a staple crop in the country. Apart from maize, rice comes second as the most cultivated food and commercial crop in Tanzania. Total Tanzanian land area on which rice is cultivated is about 681 000 ha, representing 18% of the country's total arable land. Yields are generally very low estimated in the range between 1 and 1.5 tons/ha and mostly grown under traditional methods. Furthermore, a good proportion (approx. 71%) of the rice in Tanzania is grown under rain-fed conditions. In 2018, it was estimated that about 50% of the country's rice was grown by around 230 000 smallholder farmers in Tabora, Shinyanga and Morogoro. The government of Tanzania as well as farmers have been struggling to improve rice production. We expect that the information presented in this study will be a contribution to these efforts, not only in Tanzania but also across the region.

1.7 Delineation of the study

This study tried to look in details how both irrigation water quality and soil properties affect paddy growth, production and productivity. Previous studies on paddy focused mainly on either of the two, water quality or soil properties. Also this study has been fulfilled with the help of farmers' baseline survey where agronomic practices of the farmers were established. Such practices included following official crop calendar, the way farmers prepare their land, type of inputs used and availability of extension services.

CHAPTER TWO

LITERATURE REVIEW

2.1 Paddy production in millennia—the history

Paddy production existed many years back as wild varieties which were consumed by people from different continents. All species of wild rice were cultivated on wetlands (Aagaard *et al.*, 2018). Paddy consumption started about 12 000 and 16 000 years ago (Chen *et al.*, 2016; Yang *et al.*, 2017). Three distinctive rice species included *Oryza sativa japonica*, domesticated in central China by about 7000 years BCE, *Oryza sativa indica*, domesticated in the Indian subcontinent about 2500 BCE and *Oryza glabberima*, domesticated in West Africa between 1500 and 800 BCE (Zheng *et al.*, 2016; Awan *et al.*, 2017). There is another wild variety species called *Zizania aquatic* grown in the United States (Anwar *et al.*, 2017; Hutchinson, 2017). Paddy production may be classified as upland or lowland based on altitude (Xia *et al.*, 2019). It may also be classified as rain-fed or irrigated based on the water source (Salmon *et al.*, 2015).

2.2 Global importance of paddy production

Rice is the world's second most important cereal crop following only corn (Selvaraj *et al.*, 2017). It is the most important grain with regard to human nutrition and caloric intake, providing more than one-fifth of the calories consumed worldwide by humans (Ajay *et al.*, 2013). According to the United Nations and the Food and Agriculture Policy Research Institute (FAPRI), global milled rice demand was expected to rise from 439 million tons in 2010 to 496 million tons in 2035 (Seck *et al.*, 2012). Moreover, 30 million tons of rice will be needed by Africa while in America, total rice consumption is also projected to rise (Borlaug, 2002).The projected demand for rice will outstrip the present supply in the near future, unless appropriate measures are taken to reverse current trends of unsustainable management of natural resources, inefficient growth and production (Brown, 1994; Rosegrant *et al.*, 2012).

Rice will remain the dominant feature of the nutritional and agricultural landscape of many countries and over many centuries (Li *et al.*, 2015). But the way rice is grown will have to change. The wetland traditional cultivation methods is not sustainable in many parts of Asia, where scarcities of water and labor are becoming major drivers of change (Yu *et al.*, 2018). More efficient water management systems are needed (Linquist *et al.*, 2015). Paddy production, if properly managed, can contribute greatly in the world's economy due to the high and ever-growing demand (Pretty & Bharucha, 2018). Rice cultivation has increased agricultural output and created employment opportunities in most developing economies in Asia (Furuhashi & Gay, 2017). Surplus production comes from few countries mostly located in Asia, while the sources of import demand are numerous and spread across the world (Rose, 2016). According to the most recent official data in 2017, China was the world's leading paddy rice producer followed by India (Pode, 2016). It is mainly cultivated by small farmers in holdings of less than one hectare (Mottaleb & Mohanty, 2015; Ju *et al.*, 2016).

2.3 Paddy production in Tanzania

Paddy is one of the widely grown crops in Tanzania and is the second most important food crop in terms of number of households, area planted and production volume (Lazaro *et al.*, 2017; Saidia & Mrema, 2017). Some of the leading regions in rice production include Morogoro, Kilimanjaro, Arusha, Manyara, Shinyanga, Tabora, Mwanza, Mbeya, Rukwa and Morogoro (Kolleh *et al.*, 2017). Moreover, the country has large land resources more than 50 000 km^2 which is suitable for rice production (Nijbroek & Andelman, 2016). Availability of water resources which include underground, rivers and lakes assures sustainability production of paddy. There is political will by the government to enhance paddy production and productivity (Mkonda & He, 2016). For example the government is providing an enabling environment for private sectors to participate strongly in agricultural production, processing and marketing (Massay & Kassile, 2019). Rice is grown under three major ecosystems of rain-fed, upland and irrigated (Nkuba *et al.*, 2016). The area under rice production increased from 0.39 million ha in 1995 to 0.72 million ha in 2010. Average paddy yields across the ecosystems have varied over the last 20 years from 1.25 to 2.4 tons/ha.

The rain-fed ecosystem involves the use of small roughly leveled basins surrounded by earth bunds. This system contributes to 60% of total rice production in Tanzania (Gowing *et al.*, 2018).

Rice is produced for home consumption and the surplus is directly sold to consumers by majority of smallholder farmers (Greco, 2015; Gowing *et al.*, 2018). There are cooperative society which also buy rice through warehouse receipt system (Sathapatyanon *et al.*, 2018).

There is division of labor in paddy farming. Women play a major role in paddy production hence making a significant impact to food production, processing and marketing of farm produce (Osabuohien *et al.*, 2019). They participate actively in all aspects of value chain from planting, weeding, bird scaring, harvesting, processing and marketing. Men are engaged more in land preparation, fertilizer application and transport of farm produce (Mosha *et al.*, 2018a).

2.4 Challenges facing paddy production

2.4.1 Water management

Reliability of water supply is a pre-requisite for increased paddy yields (Shiva, 2016). Rice production in the country depends on marginal rainfall which is erratic (Oestigaard, 2016). Annual distribution and variation makes rain-fed paddy production susceptible to weather changes like floods and drought within the same season (Matata & Adan, 2018). Drought condition cause hesitation by farmers to invest in large scale production remaining with subsistence level production (Mosha *et al.*, 2018a). Lack of irrigation infrastructure such as drainage and irrigation facilities may lead to low paddy production (Balamurugan & Balasubramanian, 2017). Construction costs of such infrastructure are beyond the capacity of smallholder farmers (Mosha *et al.*, 2018a). This has led to poor water management as much of irrigation water is lost through seepage and evaporation (Nakawuka *et al.*, 2018). Many irrigator associations have been established in recent years but their efforts and support is still marginal (Mdemu *et al.*, 2017).

2.4.2 Irrigation water quality

Irrigation water quality has been reported to influence paddy yields negatively or positively (Samson *et al.*, 2017; Samson *et al.*, 2018). The quality of irrigation water can be influenced by parent rock material, effluents from wastewater originating from institutions, hospitals and industries (Qadir *et al.*, 2008). The most common problems found in irrigation water include salinity, infiltration problems and toxicity (Bauder *et al.*, 2011b). Salinity problems are caused by the presence of soluble salts in irrigation water especially in arid areas (McFarlane *et al.*, 2016). Infiltration problems are caused by elevated levels of Na as compared to calcium and magnesium which leads to sodic soils (Chhabra, 2017). Sodic soils may lead to infiltration and soil structure problems (Cucci *et al.*, 2015).

2.4.3 Soil properties

Soil characteristics have also been reported as a contributing factor to paddy growth (Carvalho *et al.*, 2016). Nutrients availability in soils determines chemical properties of that soil (Olmo *et al.*, 2016; Augusto *et al.*, 2017). As crops grow they utilize nutrients (Fageria, 2016). Continued use of nutrients leads to fertility loss hence affecting paddy yields negatively (Mascie-Taylor, 1992; Van *et al.*, 2000; Crusciol *et al.*, 2016).

2.4.4 Lack of improved seed varieties

It has been reported that there is shortage of improved seed varieties which are tolerant to drought, cold weather, insects, pests and diseases (Duku *et al.*, 2016; January *et al.*, 2018). Another problem is the presence of local varieties in all ecosystems which have low yield potential, late maturing, and susceptible to lodging when improved management practices such as application of fertilizers are used (Nkuba *et al.*, 2016). It has been reported that only 10% of farmers have been using improved varieties (Kangile *et al.*, 2018).

2.4.5 Agronomic practices

Land agronomic practices affect rice production process in Tanzania. Such practices include soil fertility, land preparation, seed varieties used, pests and disease managements, planting time, lack of extension services leading to insufficient knowledge on proper dose of fertilizer to be applied and fertilizer application. The use and application of fertilizers and manure is still low. This is due to high prices which small scale famers who are the majority of paddy growers cannot afford (Adnan *et al.*, 2019).

2.5 Suitability of irrigation water for paddy growth

Irrigation water should be tested to establish its suitability for irrigation (Tyrrel *et al.*, 2006; Kokkinos *et al.*, 2017). Parameters of concern in irrigation water include major cations, anions and micronutrients (Allende & Monaghan, 2015). The major cations include calcium, magnesium, potassium and sodium (Oster *et al.*, 2016). The anions include carbonate, chloride, bicarbonate, sulfate, nitrate and boron (Pillai & Gupta, 2016). Other parameters include electrical conductivity or total dissolved solids, SAR, and pH (Jeong *et al.*, 2016; Chhabra, 2017; Mun *et al.*, 2017). The test results of those parameters in irrigation water are then compared with international standards like that of WHO or FAO before recommendations of the water is suitable for irrigation or not.

2.5.1 Major cations

The calcium is found in all natural waters (Chaussemier *et al.*, 2015). When adequately supplied with exchangeable calcium, soils are friable and usually allow water to drain easily (Hassan *et al.*, 2016; Saeed & Kadhum, 2016). This is why calcium in the form of gypsum is commonly applied to improve the physical properties of compact soils (Zhu *et al.*, 2017). Sodium will be leached from the root zone when calcium replaces the sodium on the soil colloid (Park *et al.*, 2016). The FAO guideline, 1992 suggests that irrigation water with calcium levels between 40 and 120 ppm is accepted.

Magnesium is also found in most natural waters (Hopkins, 2007). As a concentration of magnesium and calcium increases it eliminates sodium hazard in irrigation water (Bhatti *et al.*, 2017; George *et al.*, 2018). The desired range is from 6 to 24 ppm.

Potassium behaves like sodium in the soil and is found in natural waters in small amounts (Oster *et al.*, 2016). Potassium is a macronutrient taken up by plants in large quantities (Khan *et al.*, 2007). It also plays an important role in the plant's ability to resist disease (Jha, 2017). The desired level of potassium is from 5 to 10 ppm.

Sodium is very soluble and is also found in natural waters (Bauder *et al.*, 2011a). It combines with chloride and sulfates to form salts (Aamer *et al.*, 2015). Its high levels in soils may cause hard pans hence infiltration problems of soil may result (Bauder *et al.*, 2011b). This situation adversely affect paddy growth (Aamer *et al.*, 2015). Desired sodium levels in irrigation water is from 0 to 50 ppm.

2.5.2 Anions

Carbonates are salts of carbonic acid formed when carbon dioxide dissolves in water (Liao *et al.*, 2016; Iali *et al.*, 2018). They form alkalis when combined with calcium or magnesium (Shaikh & Sivaram, 1996). The effect is much stronger in presence of sodium ions (Scherer, 2013). FAO recommends maximum desired levels in irrigation water to be 50 ppm.

Bicarbonates are also salts of carbonic acid which are common in natural waters (Horneck, 2007). When moisture is reduced, calcium and magnesium carbonates can separate calcium from clay colloid, leaving high levels of sodium to replace them (Hannam *et al.*, 2016). This might lead to an increase of SAR in the soil (Mohammadi, 2019). Using irrigation water with high levels of bicarbonates may contribute to reduction in water infiltration rates and soil gas exchange (Horneck, 2007). According to FAO maximum desired range for bicarbonate in irrigation water is 120 ppm.

Chloride is an anion that is found in irrigation water (Hannam *et al.*, 2016). It contributes to the total salt content of soils (Hopkins, 2007). It is necessary for plant growth in small amounts (Scherer, 2013). High levels of chloride in irrigation water will inhibit plant growth and reduce phosphorus availability to paddy (Killenga, 2010). According to FAO threshold value for chloride in irrigation water is 140 ppm.

Sulfate is commonly found in irrigation water and contributes to total soil content in soils (Hopkins, 2007). High levels in irrigation water reduces phosphorus availability to paddy (Bauder, 2010; Hassan *et al.*, 2016). Levels more than 400 ppm will acidify the soils (Hopkins, 2007).

Total dissolved solids is measured by determining the actual salt content in ppm (Scherer, 2013). Drought condition can result in accumulation of excess salts in soil solution (Horneck, 2007). This situation can cause paddy wilting due to insufficient water absorption by the roots compared to amount lost through transpiration even if the soils have plenty of moisture (Scherer, 2013). Desired range for TDS is 960 ppm. More than 1900 ppm will increase burn potential.

Boron is necessary for paddy growth in small amounts. Adequate amount of boron is found in most waters (Taş *et al.*, 2016). Significant levels of boron can frequently occur in various water sources hence frequent water test is necessary (Shah *et al.*, 2017). Levels more than 1 ppm is toxic to some plants (Shah *et al.*, 2017). Desired level ranges from 0.2 to 0.8 ppm.

2.5.3 Total alkalinity

Total alkalinity is a measure of water’s capability to neutralize added acids (Hauser, 2018). It establishes the buffering capacity of water (Afshar *et al.*, 2017). The major chemicals that contribute to the alkalinity of water include dissolved carbonates, bicarbonates and hydroxides (Nand & Ellwood, 2018). High alkalinity can cause an increase in pH of the soils (Kiunsi, 2006). This leads to reduction in micro-nutrient availability, precipitation of nutrient in concentrated fertilizer solutions, and reduce the efficacy of pesticides and growth regulators (Antil & Singh, 2007; Karak *et al.*, 2017). Desired range of alkalinity is from 1 to 100 ppm.

2.5.4 Irrigation water pH

Irrigation water pH is the degree of acidity or alkalinity of the sample (Bauder, 2010). Chemically, it is defined as the $\log_{10}$ of hydrogen ions (H^+) in the soil solution (Bauder, 2011). The pH scale ranges from 0 to 14; a pH of 7 is considered neutral. A pH of less than 7.0 is acidic, 7.0 is neutral and above 7.0 is alkaline. Ideal pH levels that provides best conditions for irrigation ranges from 5.5 to 8.5 (Bauder, 2011).

2.5.5 Micronutrients

In irrigation water, micronutrients are important when available at levels that are acceptable for plant growth and sustenance (Table 1). Micronutrients are usually required in small amounts by plants. When their levels are in excess, they can be hazardous to plants. When their levels are low, the recommended limits deficiency symptoms will be seen.

Table 1: Required macronutrients levels in irrigation water[a]

Micronutrients	Maximum recommended limit (mg/L)	Remarks
Arsenic	0.10	Higher concentrations can be tolerated by some crops for short periods when they are grown in fine-textured soils
Beryllium	0.10	Toxicities to plants have been reported at concentrations of as low as 0.5 mg/liter in nutrient solutions and at levels in the soil greater than 4 percent of the cation-exchange capacity.
Cadmium	0.01	Concentrations equal to or less than 0.01 mg/liter require 50 years or more to exceed the recommended maximum cadmium loading rate. Removal in crops and by leaching partially compensates and perhaps allows use of the water indefinitely.
Chromium	0.10	Toxicity in nutrient solutions has been observed at a concentration of 0.50 mg/liter and in soil cultures at a rate of 10 kg/ha. Toxicity depends on the form of chromium existing in the water and soil and on soil reactions.
Cobalt	0.05	A concentration of 0.10 mg/liter is near the toxic threshold for many plants grown in nutrient solution. Toxicity varies, depending on the type of crop and soil chemistry
Copper	0.20	Concentrations of 0.1 to 1.0 mg/liter in nutrient solutions have been found to be toxic to plants, but soil reaction usually precipitate or adsorb copper, so that soluble copper does not readily accumulate.
Fluoride	1.0	This concentration is designed to protect crops grown in acidic soils. Neutral and alkaline soils usually inactivate fluoride, so higher concentrations can be tolerated
Lead	5.0	Plants are relatively tolerant to lead, and soils effectively sorb or precipitate it. Toxicity to animals typically iscaused not by lead adsorption from soils but by aerial deposition of lead on the foliage of pasture and forage plants.
Lithium	2.50	Most crops are tolerant to lithium up to 5 mg/liter in nutrient solutions. Citrus, however, is highly sensitive to lithium. Lithium is a highly mobile cation that leaches from soils over an extended period of time
Manganese	0.20	Some crops show manganese toxicities at a fraction of an mg/liter in nutrient solution, but typical soil pH and oxidation-reduction potentials control manganese in soil solution, so that the manganese concentration in irrigation water is relatively unimportant
Molybdenum	0.01	This concentration is below the phytotoxic level but is recommended to protect animals from molybdosis because of excess molybdenum in forages
Nickel	0.20	Nickel is toxic to many plants at concentrations of 0.5 to 1.0 mg/liter. Toxicity from this element decreases with an increase in pH, so acidic soils are the most sensitive

Micronutrients	Maximum recommended limit (mg/L)	Remarks
Selenium	0.02	This guideline protects livestock from selenosis because of selenium in forage. Selenium absorption by plants is greatly inhibited by sulfate, so the guideline for this element can be increased for gypsiferous soils and waters
Vanadium	0.10	Toxicity to some plants has been recorded at vanadium concentrations above 0.5 mg/liter.
Zinc	0.50	Zinc is toxic to a number of plants at a concentration of 1 mg/liter in nutrient solution, but soils have a large capacity to precipitate this element. Neutral and alkaline soils can accept much greater concentrations without developing toxicities.

National Academy of Science (1972), Pratt (1972) and Fall (2012)

2.6 Important plant nutrients found in soil and their response to paddy growth

2.6.1 Primary macronutrients

Nitrogen is among the essential primary macronutrients required by plants (Weber & Burow, 2018). It contains 40 to 50% of the dry matter of protoplasm (Aagaard *et al.*, 2018). It is also a constituent of chlorophyll (Rao *et al.*, 2017b). Its deficiency in paddy results into stunted growth, slow growth and chlorosis (Latte *et al.*, 2017).

Phosphorus is available to plants in small quantities because it is released slowly from insoluble phosphates and can easily be fixed again (Bergkemper *et al.*, 2016; Eduah *et al.*, 2017). It is a very essential nutrient required for paddy growth (Mehra *et al.*, 2017). It is involved in adenosine triphosphate (ATP) which is of immediate use in all processes that require energy (Ananthanarayanan *et al.*, 2015). Deficiency symptoms in paddy include an intense green coloration or reddening in leaves due to lack of chlorophyll (Latte *et al.*, 2017). Its high deficiency might lead to leaves denaturing and ultimately die (Jia *et al.*, 2017).

Potassium is an essential nutrient for paddy growth. It is required more than nitrogen and phosphorus (Khanghahi *et al.*, 2018). It regulates the opening and closure of stomata by potassium ion pump and regulates water loss from plant leaves (Corratgé-Faillie *et al.*, 2017). It is mobile and soluble within plant tissues. It is involved in the formation of carbohydrates and proteins. Its deficiency results in higher risks of pathogens, wilting, chlorosis, brown spotting and higher chances of damage from frost and heat (Latte & Shidnal, 2016; Narmadha & Arulvadivu, 2017).

2.6.2 Secondary and tertiary macronutrients

Sulfur is a structural component of some amino acids and vitamins (Amich *et al.*, 2016). It is less required compared to nitrogen. It is responsible for nitrogen fixation by legumes and conversion of nitrate into amino acids, then into protein (Walker & White, 2017). Deficiency includes symptoms such as yellowing of leaves and stunted growth (Walker & White, 2017).

Calcium regulates transport of other nutrients into the plant (Thoday-Kennedy *et al.*, 2015). It is a constituent of cell wall (Zhang *et al.*, 2017). It is also involved in the activation of certain plant enzymes (Zipfel & Oldroyd, 2017). It is also involved in photosynthesis and plant structure. It has a positive effect in combating salinity in soils (Meng *et al.*, 2019). Its deficiency results into defective root system, stunting growth and blossom end rot, curling of leaves towards the veins or center of the leaf (De Freitas *et al.*, 2016).

Magnesium is a constituent of chlorophyll molecule and very mobile in plants (Senbayram *et al.*, 2016). It increases paddy yield (George *et al.*, 2018). Its deficiency limits paddy growth and symptoms starts at older tissues and spread to younger tissues (Khadtare *et al.*, 2017; Wang *et al.*, 2017).

Sodium stimulates growth by increasing leaf area and stomata by replacing potassium (George *et al.*, 2018). High sodium levels is toxic to paddy hence reducing yield (Syu *et al.*, 2016). When ratio of sodium to magnesium and calcium is greater than 3 in irrigation water the soils will be sodic, soil structures will be destructed and infiltration problems of the soil will start (Singh, 2016; Chhabra, 2017; Qadir *et al.*, 2018).

2.6.3 Micronutrients

Iron helps in electron transport of plant (López-Millán *et al.*, 2016). Iron is necessary for photosynthesis and is present as enzyme cofactor in plants (Philpott *et al.*, 2017). It is not a structural part of chlorophyll but very much essential for its synthesis (Rout & Sahoo, 2015). Iron deficiency in paddy can result in auxin re-distribution, inter-veinal chlorosis and necrosis (Shen *et al.*, 2015; Carruthers, 2016).

Molybdenumis a cofactor to enzymes and important in building amino acids. It is also involved in nitrogen metabolism (Magalon & Mendel, 2015). It is part of nitrate *reductase* enzyme which is needed for reduction of nitrate and nitrogenaseenzyme required for biological nitrogen fixation (Tejada-Jiménez *et al.*, 2017). Its deficiency in plants will be accompanied by nitrogen deficiency symptoms (Hajiboland, 2018).

Boron is important micronutrient necessary for plant growth and development (Shah *et al.*, 2017). Boron is absorbed from the soil by plants as borate BO_3^{3-} ion from boric acid H_3BO (Ferreto *et al.*, 2016). It is one of the most mobile nutrients in the soil, and can be rapidly leached once released from soil minerals and organic matter (Summers, 2016). Lack of boron results in short thick cells producing stunted fruiting bodies and roots (Feller & Müller, 2017). Boron concentration in soil water solution higher than 1 ppm is toxic to most plants (Küçükakyüz *et al.*, 2018).

Copper is important for photosynthesis (Sağlam *et al.*, 2016). It is also involved in many enzyme processes necessary for effective photosynthesis, manufacture of lignin (cell walls) and in grain production (Sinisi *et al.*, 2018). Its deficiency symptoms include chlorosis (Thomas *et al.*, 2016). Manganese is essential for photosynthesis especially in the building of chloroplast (Santos *et al.*, 2017). Its deficiency may result in discolored spots on the foliage (Carruthers, 2016). Zinc plays an essential role in DNA transcription (Marchal & Miotto, 2015). Its deficiency in paddy include stunted growth of leaves due to oxidative degradation of the growth hormone auxin (Lee *et al.*, 2018). Nickel is essential for activation of urease an enzyme responsible for nitrogen metabolism in order to process urea (Myrach *et al.*, 2017). In lower plants such as paddy, nickel activates several enzymes involved in a variety of processes (Hie *et al.*, 2015). It can also substitute zinc and iron as a cofactor in some enzymes (Yin *et al.*, 2017).

Chlorine is necessary for osmosis and ionic balance (Montelius *et al.*, 2016; Gohil & Suresh, 2017). It also plays an important role in photosynthesis (Khan *et al.*, 2018). Deficiency symptoms include chlorotic and wilted appearance of leaves (Heckman, 2016; Khan *et al.*, 2018). Its excess would result in forage burn (Horneck, 2007). Aluminium is not considered as a plant nutrient, but it is capable of making the soil more acidic by taking hydroxide ions out of water, leaving hydrogen ions behind (Li & Johnson, 2016; Baquy *et al.*, 2017). It is also responsible in inhibiting plant root growth by replacing major cations in exchange sites (Li & Johnson, 2016).

Silicon is not an essential element for plant growth and development (Adrees *et al.*, 2015; Rao *et al.*, 2017a). However it is found in abundance in environment (Bityutskii *et al.*, 2017; Rao *et al.*, 2017a). It is essential in paddy growth as it provides resistance to pests and disease (Rao *et al.*, 2017a). It strengthen cell walls, improving plant strength, health and productivity (Adrees *et al.*, 2015; Chanchal *et al.*, 2016).

2.7 Soil electrical conductivity

Soil electrical conductivity is a measure of the amount of salts in soil (Scherer, 2013). It is an indicator of available water capacity, nutrient availability, and soil structure (Karak *et al.*, 2017). It affects crop yields, suitability of soils for certain crops, amount of water and nutrients available for plant use, and activity of soil micro-organisms (Rhoades, 1996; Mun *et al.*, 2017).

2.8 Soil pH

Soil pH is a measure of the acidity or basicity of soils (Jury & Stolzy, 2018). It affects many chemical processes in soils (Liu *et al.*, 2016a). It affects plant nutrient availability by controlling the chemical forms of the different nutrients and influencing the chemical reactions they undergo (Mook, 2010; Miller, 2016). The optimum pH range for most plants is between 5.5 and 7.5 (Crusciol *et al.*, 2016; Couto, 2017). However, many plants tolerate pH values outside this range.

CHAPTER THREE

MATERIALS AND METHODS

3.1 The study area

The study was carried out at one of the irrigation schemes in the Kilimanjaro region of northern Tanzania (Fig. 1). The scheme, Kivulini, is located in Mwanga district. It shares borders with Simanjiro district to the West, Moshi district to the North, the Republic of Kenya to the East and Same district to the South. The scheme abstracts its water from Ivonokwa and Mtindi springs which supply water to the three main canals: Kivulini, Bogoyo and Nanyori main canals.

Sampling sites were randomly selected, and their respective geographical positioning were determined by a handheld GPS device (Garmin International, Inc., East Street 151 East Street, Olathe, Kansas). A QGIS software Version 2.1.8 was used to prepare the map showing sampling points in the study area. The study area was further divided into three sub-regions i.e. Kivulini, Nanyori and Bogoyo using the three main canals as points of reference (Fig. 2). The sub-regions were used for comparison purposes.

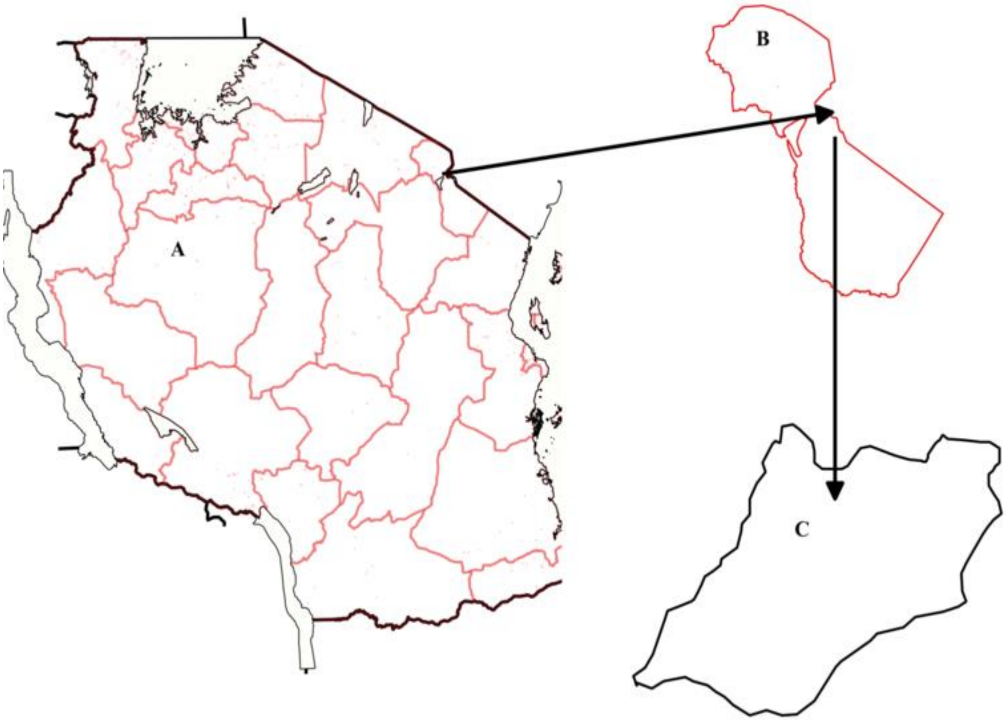

Figure 1: Map of the study area 1. Map A represents Tanzania country with all the regions. Map B represents Kilimanjaro region and Map C represents the study area at Kivulini village. Details of map C are shown in Figure 2

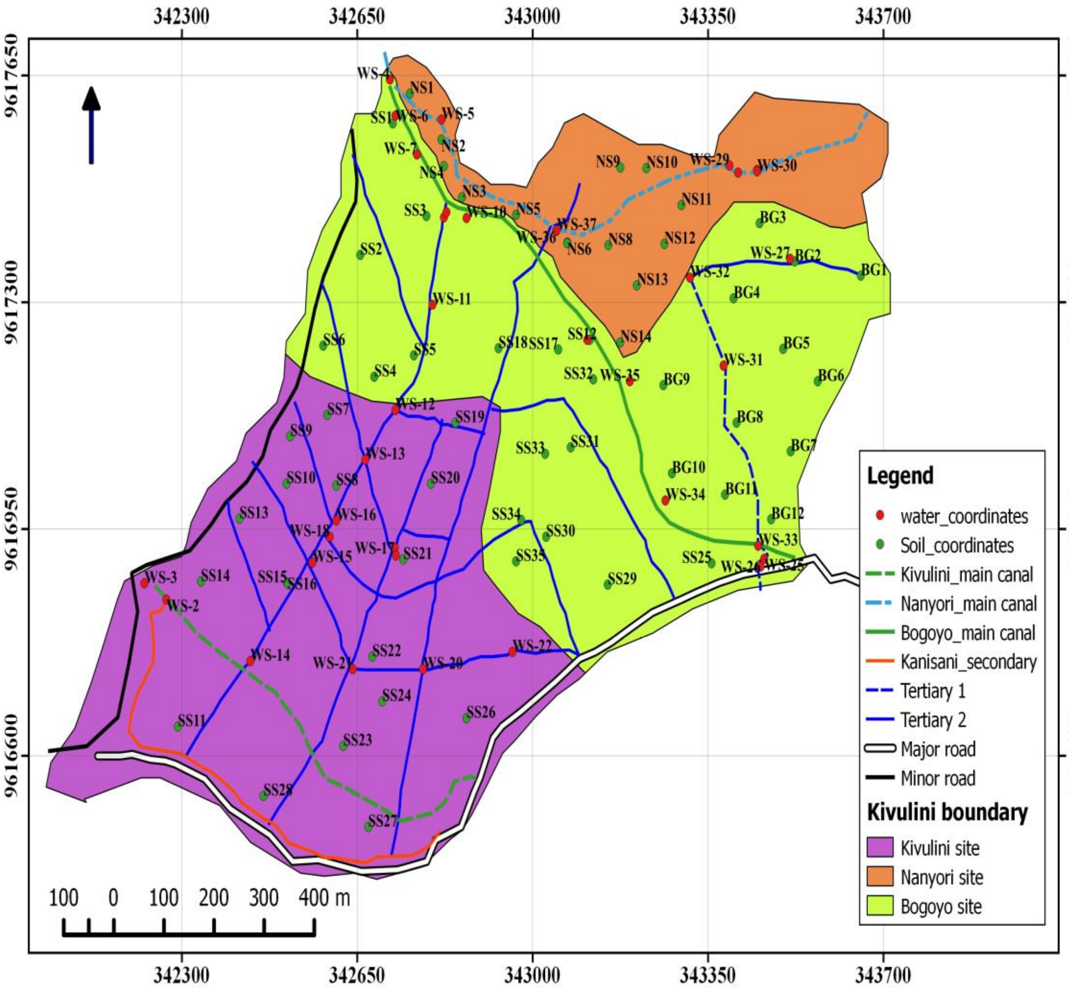

Figure 2: **Layout map of sampling area. The map shows three sub-regions of Kivulini (purple), Bogoyo (green) and Nanyori (orange) where irrigation water and soil samples for this study were collected**

3.2 Irrigation water sampling

Irrigation water sample collection was done in July 2018. A total of 37 irrigation water samples were collected at site using 1.0 L sample bottles. Before sample collection, the bottles were rinsed three times using deionized water. All other sampling procedures were followed according to methods in the literature (Moran *et al.*, 1999; Csuros, 2018).

A total of 17 samples were collected within the farms whereas other 20 samples were collected within the three main canals, drainage canals and distribution canal structures. During water sample collection, physical properties of water were recorded onsite using a multi-parameter device (Model HI 9828, HANNA Instruments, Italy). Parameters recorded onsite included the irrigation water pH, Electrical Conductivity (EC), Total Dissolved Salts (TDS), temperature, salinity, dissolved oxygen (DO) and the oxidation reduction potential (ORP). The bottles were then sealed, labeled, preserved in a cool box and transported to the NM-AIST laboratory for further analyses. At NM-AIST, the samples were acidified using analytical grade HNO_3 to a pH less than 2.0. The irrigation water samples were then stored in a refrigerator at 4.0 °C to minimize microbial activities and undesirable physicochemical reactions before further analysis.

3.3 Irrigated soils sampling

Soil samples were collected across the three regions shown in Fig. 2. A total of 61 soil samples were collected to a depth of 20.0 cm at different locations in the study area. To get one representative sample on a site, six points for sampling were randomly selected and the soils were mixed thoroughly before collecting a final sample of 0.5 kg for analysis, Samples were then stored in labeled zip-top bags and transported to NM-AIST laboratory for analysis. Accordingly, all other soil sampling procedures were followed using recommendations in the literature (Crepin & Johnson, 1993; Csuros, 2018).

3.4 Farmers' baseline survey

The farmers' baseline survey was used to collect qualitative information about the on-farm practices for individual farmers. A random sample of 56 farmers was selected using standard survey methods (Emerson, 2015). Farmer's information included: Farmer's age, gender, education level, farm size, machinery used for land preparation, amount of water reaching their plots, type of fertilizer, pesticides used and general paddy productivity. Moreover, farmers were asked whether they had access to extension services and markets.

3.5 Laboratory analyses

Irrigation water samples were analyzed for cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), anions (SO_4^{2-}, PO_4^{2-}, CO_3^{2-}, HCO_3^{-} , Cl^{-}, NO_3^{-}) and trace elements (Fe^{2+}, Zn^{2+}, Cu^{2+}, Mn^{2+} , B, As, Cd, Cr^{2+}, Pb^{2+}, Ni^{2+} and Al^{3+}) using the methods explained below. The levels of SO_4^{2-} were determined by using SulfaVer 4 Turbidity method. The levels of PO_4^{2-} were determined using PhosVer 3 Ascorbic method. The levels of NO_3^{-} were determined using NitraVer Cadmium Reduction method. The levels of B were determined using BorVer Carmine method. The anionic levels were read using HACH DR 2800 spectrophotometer.

The levels of Cl^- were determined by Argentometric Titration method using standard silver nitrate ($AgNO_3$) titrant and potassium chromate indicator solution. The levels of CO_3^{2-} and HCO_3^- were determined using standard H_2SO_2 and Bromocresol Green indicator. The levels of Na^+ and K^+ were determined by PFP7 Flame Photometer using standard solutions of Na^+ and K^+. The levels of Ca^{2+} and Mg^{2+} were determined by titration method with ethylene diaminetetraacetic acid (EDTA) using Erio T as end point of titration (Rizvi *et al*., 2015). The levels of heavy metals were determined using atomic absorption spectrometer (AAS) (PerkinElmer Analyst 100).

Sodium adsorption ratio (SAR) for irrigation water samples was calculated using the standard Equation (1) (Sattari *et al*., 2018);

$$\mathrm{SAR} = \frac{[\mathrm{Na}^+]}{\sqrt{\frac{[\mathrm{Ca}^{2+}]+[\mathrm{Mg}^{2+}]}{2}}} \tag{1}$$

where $[\mathrm{Na}^+]$, $[\mathrm{Ca}^{2+}]$, and $[\mathrm{Mg}^{2+}]$ are concentrations of sodium, calcium and magnesium ions in the irrigation water, respectively.

Soil samples were analyzed for OC, EC, pH , Fe^{2+}, Zn^{2+}, N , P and K^+ using standard methods for soil analysis (Jones Jr, 2001). Soil EC and pH were determined by a portable meter using a soil to water ratio of 1:2 using potassium chloride reagent. The OC content was determined by mixing the sample with chromic acid and H_2SO_2. Total N was determined by the Micro-Kjeldahl digestion, distillation followed by titration. Available P was determined by using the Olsen method as done in Zhan *et al.* (2015). The soil K^+ levels were determined by flame photometry procedures. Soil Fe^{2+} and Zn^{2+} were determined by an atomic absorption spectrophotometer (AAS) after digestion and extraction of samples.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Irrigation water quality

(i) Irrigation water pH, EC and TDS

Irrigation water pH values ranged from 6.23 to 7.42 with mean value of 6.66 ± 6.55. EC values for irrigation water samples ranged from 0.66 to 1.52 ds/m with average value of 0.96 ± 0.953 dS/m. Generally, the results indicate that 14% of the assessed irrigation water samples had EC values less than 0.7 ds/m (Table 2). The remaining 86% of the assessed irrigation water samples had EC values greater or equal to 0.7 ds/m.

(ii) Sodium Adsorption Ratio (SAR) levels and infiltration

The corresponding Na^+ levels ranged from 0. 15 to 2.44 Meq/l with mean value of 0.75 ± 0.67 Meq/l. Ca^{2+} levels ranged from 0.77 to 7.00 meq/l with mean value of 2.88 ± 2.86 meq/l while Mg^{2+} levels ranged from 1.82 to 6.28 Meq/l with mean value of 2.92 ± 2.63 meq/l. As aresult SAR in the study area ranged from 0.09 to 1.71 with mean value of 0.45 ± 0.41. The levels were below threshold value of 9 which is maximum level above which irrigation water infiltration would be impaired (FAO, 1992)

(iii) Chloride and boron

Chloride (Cl^-) levels in irrigation water samples ranged from 0.1 to 0.5 mg/l with average value of 0.17± 0.1 mg/l. According to FAO guidelines the levels were safe for irrigation. Boron levels ranged from 0.1 to 9 mg/l with mean value of 1.55± 1.11 mg/l (Table 4). Among the 37 water samples analyzed the results showed 32.4% of the samples fell under the no toxicity category, 54.1% fell under moderate toxicity category and 13.5% were under severe toxicity category (FAO, 1992).

(iv) Nitrate Nitrogen and bicarbonate effects

Nitrate Nitrogen levels ranged from 0.1 to 1.9 mg/l with average value 0.56 ± 0.50 mg/l. According to FAO guidelines of 1992, these levels were below 5 mg/l which is maximum recommended levels for irrigation water. Bicarbonate levels ranged from 3.44 to 10.66 meq/l with average value of 5.92 ± 5.25 meq/l. of Nitrate levels were all bellow the FAO hazard limit of 5.0 mg/L (Table 5). However, of the 37 irrigation water samples, 32 indicated levels of HCO_3^- with slight-to-moderate detrimental effect on plant growth; 5 irrigation water samples equaling 13.5% indicated levels of HCO_3^- with severe effect on plant growth. For all the irrigation water samples none indicated levels of HCO_3^- below 1.5 meq/L, which is a safe threshold set by FAO. It is possible, thus, that the observed low paddy productivity and variations in yields among the farmers on the study field, are attributable to bicarbonate levels and variation.

(v) Trace elements and nutrient elements

A total of 11 trace elements (As, Cd, Mo, Zn^{2+}, Mn^{2+}, Fe^{2+}, Ni^{2+}, Pb^{2+}, Cr^{+2} , Al^{3+} , and Cu^{2+}) in the irrigation water were analyzed. The results indicate that generally all trace elements in the analyzed samples were within the recommended limits (Fipps, 2003). P levels in irrigation water samples ranged from 0.11 to 0.95 mg/l and averaged 0.30 ± 0.22 mg/l while SO_4^{2-} levels ranged from 0 to 8 mg/l with mean value of 2.7 ± 1 mg/l. K+ levels in irrigation water samples ranged from 1.36 to 12.46 mg/l with average value of 3.62 ± 3.21 mg/l.

(vi) Irrigation water anionic and cationic composition

In the present study, the Piper diagram was used to elucidate the irrigation water anionic and cationic composition. The piper diagram is graphical presentation of chemical composition of water (Ravikumar *et al.*, 2015). The Piper diagram's bottom left ternary shows the cations while bottom right ternary shows the anions (Fig. 3). The middle diamond shape shows chemical composition of both cations and anions. The diagram is dominated by Ca^{2+} - HCO_3^-- Mg^{2+} indicating the irrigation water has more levels of Ca^{2+}, $HCO_3^-$and Mg^{2+} ions. Therefore the irrigation water might have salts comprised mainly of Ca^{2+},$HCO_3^-$and Mg^{2+} ions.

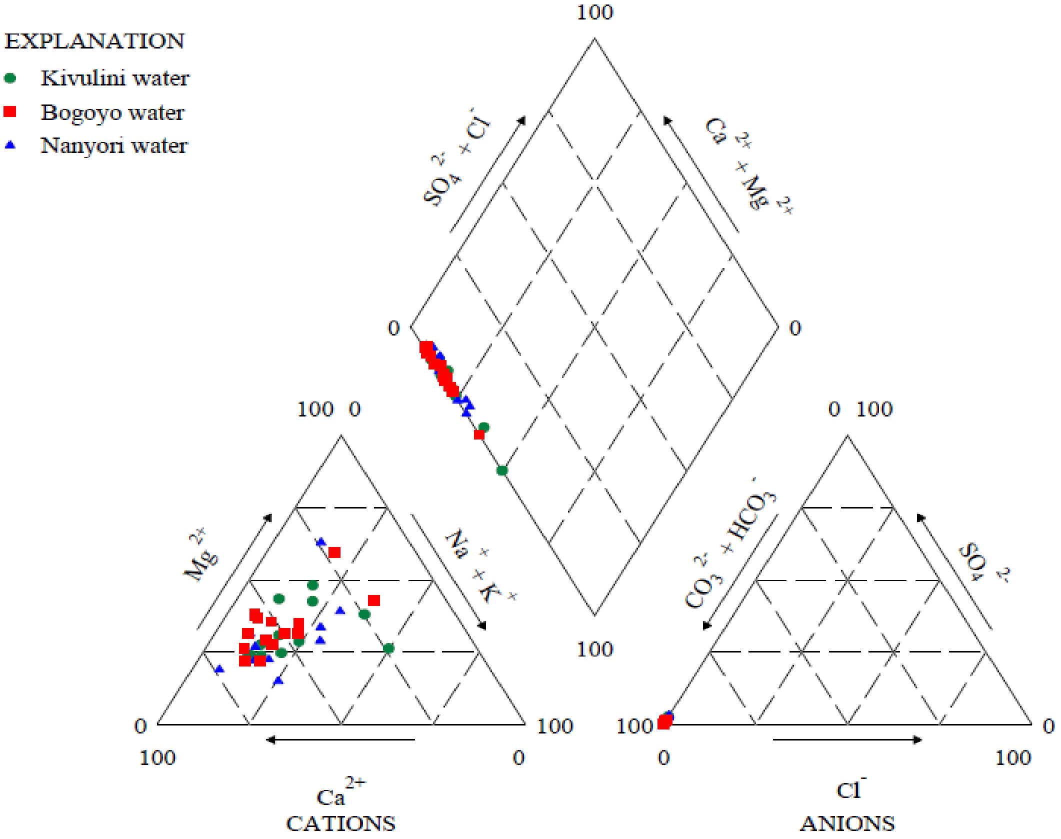

Figure 3: **Piper diagram showing chemical composition of irrigation water in three sub-regions (Kivulini, Bogoyo and Nanyori). The bottom left ternary shows the cations while bottom right ternary shows the anions. The top diamond-shaped chart represents both anions and cations distribution in the three main canals**

Table 2: Required salinity levels (Misstear *et al.*, 2006) vs. field data from the studied area considering salinity effect

Salinity measure						
Parameter (unit)	EC (dS/m)			TDS (mg/L)		
Degree of restriction	None	Slight to moderate	Severe	None	Slight to moderate	Severe
FAO guideline	< 0.7	0.7–3.0	> 3.0	<450	450–2000	>2000
Levels in field samples for the current study						
Site name						
WS-1		0.66			429	
WS-2		0.93			601	
WS-3		0.82			535	
WS-4		0.67			436	
WS-5		0.71			461	
WS-6		0.96			624	
WS-7		1.13			735	
WS-8		0.93			603	
WS-9		0.92			599	
WS-10		0.99			646	
WS-11		1.46			1462	
WS-12		1.37			1365	
WS-13		0.82			533	
WS-14		0.84			543	
WS-15		0.95			619	
WS-16		1.05			683	
WS-17		1.19			779	
WS-18		1.09			703	
WS-19		0.95			618	
WS-20		0.89			579	
WS-21		0.82			534	
WS-22		0.82			533	
WS-23		0.98			636	
WS-24		0.98			637	
WS-25		0.98			632	
WS-26		1.16			754	
WS-27		1.52			983	
WS-28		1.03			667	
WS-29		0.86			560	
WS-30		0.99			642	
WS-31		1.17			759	
WS-32		1.37			890	
WS-33		0.66			424	
WS-34		0.71			458	
WS-35		0.66			427	
WS-36		0.67			434	
WS-37		0.79			510	

Table 3: FAO guidelines for interpretation of water quality for irrigation (Misstear *et al.,* 2006) vs. field data from the studied area considering infiltration and sodium toxicity effect

Infiltration measure					
Parameter (unit)	SAR			EC (dS/m)	
Degree of restriction			None	Slight to moderate	Severe
FAO guideline	SAR 0–3	with EC	> 0.7	0.7–0.2	< 0.2
	SAR 3–6	with EC	> 1.2	1.2–0.3	< 0.3
	SAR 6–12	with EC	> 1.9	1.9–0.5	< 0.5
	SAR 12–20	with EC	> 2.9	2.9–1.3	< 1.3
	SAR 20–40	with EC	> 5.0	5.0–2.9	< 2.9
Levels in field samples for the current study					
Site name					
WS-1	0.32			0.66	
WS-2	0.57			0.93	
WS-3	0.97			0.82	
WS-4	0.21			0.67	
WS-5	0.41			0.71	
WS-6	0.48			0.96	
WS-7	1.72			1.13	
WS-8	0.31			0.93	
WS-9	0.37			0.92	
WS-10	0.64			0.99	
WS-11	0.51			1.46	
WS-12	0.53			1.37	
WS-13	0.64			0.82	
WS-14	0.56			0.84	
WS-15	0.33			0.95	
WS-16	0.24			1.05	
WS-17	0.84			1.19	
WS-18	0.71			1.09	
WS-19	0.35			0.95	
WS-20	0.50			0.89	
WS-21	0.22			0.82	
WS-22	0.10			0.82	
WS-23	0.11			0.98	
WS-24	0.09			0.98	
WS-25	0.75			0.98	
WS-26	0.13			1.16	
WS-27	0.61			1.52	
WS-28	0.58			1.03	
WS-29	0.45			0.86	
WS-30	0.47			0.99	
WS-31	0.31			1.17	
WS-32	0.20			1.37	
WS-33	0.41			0.66	
WS-34	0.33			0.71	
WS-35	0.29			0.66	
WS-36	0.26			0.67	
WS-37	0.29			0.79	

Table 4: FAO guidelines for interpretation of water quality for irrigation (Misstear *et al.*, 2006) vs. field data from the studied area considering specific ion toxicity effect

	Chloride (Cl^-) (meq/L)			Boron (B) (mg/L)		
Toxicity level (FAO guideline value)	No toxicity (< 4)	Slight to moderate	Severe toxicity (>	No toxicity (< 0.7)	Slight to moderate	Severe toxicity (>
		toxicity (4–10)	10)		toxicity (0.7–3.0)	3.0)
Levels in field samples for the current study						
Site name						
WS-1		0.1			1.2	
WS-2		0.1			0.4	
WS-3		0.2			1.3	
WS-4		0.1			3.9	
WS-5		0.1			0.8	
WS-6		0.1			0.8	
WS-7		0.2			0.8	
WS-8		0.1			0.2	
WS-9		0.1			9.0	
WS-10		0.2			1.4	
WS-11		0.3			3.3	
WS-12		0.1			0.2	
WS-13		0.2			0.4	
WS-14		0.3			2.5	
WS-15		0.1			3.7	
WS-16		0.2			1.0	
WS-17		0.1			1.8	
WS-18		0.2			1.6	
WS-19		0.5			1.3	
WS-20		0.1			2.9	
WS-21		0.1			1.4	
WS-22		0.2			0.5	
WS-23		0.1			0.8	
WS-24		0.4			1.7	
WS-25		0.1			1.0	
WS-26		0.1			0.3	
WS-27		0.4			0.1	
WS-28		0.1			0.3	
WS-29		0.1			0.5	
WS-30		0.2			1.1	
WS-31		0.1			0.4	
WS-32		0.1			1.8	
WS-33		0.1			3.7	
WS-34		0.2			0.5	
WS-35		0.1			1.8	
WS-36		0.1			0.6	
WS-37		0.1			2.4	

Table 5: FAO guidelines for interpretation (Misstear *et al.*, 2006) vs. field data from the studied area considering effects on plant growth

	Nitrate (NO_3^-) (mg/L)			Bicarbonate (HCO_3^-)(meq/L)		
Toxicity level (FAO guideline value)	No effect (< 5)	Slight to moderate effect (5–30)	Severe effect (> 30)	No effect (< 1.5)	Slight to moderate effect (1.5–8.5)	Severe effect (>8.5)
Levels in field samples for the current study						
Site name						
WS-1		1.2			5.08	
WS-2		1.1			7.54	
WS-3		1.1			5.08	
WS-4		0.4			3.77	
WS-5		0.1			4.92	
WS-6		0.3			4.26	
WS-7		0.3			4.76	
WS-8		0.2			6.23	
WS-9		0.0			4.92	
WS-10		0.2			5.25	
WS-11		0.5			9.02	
WS-12		0.5			7.54	
WS-13		0.5			4.26	
WS-14		1.0			3.44	
WS-15		0.1			5.90	
WS-16		0.5			10.66	
WS-17		0.5			10.66	
WS-18		1.2			4.92	
WS-19		0.5			5.9	
WS-20		0.5			4.26	
WS-21		1.3			6.39	
WS-22		1.3			5.08	
WS-23		0.5			6.40	
WS-24		0.4			5.41	
WS-25		0.1			4.76	
WS-26		0.3			6.89	
WS-27		0.4			10.17	
WS-28		0.4			7.54	
WS-29		0.0			5.90	
WS-30		0.3			5.08	
WS-31		1.2			8.20	
WS-32		1.0			8.04	
WS-33		0.2			5.25	
WS-34		1.9			5.08	
WS-35		0.2			4.10	
WS-36		0.6			4.92	
WS-37		0.1			7.22	

4.1.2 Irrigated soil quality

(i) Soil EC, pH and soil organic carbon (SOC)

Electrical Conductivity (EC) values ranged between 0.2 and 1.9 dS/m. The average EC value was 0.45 dS/m. As can be seen in S3 (Appendices), the pH values in the present study ranged from 6.31 to 10.09. Of the total 61 soil samples, 57 sample (equivalent to 93%) had pH values between 6.0 and 8.5. Moreover, SOC ranged between 0.1 and 2.4%

(ii) Soil macro- and micro-nutrients: Nitrogen (N), Phosphorus (P) and Potassium (K)

The soil TN-content values ranged from 86 to 2155 mg/kg with average value of 1232 ± 540 mg/kg. The P values ranged between 54.8 and 946.5 mg/kg with the mean value of 224.2 ± 149.4 mg/kg. The values of K ranged from 8.8 to 49.9 mg/kg soil, with a mean value of 13.9 ± 5.6 mg/kg.

(iii) Iron (Fe) and Zinc (Zn)

The soil Zn levels ranged from 3.9 to 204.1 mg/kg with mean value of 50.8 ± 43.6 mg/kg. On the other hand Fe concentration ranged from 2.6 to 169.5 mg/kg soil with the mean value of 19.8 ± 36.6 mg/kg.

4.1.3 Farmers' survey results

Out of 56 farmers who participated in the survey, 20% grew *Saro 5* paddy variety while 80% grew *IR 64* paddy variety. Respondents' data analysis found that *Saro 5* variety's productivity ranged from 0.4 to 1.8-ton ha^{-1} while *IR 64* ranged from 0.7 to 3.8 ton ha^{-1}. Respondents pointed out that they use urea-based fertilizers to enhance paddy growth. They also use various pesticides to control diseases and pests. The farmer's gender, age, and education level did not correlate with paddy productivity. Also, type of pesticides and fertilizers had no correlation with paddy productivity.

4.2 Discussions

4.2.1 Irrigation water samples

From the results the analyzed water samples showed characters that had influence on the productivity of paddy in the study area. The levels of EC and TDS in irrigation water samples were too little to cause salinity problems to the irrigated fields. Also Na^+ and SAR levels had no significant harm to paddy growth and productivity. The irrigation water in study area had no toxic effect from Cl^- as its levels were low compared to FAO guidelines. However some few parts of the field had elevated levels of Boron that would hinder paddy growth. Moreover, few parts of irrigated fields had elevated levels of HCO_3^- which might have severe effect on paddy growth. Nitrate levels were below maximum recommended limit as suggested by FAO hence had no significant harm to paddy growth. Generally, the N, S, and K levels in the sampled irrigation water were within the recommended limits for agricultural application (Hopkins *et al.*, 2007). The pH levels were within acceptable range. This was in line with trace elements levels in the analyzed samples which were within the recommended limits hence posing no harmful effect to paddy itself and animals eating paddy. Solubility of trace elements in irrigation water depends on water pH (Fipps, 2003). The piper diagram indicated that irrigation water might had salts comprised mainly of Ca^{2+}, HCO_3^- and Mg^{2+} ions.

4.2.2 Irrigated soil properties

The results for physico-chemical properties of laboratory soil tests are summarized in the table S3 in the appendix. Sustainable paddy productivity needs to take into consideration the paddy soil properties in the irrigated scheme. Globally, soil quality variabilities in paddy fields are well recognized. Paddy soil quality parameters such as soil EC, pH, organic carbon, nutrients and trace elements are important in determining sustained paddy productivity. High soil EC levels, although not a direct measure of the presence of certain compounds, has been correlated to the presence of ammonia, sulphate, chloride, potassium and nitrate (Aimrun *et al.*, 2011; Zhou *et al.*, 2014). However, from the results it was observed that soil levels (below 4 ds/m) in the study area was not saline (Touch *et al.*, 2015). Soil pH is an important parameter in paddy production. Paddy is known to grow and flourish in soils with pH levels as low as 5.5 (Yu, 1991). However, low soil pH values may lead to nutrient leaching. In the studied area pH levels was favourable for paddy yield. Moreover, from the results it can be concluded that SOC was suitable for paddy yields. Stable soil structure has positive influence on crop yields (Lee *et al.*, 2009).

Greater variations in Fe levels might be the reason for paddy yields among the fields in the studied area. Furthermore, there is probably iron deficiency in the studied area. A similar irrigation scheme in Brazil, for example, was found to have Fe levels between 159 and 324 mg/kg (Fageria *et al.*, 2008). In another study conducted in paddy irrigation schemes of Ivory

Coast paddy reported Fe-content values ranging from 77 to 137 mg/kg soil (Sahrawat *et al.*, 2000).

There are many soil factors that influence Zn availability to plants including high pH, high concentrations of phosphate, bicarbonate, Na, Ca, and Mg in the soils solution (Alloway, 2009). Rice (paddy) is a highly susceptible crop to Zn deficiency (Alloway, 2009).

A study conducted in Poland, found soil Zn levels ranging between 8.2 and 92.3 mg Zn per kg soil. The mean value was 41.2 ± 24.4 mg/kg whereas the median was 38.05 mg/kg (Kabala & Singh, 2001). Another study conducted in China obtained soil Zn concentration in the range of 19.8 to 119 mg/kg soil, with a mean value of 65.5 ± 22.2 mg/kg soil. The median Zn concentration in the soils was found to be 61.8 mg/kg (Wang *et al.*, 2003). Although the mean and somehow the median values in these studies are comparable to those obtained in the present study, the deviations are not. The soils in the present study may not be Zn-deficient, but it is probable that plot-to-plot variations in paddy yields may be attributable to the variations in soil Zn content.

Soil N is an important macro-nutrient for plants. Soil N deficiencies lead to poor crop production. Excess N in the environment leads to environmental degradation. Elevated N levels may result into paddy lodging and eutrophication of disposed drainage water (Choudhury & Kennedy, 2005; Corbin *et al.*, 2016). The source of N in paddy soils is either through natural supply or by addition through synthetic NPK or organic fertilizers. The amount of N naturally available in the soils is usually insufficient to support paddy growth. In most cases, supply of N to the soils through fertilizers is thus inevitable. Soil N content vary from place to place due to many factors such as soil type, soil pH, type and amount of fertilizer used, organic carbon content, and climate. In Hunan province of China, a long-term study on paddy soils was conducted in areas with subtropical climate (Qaswar *et al.*, 2019). The initial soil properties indicated total nitrogen (TN) levels of 1100 and 1250 mg/kg soil. In a different long-term study on paddy soils amendment to improve organic carbon and total nitrogen in eight different regions in China, the initial soil TN reported ranged between 920 and 2720 mg/kg soil (Tong *et al.*, 2009).

In the present study, the mean soil TN value was 1232 ± 540 mg/kg. The median value was 1293 mg/kg. The mean and median values were in similar magnitude, although the standard deviation from the mean was high. The soil TN-content values ranged from 86 to 2155 mg/kg.

Although the range in paddy soil TN-content in the present study seems broad, the median value indicates that most soil samples had TN concentration around 1293 mg/kg. These values are similar to the values reported in the paddy soils of subtropical China (Tong *et al.*, 2009; Qaswar *et al.*, 2019). However, plot-to-plot variations in TN levels for the present study are still high. Poor on-farm practices related to agricultural inputs such as synthetic fertilizers, organic fertilizers and pesticides may contribute to the observed variations. Such practices are known to cause economic and environmental problem in the agricultural sector (Ju *et al.*, 2009).

After nitrogen, soil phosphorus (P) ranks second as the most essential nutrient for plant growth (Ahmed *et al.*, 2019). Similar to N, excess use of P through fertilizer has negative effects on the natural environment. It is therefore imperative to monitor the levels of phosphorus in paddy soils. Although paddy soil total P-content may be high, only 0.1% of total phosphorus is usually available for plant uptake (Khan *et al.*, 2017). Historical data for tropical Asia indicate that in the 1970s the average paddy soil total phosphorus (TP) in nine Asian countries was 837 ± 668 mg/kg; range in TP concentration was from 10 – 5530 mg/kg soil (Kawaguchi & Kyuma, 1975)

In the present study, the soil available P (Olsen P) was analyzed. A recent study done for rice production indicated an average Olsen P value of 3.4 mg/kg (Shi, 2015). When compared the values obtained in another study done at Rothamsted in the UK, it is obvious that the Olsen P values in this study are extremely high (Syers, 2008). The high Olsen P may have had a negative impact on paddy yields. On-farm management that targets sustainable use of P-fertilizers in the studied area is therefore highly recommended. Sustainable application of P-fertilizers is recommended because of three main reasons. First, to improve paddy soil P-content in the area, hence improve crop yields. Second, globally, phosphate-containing rocks from which P-fertilizers are manufactured are rapidly declining (Cordell *et al.*, 2009). The economic application of P-fertilizers.

Another highly essential plant macronutrient is potassium (K). An appropriate supply of K to plants is known to improve plants' root growth and to improve plant vigor as it helps in preventing lodging and improving plant's resistance to diseases and pests. Potassium is highly mobile in both the soil and plant body. In spite of its importance to soil and plants, studies emphasizing on the supply of K to soil and plants are sparse (Li *et al.*, 2018). Most studies aim at the supply and management of N and P. A previous study on potassium in soils and crops of India has recorded K in soil solution ranging between 1 and 10 mg/kg (Sekhon, 1999).

Slaton *et al.* (2009) recommended soil K level of > 130 mg/kg for improved paddy productivity. It is obvious that the values obtained in the current study are too low to support good paddy yields. The observed low and highly varied yields among smallholder farmers at the study site may be attributable to low availability of potassium in the soils.

4.2.3 Farmers' survey

Farmers' survey was conducted to determine agronomic practices in the study area. This was done to give an indication of how the farms in the study area are taken care. No statistical analysis was done on the obtained data. Out of 56 farmers who participated in the survey, 20% grew *Saro 5* paddy variety while 80% grew *IR 64* paddy variety. Respondents' data analysis found that *Saro 5* variety's productivity ranged from 0.4 to 1.8-ton ha^{-1} while *IR 64* ranged from 0.7 to 3.8 ton ha^{-1}. Respondents pointed out that they use urea-based fertilizers to enhance paddy growth. They also use various pesticides to control diseases and pests. The farmer's gender, age, and education level did not correlate with paddy productivity. Also, type of pesticides and fertilizers had no correlation with paddy productivity.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study investigated how irrigation water quality, irrigated soils and farmers' biodata and practices may be influencing paddy productivity at an irrigation scheme near the foot of Mt. Kilimanjaro, Tanzania. Irrigation water quality parameters such as SAR, EC, B, and HCO_3^- were found in levels that may have negative influence on paddy productivity in the studied area. Levels of pH, trace elements, chloride and sodium ions in the irrigation water were normal.

Soil parameters indicated high variability in content. Soil Fe and Zn, very important soil micronutrients, were highly varied from plot to plot. It was further found that Fe soil content in the studied area compared to other similar places is probably Fe-deficient. Total soil nitrogen was also highly variable among the analyzed samples. Furthermore, phosphorus (measured as Olson P) was too high in the present study area compared to other studies conducted in paddy soils.

Poor irrigation water quality and high variability in the irrigated soils may be causing observed general poor yields and plot-to-plot yield differences. It seems that farmers at the current study site work individually. They make individual decisions on how to apply agricultural inputs and how to conduct on-farm activity management. This is evidenced by the variabilities in paddy yields at the studied site. It is also evidenced by variabilities in the irrigated soil and irrigation water quality.

5.2 Recommendations

A further study on how agricultural extension services are offered at this irrigation scheme is highly recommended. Also, a plot-by-plot long-term study of on-farm practices would generate more information on the reasons for poor and varied paddy yields. Finally, training on the best agronomic practices to both extension officers and farmers is important for better and sustainable paddy yields.

REFERENCES

Aagaard, K., Eash, J., Ford, W., Heglund, P. J., McDowell, M., & Thogmartin, W. E. (2018). Modeling the Relationship between Water Level, Wild Rice Abundance, and Waterfowl Abundance at a Central North American Wetland. *Wetlands, 39*(1), 149-160

Aamer, K. K. M., Asif, N. M., Hussain, S., Aziz, T., & Schoenau, J. (2015). High sodium in irrigation water caused B toxicity at low soil solution and shoot B concentration in maize (*Zea mays* L.). *Journal of Plant Nutrition, 38*(5), 728-741.

Achandi, E. L., & Mujawamariya, G. (2016). Market participation by smallholder rice farmers in Tanzania: A double hurdle analysis. *Studies in Agricultural Economics, 118*(2), 112-115.

Adrees, M., Ali, S., Rizwan, M., Zia-ur-Rehman, M., Ibrahim, M., Abbas, F., Farid, M., Qayyum, M. F., & Irshad, M. K. (2015). Mechanisms of silicon-mediated alleviation of heavy metal toxicity in plants: A review. *Ecotoxicology and Environmental Safety, 119*, 186-197.

Afshar, M. G., Tercier-Waeber, M., Wehrli, B., & Bakker, E. (2017). Direct sensing of total alkalinity profile in a stratified lake. *Geochemical Perspective Letters, 3*(1), 85-93.

Ahmed, W., Jing, H., Kaillou, L., Qaswar, M., Khan, M. N., Jin, C., Geng, S., Qinghai, H., Yiren, L., Guangrong, L., Mei, S., Chao, L., Dongchu, L., Ali, S., Normatov, Y., Mehmood, S., & Zhang, H. (2019). Changes in phosphorus fractions associated with soil chemical properties under long-term organic and inorganic fertilization in paddy soils of southern China. *PloS One*, *14*(5), e0216881-e0216881.

Aimrun, W., Amin, M., Ezrin, M., & Mastura, M. (2011). Paddy soil properties and yield characteristics based on apparent electrical conductivity zone delineation for a humid tropical rice farm. *African Journal of Agricultural Research*, *6*(23), 5339-5350.

Ajay, G., Suneel, M., Kumar, K. K., & Prasad, P. S. (2013). Quality evaluation of rice grains using morphological methods. *International Journal of Soft Computing and Engineering*, *2*(6), 35-37.

Alavaisha, E., Lyon, S. W., & Lindborg, R. (2019). Assessment of Water Quality Across Irrigation Schemes: A Case Study of Wetland Agriculture Impacts in Kilombero Valley, Tanzania. *Water*, *11*(4), 1-22.

Alfarisy, A. A., Chen, Q., & Guo, M. (2018). *Deep learning based classification for paddy pests and diseases recognition. Proceedings of 2018 International Conference on Mathematics and Artificial Intelligence*. https://doi.org/10.1145/3208788.3208795

Allende, A., & Monaghan, J. (2015). Irrigation water quality for leafy crops: A perspective of risks and potential solutions. *International Journal of Environmental Research and Public Health*, *12*(7), 7457-7477.

Alloway, B. J. (2009). Soil factors associated with zinc deficiency in crops and humans. *Environmental Geochemistry and Health*, *31*(5), 537-548.

Amich, J., Dümig, M., O'Keeffe, G., Binder, J., Doyle, S., Beilhack, A., & Krappmann, S. (2016). Exploration of sulfur assimilation of Aspergillus fumigatus reveals biosynthesis of sulfur-containing amino acids as a virulence determinant. *Infection and Immunity*, *84*(4), 917-929.

Ananthanarayanan, A., Wang, Y., Routh, P., Sk, M. A., Than, A., Lin, M., Zhang, J., Chen, J., Sun, H., & Chen, P. (2015). Nitrogen and phosphorus co-doped graphene quantum dots: Synthesis from adenosine triphosphate, optical properties, and cellular imaging. *Nanoscale*, *7*(17), 8159-8165.

Antil, R. S., & Singh, M. (2007). Effects of organic manures and fertilizers on organic matter and nutrients status of the soil. *Archives of Agronomy and Soil Science*, *53*(5), 519-528.

Anwar, F., Zengin, G., Alkharfy, K., & Marcu, M. (2017). Wild rice (*Zizania* sp.): A potential source of valuable ingredients for nutraceuticals and functional foods. *Rivista Italiana Delle Sostanze Grasse, 565*, 81-89.

Assouline, S., Russo, D., Silber, A., & Or, D. (2015). Balancing water scarcity and quality for sustainable irrigated agriculture. *Water Resources Research*, *51*(5), 3419-3436.

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.

Augusto, L., Achat, D. L., Jonard, M., Vidal, D., & Ringeval, B. (2017). Soil parent material—a major driver of plant nutrient limitations in terrestrial ecosystems. *Global Change Biology, 23*(9), 3808-3824.

Awan, T. H., Ahmadizadeh, M., Jabran, K., Hashim, S., & Chauhan, B. S. (2017). *Domestication and development of rice cultivars. Rice Production Worldwide, Springer.* https://link.springer.com/book/10.1007%2F978-3-319-47516-5

Balamurugan, P., & Balasubramanian, V. (2017). Challenges and opportunities for increasing rice production in sub saharan Africa. *Journal of Innovative Agriculture, 4*(2), 1-10.

Baquy, M., Li, J. Y., Xu, C. Y., Mehmood, K., & Xu, R. K. (2017). Determination of critical pH and Al concentration of acidic Ultisols for wheat and canola crops. *Solid Earth, 8*(1), 149-159.

Bauder, T. A. (2011). *Irrigation Water Quality Criteria* [Doctoral dissertation, Colorado State *University*]. https://extension.colostate.edu/docs/pubs/crops/00506.pdf

Bauder, T. A., Waskom, R., Sutherland, P., & Davis, J. (2011a). *Irrigation water quality criteria, Colorado State University Extension*. https://extension.colostate.edu/topic-areas/agriculture/irrigation-water-quality-criteria-0-506/

Bauder, T. A., Waskom, R., Sutherland, P., Davis, J., Follett, R., & Soltanpour, P. (2011b). I*rrigation water quality criteria. Service in action*. https://itc.tamu.edu/files/2018/05/00506.pdf

Bergkemper, F., Schöler, A., Engel, M., Lang, F., Krüger, J., Schloter, M., & Schulz, S. (2016). Phosphorus depletion in forest soils shapes bacterial communities towards phosphorus recycling systems. *Environmental Microbiology, 18*(6), 1988-2000.

Bhatti, M. T., Sarwar, M. K., Tahir, A. A., & Yar, M. (2017). Effect of irrigation application on soil and land productivity of wheat under semi-arid environment. *Journal of Agricultural Research, 55*(1), 1-14.

Bidzakin, J. K., Fialor, S. C., Awunyo-Vitor, D., & Yahaya, I. (2018). Impact of Irrigation Ecology on Rice Production Efficiency in Ghana. *Advances in Agriculture*, *2018*, 1-10. https://doi.org/10.1155/2018/5287138

Bityutskii, N. P., Yakkonen, K. L., Petrova, A. I., & Shavarda, A. L. (2017). Interactions between aluminium, iron and silicon in Cucumber sativus L. grown under acidic conditions. *Journal of Plant Physiology*, *218*, 100-108.

Borlaug, N. E. (2002). Feeding a world of 10 billion people: the miracle ahead. *In Vitro Cellular and Developmental Biology-Plant*, *38*(2), 221-228.

Brown, L. R. (1994). Who will feed China. *World Watch*, *7*(5), 10-19.

Bruinsma, J. (2017). *World agriculture: Towards 2015/2030: An FAO study. Routledge.* https://doi.org/10.4324/9781315083858

Cao, Y., & Yin, B. (2015). Effects of integrated high-efficiency practice versus conventional practice on rice yield and N fate. *Agriculture, Ecosystems and Environment*, *202,* 1-7.

Carrijo, D. R., Lundy, M. E., & Linquist, B. A. (2017). Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. *Field Crops Research*, *203,* 173-180.

Carruthers, S. (2016). Zinc: Deficiency and toxicity. *Practical Hydroponics and Greenhouses*, *172,* 42 - 45.

Carvalho, M., Madari, B., Bastiaans, L., Van-Oort, P., Leal, W., Heinemann, A., Da-Silva, M., Maia, A., Parsons, D., & Meinke, H. (2016). Properties of a clay soil from 1.5 to 3.5 years after biochar application and the impact on rice yield. *Geoderma*, *276*, 7-18.

Chanchal., M., C., Kapoor, R., & Ganjewala, D. (2016). Alleviation of abiotic and biotic stresses in plants by silicon supplementation. *Scientia*, *13*(2), 59-73.

Chaussemier, M., Pourmohtasham, E., Gelus, D., Pécoul, N., Perrot, H., Lédion, J., Cheap-Charpentier, H., & Horner, O. (2015). State of art of natural inhibitors of calcium carbonate scaling: A review article. *Desalination*, *356,* 47-55.

Chen, X. L., Hu, S. M., Hu, Y. W., Wang, W. L., Ma, Y. Y., Lü, P., & Wang, C. S. (2016). Raising practices of Neolithic livestock evidenced by stable isotope analysis in the Wei River valley, North China. *International Journal of Osteoarchaeology*, *26*(1), 42-52.

Chhabra, R. (2017). *Soil salinity and water quality. https://www.routledge.com/Soil-Salinity-and-Water-Quality/Chhabra/p/book/9789054107279*

Choudhury, A. T. M. A., & Kennedy, I. R. (2005). Nitrogen Fertilizer Losses from Rice Soils and Control of Environmental Pollution Problems. *Communications in Soil Science and Plant Analysis, 36*(11-12),1625-1639.

Corbin, J. L., Orlowski, J. M., Harrell, D. L., Golden, B. R., Falconer, L., Krutz, L. J., Gore, J., Cox, M. S., & Walker, T. W. (2016). Nitrogen Strategy and Seeding Rate Affect Rice Lodging, Yield, and Economic Returns in the Midsouthern United States. *Agronomy Journal*, *108*(5), 1938-1943.

Cordell, D., Drangert, J. O., & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change*, *19*(2), 292-305.

Corratgé-Faillie, C., Ronzier, E., Sanchez, F., Prado, K., Kim, J. H., Lanciano, S., Leonhardt, N., Lacombe, B., & Xiong, T. C. (2017). The Arabidopsis guard cell outward potassium channel GORK is regulated by CPK 33. *FEBS Letters*, *591*(13), 1982-1992.

Couto, W. (2017). Soil pH and plant productivity. *Handbook of agricultural productivity*. *CRC Press*. https://www.taylorfrancis.com/chapters/edit/10.1201/9781351072878-6/ soil-ph-plant-productivity-walter-couto

Crepin, J., & Johnson, R. L. (1993). Soil sampling for environmental assessment. *Soil Sampling and Methods of Analysis 1993,* 5-24

Crusciol, C. A., Artigiani, A. C., Arf, O., Carmeis, F., A. C., Soratto, R. P., Nascente, A. S., & Alvarez, R. C. (2016). Soil fertility, plant nutrition, and grain yield of upland rice affected by surface application of lime, silicate, and phosphogypsum in a tropical no-till system. *Catena*, *137,* 87-99.

Csuros, M. (2018). E*nvironmental sampling and analysis for technicians. CRC press. Florida, USApp.* https://doi.org/10.1201/9780203756867

Cucci, G., Lacolla, G., Pagliai, M., & Vignozzi, N. (2015). Effect of reclamation on the structure of silty-clay soils irrigated with saline-sodic waters. *International Agrophysics, 29*(1), 23-30.

De Freitas, S. T., Amarante, C. D., & Mitcham, E. (2016). C*alcium Deficiency Disorders in Plants. Postharvest ripening physiology of crops. CRC Press*. http://postharvest.ucdavis.edu/files/265201.pdf

Deng, N., Ling, X., Sun, Y., Zhang, C., Fahad, S., Peng, S., Cui, K., Nie, L., & Huang, J. (2015). Influence of temperature and solar radiation on grain yield and quality in irrigated rice system. *European Journal of Agronomy, 64,* 37-46.

Duku, C., Sparks, A. H., & Zwart, S. J. (2016). Spatial modelling of rice yield losses in Tanzania due to bacterial leaf blight and leaf blast in a changing climate. *Climatic Change*, *135*(3-4), 569-583.

Eduah, J. O., Breuning-Madsen, H., Abekoe, M., & Andersen, M. N. (2017). Phosphorus Fractionation and Sorption Characteristics of Biochar Amended Soils of Ghana. *In: Tropentag 2017. International Research of Food Security, Natural Resource Management and Rural Development, 2017,* 20-22

Elmoghazy, A. M., & Elshenawy, M. M. (2019). Sustainable Cultivation of Rice in Egypt. Sustainability of Agricultural Environment in Egypt: Part I: *Soil-Water-Food Nexus*: *77*, 119-144.

Emerson, R. W. (2015). Convenience sampling, random sampling, and snowball sampling: how does sampling affect the validity of research? *Journal of Visual Impairment and Blindness*, *109*(2), 164-168.

Fageria, N., Santos, A., Barbosa F. M., & Guimarães, C. (2008). Iron toxicity in lowland rice. *Journal of Plant Nutrition*, *31*(9), 1676-1697.

Fageria, N., Slaton, N., & Baligar, V. (2003). Nutrient management for improving lowland rice productivity and sustainability. *Advances in Agronomy*, *80*(1), 63-152.

Fageria, N. K. (2016). *The use of nutrients in crop plants*. CRC presspp. *https://www.routledge*.com/The-Use-of-Nutrients-in-Crop-Plants/Fageria/p/ book/9780367386887

Feller, C., & Müller, A. (2017). Characterization of macro and micro nutrient deficiency symptoms in asparagus (*Asparagus officinalis* L.). *In: XIV International Asparagus Symposium 1223, 87-94*

Ferreto, D. O. C., Rodrigues, J. D. P., Ibarr, M. A., de Oliveira, C. S., Vieira, R. C. B., Weber, M. A., & Vieira, F. C. B. (2016). Boron fertilization and liming for Eucalyptus urograndis cropped on sandy arenosol of Brazilian pampa. *Journal of Plant Nutrition, 39*(3), 399-409.

Fipps, G. (2003). *Irrigation water quality standards and salinity management strategies.* Texas FARMER Collection. https://oaktrust.library.tamu.edu/bitstream/handle/1969.1/87829/pdf_94.pdf?seq

Furuhashi, G., & Gay, H. (2017). *Market Implications of Integration of Asian Rice Markets*. http://dx.doi.org/10.1787/c81e00c6-en

Gale, H. F., Hansen, J., & Jewison, M. (2015). China's growing demand for agricultural imports. *USDA-ERS Economic Information Bulletin*. http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib136

George, D., Girirajdevi, L., & Raj, K. (2018). Magnesium sulphate fertilization for yield enhancement in direct seeded rice. *Journal of Crop and Weed*. *14*(2), 195-198.

Gohil, J. M., & Suresh, A. K. (2017). Chlorine attack on reverse osmosis membranes: Mechanisms and mitigation strategies. *Journal of Membrane Science*, *541*, 108-126.

Gowing, J., Bunclark, L., Mahoo, H., & Kahimba, F. (2018). *The 'Majaluba'Rice Production System: A Rainwater Harvesting 'Bright Spot'in Tanzania, Rainwater-Smart Agriculture in Arid and Semi-Arid Areas. Springer*. https://doi.org/10.1007/978-3-319-66239-8_16

Granatstein, D., & Bezdicek, D. F. (1992). The need for a soil quality index: local and regional perspectives. *American Journal of Alternative Agriculture*, *7*(1-2), 12-16. https://doi.org/10.1017/S0889189300004380

Greco, E. (2015). Landlords in the making: Class dynamics of the land grab in Mbarali, Tanzania. *Review of African Political Economy*, *42*(144), 225-244.

Haefele, S. M., Wopereis, M. C. S., Schloebohm, A. M., & Wiechmann, H. (2004). Long-term fertility experiments for irrigated rice in the West African Sahel: effect on soil characteristics. *Field Crops Research*, *85*(1), 61-77.

Hajiboland, R. (2018). *Nutrient Deficiency and Abundance in Tea Plants: Metabolism to Productivity, Stress Physiology of Tea in the Face of Climate Change. Springer*. https://doi.org/10.1007/978-981-13-2140-5_9

Hannam, K. N. D., Kehila, D., Millard, P., Midwood, A. J., Neilsen, D., Neilsen, G. H., Forge, T. A., Nichol, C., & Jones, M. N. D. (2016). Bicarbonates in irrigation water contribute to carbonate formation and CO2 production in orchard soils under drip irrigation. *Geoderma*, *266,* 120-126.

Hassan, P., Jusop, S., Ismail, R., Aris, A. Z., & Panhwar, Q. A. (2016). Soil and Water Quality of an Acid Sulfate Soil Area in Kelantan Plains, Malaysia and its Effect on the Growth of Rice. *Asian Journal of Agriculture and Food Sciences, 4*(03), 53-61

Hauser, B. (2018). *Drinking water chemistry: A laboratory manual. CRC Presspp*. https://books.google.com.bd/books?id=SVxcRu68YGwC&printsec=frontcover#v=onepage&q&f=false

He, X., Qiao, Y., Liang, L., Knudsen, M. T., & Martin, F. (2018). Environmental life cycle assessment of long-term organic rice production in subtropical China. *Journal of Cleaner Production*, 176, 880-888.

Heckman, J. R. (2016). *Chlorine, Handbook of plant nutrition.* CRC Press, https://doi.org/ 10.1201/9781420014877

Hie, L., Nathel, N. F. F., Shah, T. K., Baker, E. L., Hong, X., Yang, Y. F., Liu, P., Houk, K., & Garg, N. K. (2015). Conversion of amides to esters by the nickel-catalysed activation of amide C–N bonds. *Nature*, *524*(7563),79-83.

Hopkins, B. G., Horneck, D. A., Stevens, R. G., Ellsworth, J. W., & Sullivan, D. M. (2007). Managing irrigation water quality for crop production in the Pacific Northwest, Pacific Northwest Extension. *Oregon State University, 17*(2), 13-18

Hopkins, E. A. (2007). Managing Irrigation Water Quality. *Journal of Water and Environment, 12(4), 28 -33*

Horneck, E. A. (2007). Managing Salt-affected Soils for Crop Production. *Journal of Irrigation science, 12*(6), 12 - 17

Hu, L., Zhang, J., Ren, W., Guo, L., Cheng, Y., Li, J., Li, K., Zhu, Z., Zhang, J., & Luo, S. (2016). Can the co-cultivation of rice and fish help sustain rice production? *Scientific Reports, 6,* 28728.

Hutchinson, J. T. (2017). Propagation and production of an endangered aquatic macrophyte: Texas wildrice (*Zizania texana* Hitchc.). *Native Plants Journal*, 18(1), 77-85.

Iali, W., Rayner, P. J., & Duckett, S. B. (2018). Using parahydrogen to hyperpolarize amines, amides, carboxylic acids, alcohols, phosphates, and carbonates. *Science Advances*, *4*(1), 57 - 65

Islam, S. M., Gaihre, Y. K., Shah, A., Singh, U., Sarkar, M. I. U., Satter, M. A., Sanabria, J., & Biswas, J. C. (2016). Rice yields and nitrogen use efficiency with different fertilizers and water management under intensive lowland rice cropping systems in Bangladesh. *Nutrient Cycling in Agroecosystems*, *106*(2), 143-156.

January, B., Rwegasira, G. M., & Tefera, T. (2018). Farmers' Perceptions of Rice Production Constraints and Stem Borers Management Practices in Tanzania. *Journal of Agricultural Science*, *10*(6), 6-15

Jeong, H., Kim, H., & Jang, T. (2016). Irrigation water quality standards for indirect wastewater reuse in agriculture: A contribution toward sustainable wastewater reuse in South Korea. *Water*, *8*(4), 1-18.

Jha, Y. (2017). Potassium mobilizing bacteria: Enhance potassium intake in paddy to regulates membrane permeability and accumulate carbohydrates under salinity stress. *Brazilian Journal of Biological Sciences*, *4*(8), 333-344.

Jia, H., Zhang, S., Wang, L., Yang, Y., Zhang, H., Cui, H., Shao, H., & Xu, G. (2017). OsPht1; 8, a phosphate transporter, is involved in auxin and phosphate starvation response in rice. *Journal of Experimental Botany*, *68*(18), 5057-5068.

Jones Jr, J. B. (2001). *Laboratory guide for conducting soil tests and plant analysis*. *CRC press.* F*lorida, USApp.* https://www.turfdietitian.com/?gclid=CjwKCAjwgb6IBhAREiwAgMYKRqBqVZJYddD0YIlUff1jjOvxYxXFMul-5SVtAngj_3VVXHuAQCykaBoCCW4QAvD_BwE

Ju, X. T., Xing, G. X., Chen, X. P., Zhang, S. L., Zhang, L. J., Liu, X. J., Cui, Z. L., Yin, B., Christie, P., & Zhu, Z. L. (2009). Reducing environmental risk by improving N management in intensive Chinese agricultural systems. *Proceedings of the National Academy of Sciences*, *106*(9), 3041-3046.

Ju, X., Gu, B., Wu, Y., & Galloway, J. N. (2016). Reducing China's fertilizer use by increasing farm size. *Global Environmental Change*, *41*, 26-32.

Jury, W. A., & Stolzy, L. H. (2018). S*oil physics*, *Handbook of Soils and Climate in Agriculture. CRC Press.* https://www.taylorfrancis.com/chapters/edit/10.1201/9781351073073-3/soil-physics-lewis-stolzy-william-jury

Kabala, C., & Singh, B. R. (2001). Fractionation and mobility of copper, lead, and zinc in soil profiles in the vicinity of a copper smelter. *Journal of Environmental Quality*, *30*(2), 485-492.

Kadigi, R. M., Kashaigili, J. J., & Mdoe, N. S. (2004). The economics of irrigated paddy in Usangu Basin in Tanzania: Water utilization, productivity, income and livelihood implications. *Physics and Chemistry of the Earth, Parts A/B/C*, *29*(15-18), 1091-1100.

Kangile, R. J., Gebeyehu, S., & Mollel, H. (2018). Improved rice seed use and drivers of source choice for rice farmers in Tanzania. *Journal of Crop Improvement*, *32*(5), 622-634.

Karak, T., Kutu, F. R., Nath, J. R., Sonar, I., Paul, R. K., Boruah, R. K., Sanyal, S., Sabhapondit, S., & Dutta, A. K. (2017). Micronutrients (B, Co, Cu, Fe, Mn, Mo, and Zn) content in made tea (*Camellia sinensis* L.) and tea infusion with health prospect: A critical review. *Critical Reviews in Food Science and Nutrition*, *57*(14), 2996-3034.

Kawaguchi, K., & Kyuma, K. (1975). *Paddy Soils in Tropical Asia: Part 5. Soil Fertility Evaluation. Kyoto University.* https://doi.org/10.20495/tak.13.3_385

Khadtare, S., Shinde, S., Akashe, V., Indi, D., & Toradmal, V. (2017). Effect of magnesium sulphate on yield, economics and growth attributes of rainfed safflower (Carthamus tinctorious) in scarcity zone of Maharashtra. *Indian Journal of Agricultural Research*, *51*(6), 591 - 595

Khaleghian, H., Karimi, K., & Behzad, T. (2015). Ethanol production from rice straw by sodium carbonate pretreatment and Mucor hiemalis fermentation. *Industrial Crops and Products*, *76*, 1079-1085.

Khan, M., Ahmad, R., Khan, M. D., Rizwan, M., Ali, S., Khan, M. J., Azam, M., Irum, G., Ahmad, M. N., & Zhu, S. (2018). *Trace Elements in Abiotic Stress Tolerance, Plant Nutrients and Abiotic Stress Tolerance. Springer.* http://dx.doi.org/10.1007/978-981-10-9044-8_5

Khan, M. M. A., Haque, E., Paul, N. C., Khaleque, M. A., Al-Garni, S. M. S., Rahman, M., & Islam, M. T. (2017). Enhancement of Growth and Grain Yield of Rice in Nutrient Deficient Soils by Rice Probiotic Bacteria. *Rice Science*, *24*(5), 264-273.

Khan, R., Gurmani, A. R., Gurmani, A. H., & Zia, M. S. (2007). Effect of potassium application on crop yields under wheat rice system. *Sarhad Journal of Agriculture, 23*(2), 1-5.

Khanghahi, M. Y., Pirdashti, H., Rahimian, H., Nematzadeh, G., & Sepanlou, M. G. (2018). Potassium solubilising bacteria (KSB) isolated from rice paddy soil from isolation, identification to K use efficiency. *Symbiosis*, *76*(1), 13-23.

Killenga, E. A. (2010). B*reeding investigations for salt tolerance in rice incorporating characterisation of salt affected soils and farmers perceptions and prefferences for tolerant cultivars in north-eastern Tanzania*, [Doctoral dissertation, University of KwaZulu-Natal], Pietermaritzburg, Republic of South Africa. https://ukzn-dspace .ukzn.ac.za/bitstream/handle /10413/7990/Kashenge-Killenga_Sophia_2010. PDF? sequence=1&isAllowed=y

Kim, W. H., Lee, J. K., Lim, Y. C., Shine, J. S., Jung, M. W., Ji, H. C., Seo, S., Lee, H. W., & Yoon, B. K. (2009). Selection of Promising Forage Pea Cultivars on Paddy Field. *Journal of The Korean Society of Grassland and Forage Science*, *29*(1), 7-12.

Kiunsi, R. B. (2006). The extent and effects of salinity and alkalinity in community base irrigation schemes in the dryland areas of Tanzania. Case study: Chali and Bahi irrigation schemes in Dodoma region. *Journal of Building and Land Development*, *13*(2), 41-48.

Kokkinos, P., Kozyra, I., Lazic, S., Söderberg, K., Vasickova, P., Bouwknegt, M., Rutjes, S., Willems, K., Moloney, R., & De-Roda, H. A. (2017). Virological quality of irrigation water in leafy green vegetables and berry fruits production chains. *Food and Environmental Virology*, *9*(1), 72-78.

Kolleh, D. S., Sibuga, K. P., & King, C. F. (2017). Upland rice growth and yield response to weed management practices under rainfed conditions in Morogoro, Tanzania. *African Journal of Agricultural Research*, *12*(10), 829-840.

Krishnamurthy, S., Gautam, R., Sharma, P., & Sharma, D. (2016). Effect of different salt stresses on agro-morphological traits and utilisation of salt stress indices for reproductive stage salt tolerance in rice. *Field Crops Research*, *190*, 26-33.

Küçükakyüz, K., Yıldıztekin, M., Civelek, H. S., Nadeem, S., & Tuna, A. L. (2018). Antioxidative Defence Mechanisms in Tomato (*Lycopersicum esculentum* L.) Plants Sprayed with Different Pesticides and Boron compounds. *International Journal of Secondary Metabolite*, *5*(3), 200-209.

Kumar, R., Chatterjee, D., Kumawat, N., Pandey, A., Roy, A., & Kumar, M. (2014). Productivity, quality and soil health as influenced by lime in ricebean cultivars in foothills of northeastern India. *The Crop Journal*, *2*(5), 338-344.

Kumar, S., Kour, S., Gupta, M., Kachroo, D., & Singh, H. (2017). Influence of rice varieties and fertility levels on performance of rice and soil nutrient status under aerobic conditions. *Journal of Applied and Natural Science*, *9*(2), 1164-1169.

Latte, M., & Shidnal, S. (2016). Multiple nutrient deficiency detection in paddy leaf images using color and pattern analysis. *In: 2016 International Conference on Communication and Signal Processing*. https://doi.org/10.1109/ ICCSP. 2016.7754352

Latte, M., Shidnal, S., & Anami, B. (2017). Rule Based Approach to Determine Nutrient Deficiency in Paddy Leaf Images. *International Journal of Agricultural Technology*, *13*(2), 227-245.

Lazaro, E., Sam, A. G., & Thompson, S. R. (2017). Rice demand in Tanzania: an empirical analysis. *Agricultural Economics*, *48*(2), 187-196.

Lee, J. S., Wissuwa, M., Zamora, O. B., & Ismail, A. M. (2018). Novel Sources of aus Rice for Zinc Deficiency Tolerance Identified Through Association Analysis Using High-Density SNP Array. *Rice Science*, *25*(5), 293-296.

Lee, S. B., Lee, C. H., Jung, K. Y., Do-Park, K., Lee, D., & Kim, P. J. (2009). Changes of soil organic carbon and its fractions in relation to soil physical properties in a long-term fertilized paddy. *Soil and Tillage Research*, *104*(2), 227-232.

Li, D., Nanseki, T., Matsue, Y., Chomei, Y., & Yokota, S. (2016). Determinants of paddy yield of individual fields measured by it combine: Empirical analysis from the perspective of large-scale farm management in Japan. *Agricultural Information Research*, *25*(1), 39-46.

Li, W., & Johnson, C. E. (2016). Relationships among pH, aluminum solubility and aluminum complexation with organic matter in acid forest soils of the Northeastern United States. *Geoderma*, *271*, 234-242.

Li, X., Wellen, C., Liu, G., Wang, Y., & Wang, Z. L. (2015). Estimation of nutrient sources and transport using Spatially Referenced Regressions on Watershed Attributes: A case study in Songhuajiang River Basin, China. *Environmental Science and Pollution Research*, *22*(9), 6989-7001.

Li, X., Zhang, Y., Wang, W., Khan, M. R., Cong, R., & Lu, J. (2018). Establishing grading indices of available soil potassium on paddy soils in Hubei province, China. *Scientific Reports*, *8*(1), 1-8.

Liao, H., Shelor, C. P., & Dasgupta, P. K. (2016). Water ICE: Ion exclusion chromatography of very weak acids with a pure water eluent.*Analytical Chemistry*, *88*(9), 4965-4970.

Linquist, B. A., Anders, M. M., Adviento-Borbe, M. A. A., Chaney, R. L., Nalley, L. L., Da Rosa, E. F., & Van-Kessel, C. (2015). Reducing greenhouse gas emissions, water use, and grain arsenic levels in rice systems. *Global Change Biology*, *21*(1), 407-417.

Liu, J., Liu, H., Liu, R., Amin, M. M., Zhai, L., Lu, H., Wang, H., Zhang, X., Zhang, Y., & Zhao, Y. (2018). *Water Quality in Irrigated Paddy Systems, Irrigation in Agroecosystems.* IntechOpen. https://dx.doi.org/10.5772/intechopen.77339

Liu, X., Tao, Y., Wen, G., Kong, F., Zhang, X., & Hu, Z. (2016a). Influence of soil and irrigation water ph on the availability of phosphorus in struvite derived from urine through a greenhouse pot experiment. *Journal of Agricultural and Food Chemistry*, *64*(17), 3324-3329.

Liu, Y., Lu, H., Yang, S., & Wang, Y. (2016b). Impacts of biochar addition on rice yield and soil properties in a cold waterlogged paddy for two crop seasons. *Field Crops Research*, *191*, 161-167.

López-Millán, A. F., Duy, D., & Philippar, K. (2016). Chloroplast iron transport proteins–function and impact on plant physiology. *Frontiers in Plant Science*, 7, 1-12. https://doi.org/10.3389/fpls.2016.00178

Magalon, A., & Mendel, R. (2015). Biosynthesis and Insertion of the Molybdenum Cofactor. *EcoSal Plus*, *6*(2), 28-37

Mahender, A., Swamy, B., Anandan, A., & Ali, J. (2019). Tolerance of iron-deficient and-toxic soil conditions in rice. *Plants*, *8*(2), 31-33

Marchal, C., & Miotto, B. (2015). Emerging concept in DNA methylation: role of transcription factors in shaping DNA methylation patterns. *Journal of Cellular Physiology*, *230*(4), 743-751.

Mascie-Taylor, C. (1992). Endemic disease, nutrition and fertility in developing countries. *Journal of Biosocial Science*, *24*(3), 355-365.

Massay, G. E., & Kassile, T. (2019). *Land-based investments in Tanzania: Legal framework and realities on the ground. In Reclaiming Africa. Springer, Singapore.* https://doi.org/10.1007/978-981-10-5840-0_8

Matata, A. C., & Adan, A. (2018). *Causes of climate change and its impact in the multi sectoral areas in Africa-Need for enhenced adaptation policies.* https://repo.umma.ac.ke/handle/123456789/31

McFarlane, D., George, R., Barrett-Lennard, E., & Gilfedder, M. (2016). Salinity in dryland agricultural systems: *Challenges and opportunities, Innovations in Dryland Agriculture. Springer.* https://doi.org/10.1007/978-3-319-47928-6_19

Mdemu, M. V., Mziray, N., Bjornlund, H., & Kashaigili, J. J. (2017). Barriers to and opportunities for improving productivity and profitability of the Kiwere and Magozi irrigation schemes in Tanzania. *International Journal of Water Resources Development*, *33*(5), 725-739.

Mehra, P., Pandey, B. K., & Giri, J. (2017). Improvement in phosphate acquisition and utilization by a secretory purple acid phosphatase (OsPAP21b) in rice. *Plant Biotechnology Journal*, *15*(8), 1054-1067.

Meng, Q., Ma, X., Zhang, J., & Yu, Z. (2019). The long-term effects of cattle manure application to agricultural soils as a natural-based solution to combat salinization. *Catena*, *175*, 193-202.

Miller, J. O. (2016). *Soil PH and Nutrient Availability*. http://hdl.handle.net/1903/18519

Misstear, B., Banks, D., & Clark, L. (2006). Appendix 3 FAO irrigation water quality guidelines. *Water Wells and Boreholes*, *6*(12), 469-470.

Mkonda, M. Y., & He, X. (2016). *Production trends of food crops, opportunities, challenges and prospects to improve Tanzanian rural livelihoods. http://www.suaire.sua.ac.tz /handle/123456789/2831*

Mohammadi, B. (2019). Letter to the editor “Estimation of sodium adsorption ratio indicator using data mining methods: A case study in Urmia Lake basin, Iran” by Mohammad Taghi Sattari, Arya Farkhondeh, and John Patrick Abraham. *Environmental Science and Pollution Research*, *26*(10), 10,439 - 10,440

Montelius, M., Svensson, T., Lourino-Cabana, B., Thiry, Y., & Bastviken, D. (2016). Chlorination and dechlorination rates in a forest soil—a combined modelling and experimental approach. *Science of the Total Environment*, *554*, 203-210.

Mook, N. I. A. L. S. (2010). *Factors affecting paddy productivity under integrated agriculture development area of North Terengganu (IADA KETARA): A case study.* http://www.iipm.com.my/ipicex2014/docs/posters/Nordiana%20and%20 Low.pdf

Moran, S., Charette, M., Pike, S., & Wicklund, C. (1999). Differences in seawater particulate organic carbon concentration in samples collected using small-and large-volume methods: The importance of DOC adsorption to the filter blank. *Marine Chemistry*, *67*(1-2), 33-42.

Mosha, D. B., Vedeld, P., Katani, J. Z., Kajembe, G. C., & Tarimo, A. (2018a). C*ontribution of Paddy Production to Household Income in Farmer-Managed Irrigation Scheme Communities in Iringa Rural and Kilombero Districts, Tanzania*. http://suaire.sua.ac.tz/handle/123456789/2528

Mosha, D. B., Vedeld, P., Katani, J. Z., Kajembe, G. C., & Tarimo, A. K. (2018b). *Contribution of Paddy Production to Household Income in Farmer-Managed Irrigation Scheme Communities in Iringa Rural and Kilombero Districts, Tanzania*. http://suaire.sua.ac.tz/handle/123456789/2528

Mottaleb, K. A., & Mohanty, S. (2015). Farm size and profitability of rice farming under rising input costs. *Journal of Land Use Science*, *10*(3), 243-255.

Mun, S. C., Park, J. J., Park, Y. T., Kim, D. Y., Lee, S. W., Cobos, M., Ye, S. J., Macosko, C. W., & Park, O. O. (2017). High electrical conductivity and oxygen barrier property of polymer-stabilized graphene thin films. *Carbon*, *125*, 492-499.

Myrach, T., Zhu, A., & Witte, C. P. (2017). The assembly of the plant urease activation complex and the essential role of the urease accessory protein G (UreG) in delivery of nickel to urease. *Journal of Biological Chemistry*, *292*(35), 14556-14565.

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.

Nand, V., & Ellwood, M. J. (2018). A simple colorimetric method for determining seawater alkalinity using bromophenol blue. *Limnology and Oceanography: Methods*, *16*(7), 401-410.

Narmadha, R., & Arulvadivu, G. (2017). *Detection and measurement of paddy leaf disease symptoms using image processing. In 2017 International Conference on Computer Communication and Informatics. http://dx.doi.org/10.1109/ICCCI.2017. 8117730*

Nijbroek, R. P., & Andelman, S. J. (2016). Regional suitability for agricultural intensification: A spatial analysis of the Southern Agricultural Growth Corridor of Tanzania. *International Journal of Agricultural Sustainability*, *14*(2), 231-247.

Nkuba, J., Ndunguru, A., Madulu, R., Lwezaura, D., Kajiru, G., Babu, A., Chalamila, B. and Ley, G. (2016). Rice value chain analysis in Tanzania: Identification of constraints, opportunities and upgrading strategies. *African Crop Science Journal*, *24*(1), 73-87.

Oestigaard, T. (2016). *13 Rainfed Agriculture, Drought and Hunger in Tanzania*. http://www.suaire.sua.ac.tz/handle/123456789/2124

Olmo, M., Villar, R., Salazar, P., & Alburquerque, J. A. (2016). Changes in soil nutrient availability explain biochar's impact on wheat root development. *Plant and Soil*, *399*(1-2), 333-343.

Osabuohien, E. S., Efobi, U. R., Herrmann, R. T., & Gitau, C. M. (2019). Female labor outcomes and large-scale agricultural land investments: Macro-micro evidencefrom Tanzania. *Land Use Policy*, *82*, 716-728.

Oster, J., Sposito, G., & Smith, C. (2016). Accounting for potassium and magnesium in irrigation water quality assessment. *California Agriculture*, *70*(2), 71-76.

Park, H., Jeong, Y., Jun, Y., Jeong, J. H., & Oh, J. E. (2016). Strength enhancement and pore-size refinement in clinker-free CaO-activated GGBFS systems through substitution with gypsum. *Cement and Concrete Composites*, *68*, 57-65.

Pede, V. O., McKinley, J., Singbo, A., & Kajisa, K. (2015). *Spatial dependency of technical efficiency in rice farming: The case of Bohol, Philippines*. http://dx.doi.org/10.22004/ag.econ.205456

Philpott, C. C., Ryu, M. S., Frey, A., & Patel, S. (2017). Cytosolic iron chaperones: proteins delivering iron cofactors in the cytosol of mammalian cells. *Journal of Biological Chemistry, 292*(31), 12764-12771.

Pillai, I. M. S., & Gupta, A. K. (2016). Effect of inorganic anions and oxidizing agents on electrochemical oxidation of methyl orange, malachite green and 2, 4-dinitrophenol. *Journal of Electroanalytical Chemistry, 762,* 66-72.

Pode, R. (2016). Potential applications of rice husk ash waste from rice husk biomass power plant. *Renewable and Sustainable Energy Reviews, 53,* 1468-1485.

Pretty, J., & Bharucha, Z. P. (2018). *Sustainable Intensification of Agriculture: Greening the World's Food Economy.* Routledgepp. https://doi.org/10.4324/9781138638044

Qadir, A., Malik, R. N., & Husain, S. Z. (2008). Spatio-temporal variations in water quality of Nullah Aik-tributary of the river Chenab, Pakistan. *Environmental Monitoring and Assessment*, *140*(1-3), 43-59.

Qadir, M., Schubert, S., Oster, J. D., Sposito, G., Minhas, P. S., Cheraghi, S. A., Murtaza, G., Mirzabaev, A., & Saqib, M. (2018). High-magnesium waters and soils: Emerging environmental and food security constraints. *Science of the Total Environment*, *140* (1), 43-59.

Qaswar, M., Ahmed, W., Jing, H., Hongzhu, F., Xiaojun, S., Xianjun, J., Kailou, L., Yongmei, X., Zhongqun, H., & Asghar, W. (2019). Soil carbon (C), nitrogen (N) and phosphorus (P) stoichiometry drives phosphorus lability in paddy soil under long-term fertilization: A fractionation and path analysis study. *PloS One*, *14*(6), 1-20. https://doi.org/10.1371/journal.pone.0218195

Ramesh, T., Bolan, N. S., Kirkham, M. B., Wijesekara, H., Freeman II, O. W., Korres, N. E., Burgos, N. R., Travlos, I., Vurro, M., & Salas-Perez, R. (2019). Soil organic carbon dynamics: Impact of land use changes and management practices: A review. *Advances in Agronomy*, *156*, 1-107.

Rao, G. B., Pi, P. Y., & Syriac, E. K. (2017a). Silicon nutrition in rice: A review. *Journal of Pharmacognosy and Phytochemistry*, *6*(6), 390-392.

Rao, P. L., Jayasree, G., & Prakash, T. R. (2017). Effect of soil amendments on texture, porosity of soil and chlorophyll content in maize. *Journal of Pharmacognosy and Phytochemistry*, *6*(3), 435-437.

Ravikumar, P., Somashekar, R., & Prakash, K. (2015). A comparative study on usage of Durov and Piper diagrams to interpret hydrochemical processes in groundwater from SRLIS river basin, Karnataka, India. *Elixir International Journal*, *80*, 31073-31077.

Rehman, M. Z. U., Rizwan, M., Ali, S., Fatima, N., Yousaf, B., Naeem, A., Sabir, M., Ahmad, H. R., & Ok, Y. S. (2016). Contrasting effects of biochar, compost and farm manure on alleviation of nickel toxicity in maize (*Zea mays* L.) in relation to plant growth, photosynthesis and metal uptake. *Ecotoxicology and Environmental Safety*, *133,* 218-225.

Rhoades, J. D. (1996). Salinity: Electrical conductivity and total dissolved solids. *Methods of Soil Analysis: Part 3 Chemical Methods*, *5*, 417-435.

Rizvi, N., Katyal, D., & Joshi, V. (2015). Assessment of water quality of Hindon River in Ghaziabad and Noida, India by using multivariate statistical methods. *Journal of Global Ecology and Environment*, *3*(2), 80-90.

Rose, B. (2016). *Appendix to the rice economy of Asia*. Routledgepp. https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Rose%2C+B.+%282016%29.+Appendix+to+the+rice+economy+of+Asia.+Routledgepp+.ISBN+1315661225&btnG=#:~:text=Rose%2C%20B.%20(2016).-,Appendix%20to%20The%20rice%20economy%20of%20Asia.%20Routledge.,-Chicago

Rosegrant, M. W., Tokgoz, S., & Bhandary, P. (2012). The new normal? A tighter global agricultural supply and demand relation and its implications for food security. *American Journal of Agricultural Economics*, *95*(2), 303-309.

Rout, G. R., & Sahoo, S. (2015). Role of iron in plant growth and metabolism. *Reviews in Agricultural Science*, *3*, 1-24.

Saeed, K. A., & Kadhum, A. Y. (2016). The Strength Behaviour of Lime Stabilized Organic Clay Soil Modified by Catalyst Additeives. *Journal of University of Babylon*, *24*(4), 1040-1072.

Sağlam, A., Yetişsin, F., Demiralay, M., & Terzi, R. (2016). *Copper stress and responses in plants. In plant metal interaction, Elsevier.* https://doi.org/10.1016/B978-0-12-803158-2.00002-3

Sahrawat, K., Jones, M., & Diatta, S. (2000). The role of tolerant genotypes and plant nutrients in the management of acid soil infertility in upland rice. International Nuclear Information System (INIS). Switzerland. *The Journal of Agricultural Science, 126* (2), 143-149.

Saidia, P. S., & Mrema, J. (2017). Effects of farmyard manure and activated effective microorganisms on rain-fed upland rice in Mwanza, Tanzania. *Organic Agriculture, 7*(2), 83-93.

Salmon, J. M., Friedl, M. A., Frolking, S., Wisser, D., & Douglas, E. M. (2015). Global rain-fed, irrigated, and paddy croplands: A new high resolution map derived from remote sensing, crop inventories and climate data. *International Journal of Applied Earth Observation and Geoinformation*, *38,* 321-334.

Samson, S., Mdegela, R. H., Permin, A., Mahonge, C. P., & Mlangwa, J. E. (2018). Incentives for low-quality water irrigation of food crops in Morogoro, Tanzania. *Environment, Development and Sustainability, 20*(1), 479-494.

Samson, S., Mdegela, R. H., Permin, A., Mlangwa, J., & Mahonge, C. P. (2017). *Obstacles to low quality water irrigation of food crops in Morogoro, Tanzania.* http://suaire.suanet.ac.tz/bitstream/handle/123456789/2124/Suzana%20Samson.pdf?sequence=1&isAllowed=y

Santos, E. F., Santini, J. M. K., Paixão, A. P., Júnior, E. F., Lavres, J., Campos, M., & Dos-Reis, A. R. (2017). Physiological highlights of manganese toxicity symptoms in soybean plants: Mn toxicity responses. *Plant Physiology and Biochemistry*, *113*, 6-19.

Sathapatyanon, J., Kuwornu, J. K., Shivakoti, G. P., Soni, P., Anal, A. K., & Datta, A. (2018). The role of farmer organizations and networks in the rice supply chain in Thailand. *Journal of Agribusiness in Developing and Emerging Economies*, *8*(3), 554-578.

Sattari, M., Pal, M., Mirabbasi, R., & Abraham, J. (2018). Ensemble of M5 model tree based modelling of sodium adsorption ratio. *Journal of AI and Data Mining, 6*(1), 69-78.

Scherer, E. A. (2013). S*oil, Water and Plant Characteristics Important toIrrigation*. *Fargo.* https://www.ag.ndsu.edu/publications/crops/soil-water-and-plant-characteristics-important-to-irrigation

Seck, P. A., Diagne, A., Mohanty, S., & Wopereis, M. C. (2012). Crops that feed the world 7: Rice. *Food Security, 4*(1), 7-24.

Sekhon, G. (1999). Potassium in Indian soils and crops. *Proceedings of Indian National Science Academy B*, 65, 83-108.

Selvaraj, M. G., Ishizaki, T., Valencia, M., Ogawa, S., Dedicova, B., Ogata, T., Yoshiwara, K., Maruyama, K., Kusano, M., & Saito, K. (2017). Overexpression of an Arabidopsis thaliana galactinol synthase gene improves drought tolerance in transgenic rice and increased grain yield in the field. *Plant Biotechnology Journal*, *15*(11), 1465-1477.

Senbayram, M., Gransee, A., Wahle, V., & Thiel, H. (2016). Role of magnesium fertilisers in agriculture: plant–soil continuum. *Crop and Pasture Science*, *66*(12), 1219-1229.

Shah, A., Wu, X., Ullah, A., Fahad, S., Muhammad, R., Yan, L., & Jiang, C. (2017). Deficiency and toxicity of boron: Alterations in growth, oxidative damage and uptake by citrange orange plants. *Ecotoxicology and Environmental Safety*, *145*, 575-582.

Shaikh, A. A. G., & Sivaram, S. (1996). Organic carbonates. *Chemical Reviews*, *96*(3), 951-976.

Shao, G., Cui, J., Lu, B., Brian, B. J., Ding, J., & She, D. (2015). Impacts of controlled irrigation and drainage on the yield and physiological attributes of rice. *Agricultural Water Management*, *149*, 156-165.

Shen, C., Yue, R., Sun, T., Zhang, L., Yang, Y., & Wang, H. (2015). OsARF16, a transcription factor regulating auxin redistribution, is required for iron deficiency response in rice (*Oryza sativa* L.). *Plant Science*, *231*, 148-158.

Shi, L. L., Mx. S., Lu, C. Y., Wang., H. H., Zhou., X. W., Jin, M. J., & Wu, T. D. (2015). Soil phosphorus dynamic, balance and critical P values in long-term fertilization experiment in Taihu Lake region, China. *Journal of Integrative Agriculture*, *14*(12), 2446 - 2455.

Shiba, T., Hirae, M., Hayano-Saito, Y., Ohto, Y., Uematsu, H., Sugiyama, A., & Okuda, M. (2018). Spread and yield loss mechanisms of rice stripe disease in rice paddies. *Field Crops Research*, *217*, 211-217.

Shiva, V. (2016). T*he violence of the green revolution: Third world agriculture, ecology, and politics. University Press of Kentuckypp.* https://www.amazon.com/Violence-Green-Revolution-Agriculture-Politics/dp/0862329655

Singh, K. (2016). Microbial and enzyme activities of saline and sodic soils. *Land Degradation and Development*, *27*(3), 706-718.

Singh, K., Mishra, A. K., Singh, B., Singh, R. P., & Patra, D. D. (2016). Tillage effects on crop yield and physicochemical properties of sodic soils. *Land Degradation and Development*, *27*(2), 223-230.

Singh, M. V. (2008). Micronutrient deficiencies in crops and soils in India. In: Alloway, B. J. (Ed.). *Micronutrient deficiencies in global crop production. Springer International Publishing AG, Switzerland.* https://doi.org/10.1007/978-1-4020-6860-7_4

Sinisi, V., Pelagatti, P., Carcelli, M., Migliori, A., Mantovani, L., Righi, L., Leonardi, G., Pietarinen, S., Hubsch, C., & Rogolino, D. (2018). A Green Approach to Copper-Containing Pesticides: Antimicrobial and Antifungal Activity of Brochantite Supported on Lignin for the Development of Biobased Plant Protection Products. *Sustainable Chemistry and Engineering*, *3*(7), 3213 - 3221.

Slaton, N. A., Golden, B. R., Norman, R. J., Wilson, C. E., & DeLong, R. E. (2009). Correlation and calibration of soil potassium availability with rice yield and nutritional status. *Soil Science Society of America Journal*, *73*(4), 1192-1201.

Summers, J. (2016). Boron application in olive trees. *Australian and New Zealand Olivegrower and Processor: National Journal of the Olive Industry, 100,* 30-31.

Syers, J., Johnston, A., & Curtin, D. (2008). *Efficiency of soil and fertilizer phosphorus use. FAO Fertilizer and Plant Nutrition Bulletin.* https://agris.fao.org/agris-search/search.do?recordID=XF2009437445

Syu, C. H., Huang, C. C., Jiang, P. Y., Chien, P. H., Wang, H. Y., Su, J. Y., & Lee, D. Y. (2016). Effects of foliar and soil application of sodium silicate on arsenic toxicity and accumulation in rice (*Oryza sativa* L.) seedlings grown in As-contaminated paddy soils. *Soil Science and Plant Nutrition*, *62*(4), 357-366.

Taş, İ., Kirnak, H., Karaman, S., & Gökalp, Z. (2016). Effects of irrigation water quality (different salinity levels and boron concentrations) on morphological characteristics of grafted and non-grafted eggplants. *Current Trends in Natural Sciences*, *5*(9), 179-186.

Tejada-Jiménez, M., Gil-Díez, P., León-Mediavilla, J., Wen, J., Mysore, K. S., Imperial, J., & González-Guerrero, M. (2017). Medicago truncatula Molybdate Transporter type 1 (MtMOT1. 3) is a plasma membrane molybdenum transporter required for nitrogenase activity in root nodules under molybdenum deficiency. *New Phytologist*, *216*(4), 1223-1235.

Thitisaksakul, M., Tananuwong, K., Shoemaker, C. F., Chun, A., Tanadul, O. U. M., Labavitch, J. M., & Beckles, D. M. (2015). Effects of timing and severity of salinity stress on rice (*Oryza sativa* L.) yield, grain composition, and starch functionality. *Journal of Agricultural and Food Chemistry*, *63*(8), 2296-2304.

Thoday-Kennedy, E. L., Jacobs, A. K., & Roy, S. J. (2015). The role of the CBL–CIPK calcium signalling network in regulating ion transport in response to abiotic stress. *Plant Growth Regulation*, *76*(1), 3-12.

Thomas, G., Andresen, E., Mattusch, J., Hubáček, T., & Küpper, H. (2016). Deficiency and toxicity of nanomolar copper in low irradiance—A physiological and metalloproteomic study in the aquatic plant Ceratophyllum demersum. *Aquatic Toxicology*, *177*, 226-236.

Tippe, D. E., Rodenburg, J., Schut, M., Van-Ast, A., Kayeke, J., & Bastiaans, L. (2017). Farmers' knowledge, use and preferences of parasitic weed management strategies in rain-fed rice production systems. *Crop Protection*, *99*, 93-107.

Tong, C., Xiao, H., Tang, G., Wang, H., Huang, T., Xia, H., Keith, S. J., Li, Y., Liu, S., & Wu, J. (2009). Long-term fertilizer effects on organic carbon and total nitrogen and coupling relationships of C and N in paddy soils in subtropical China. *Soil and Tillage Research*, *106*(1), 8-14.

Touch, S., Pipatpongsa, T., Takeda, T., & Takemura, J. (2015). The relationships between electrical conductivity of soil and reflectance of canopy, grain, and leaf of rice in northeastern Thailand. *International Journal of Remote Sensing*, *36*(4), 1136-1166.

Tyrrel, S., Knox, J., & Weatherhead, E. (2006). Microbiological water quality requirements for salad irrigation in the United Kingdom. *Journal of Food Protection*, *69*(8), 2029-2035.

Ugalahi, U. B., Adeoye, S. O., & Agbonlahor, M. U. (2016). Irrigation Potentials and rice self-sufficiency in Nigeria: A review. *African Journal of Agricultural Research*, *11*(5), 298-309.

Van, V. T., Berge, O., Ke, S. N., Balandreau, J., & Heulin, T. (2000). Repeated beneficial effects of rice inoculation with a strain of Burkholderia vietnamiensison early and late yield components in low fertility sulphate acid soils of Vietnam. *Plant and Soil*, *218*(1-2), 273-284.

Walker, G. M., & White, N. A. (2017). *Introduction to fungal physiology. Fungi: Biology and Applications*. https://www.sciencedirect.com/science/article/pii/B9780128031582000023

Wang, X., Yan, W., An, Z., Lu, Q., Shi, W., Cao, Z., & Wong, M. (2003). Status of trace elements in paddy soil and sediment in Taihu Lake region. *Chemosphere*, *50*(6), 707-710.

Wang, Z., Hong, X., Hu, K., Wang, Y., Wang, X., Du, S., Li, Y., Hu, D., Cheng, K., & An, B. (2017). Impaired Magnesium Protoporphyrin IX Methyltransferase (ChlM) Impedes Chlorophyll Synthesis and Plant Growth in Rice. *Frontiers in Plant Science*, *8*, 1-18. https://doi.org/10.3389/fpls.2017.01694

Watto, M. A., & Mugera, A. W. (2014). Measuring Production and Irrigation Efficiencies of Rice Farms: Evidence from the P unjab Province, Pakistan. *Asian Economic Journal*, *28*(3), 301-322.

Weber, K., & Burow, M. (2018). Nitrogen–essential macronutrient and signal controlling flowering time. *Physiologia Plantarum*, *162*(2), 251-260.

White, P. J., & Brown, P. H. (2010). Plant nutrition for sustainable development and global health. *Annals of Botany, 105*(7), 1073-1080.

Wilson, R. T., & Lewis, I. (2015). *The rice value chain in Tanzania. A Report from the Southern Highlands Food Systems Programme, FAO*. http://www.ipcinfo.org/ fileadmin/user_upload/ivc/PDF/SFVC/Tanzania_rice.pdf

Xia, H., Luo, Z., Xiong, J., Ma, X., Lou, Q., Wei, H., Qiu, J., Yang, H., Liu, G., & Fan, L. (2019). Bi-directional Selection in Upland Rice Leads to Its Adaptive Differentiation from Lowland Rice in Drought Resistance and Productivity. *Molecular Plant, 12*(2), 170-184.

Xuan, V. T. (2018). *Rice production, agricultural research, and the environment, Vietnam's rural transformation.* Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9780429503269-7/rice- production-agricultural-research-environment-vo-tong-xuan

Yang, X., Wang, W., Zhuang, Y., Li, Z., Ma, Z., Ma, Y., Cui, Y., Wei, J., & Fuller, D. Q. (2017). New radiocarbon evidence on early rice consumption and farming in South China. *The Holocene, 27*(7), 1045-1051.

Yin, R., Mo, J., Dai, J., & Wang, H. (2017). Nickel (II) inhibits Tet-mediated 5-methylcytosine oxidation by high affinity displacement of the cofactor iron (II). *ACS Chemical Biology*. *12*(6), 1494-1498.

Yu, T. R. (1991) Characteristics of soil acidity of paddy soils in relation to rice growth. In: Wright, R. J., Baligar, V. C., Murrmann, R. P. (Eds.), *Plant-Soil Interactions at Low pH. Developments in Plant and Soil Sciences*. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-3438-5_12

Yu, X., Mingju, E., Sun, M., Xue, Z., Lu, X., Jiang, M., & Zou, Y. (2018). Wetland recreational agriculture: Balancing wetland conservation and agro-development. *Environmental Science and Policy, 87,* 11-17.

Zhan, X., Zhang, L., Zhou, B., Zhu, P., Zhang, S., & Xu, M. (2015). Changes in Olsen phosphorus concentration and its response to phosphorus balance in black soils under different long-term fertilization patterns. *PloS One, 10*(7), 1-15.

Zhang, S., Pan, Y., Tian, W., Dong, M., Zhu, H., Luan, S., & Li, L. (2017). Arabidopsis CNGC14 mediates calcium influx required for tip growth in root hairs. *Molecular Plant*, *10*(7), 1004-1006.

Zheng, Y., Crawford, G. W., Jiang, L., & Chen, X. (2016). Rice domestication revealed by reduced shattering of archaeological rice from the Lower Yangtze valley. *Scientific Reports*, *6*(1), 1-9.

Zhou, W., Lv, T. F., Chen, Y., Westby, A. P., & Ren, W. J. (2014). Soil physicochemical and biological properties of paddy-upland rotation: A review. *The Scientific World Journal*, *2014*, 1-8. https://doi.org/10.1155/2014/856352

Zhu, F., Hou, J., Xue, S., Wu, C., Wang, Q., & Hartley, W. (2017). Vermicompost and gypsum amendments improve aggregate formation in bauxite residue. *Land Degradation and Development*, *28*(7), 2109-2120.

Zipfel, C., & Oldroyd, G. E. (2017). Plant signalling in symbiosis and immunity. *Nature*, 543, 328–336.

APPENDICES

The following tables contain data from the field site at Kivulini Irrigation Scheme in Kilimanjaro region of Tanzania. These raw data complement the analyzed information presented in this dissertation.

Appendix 1: Results of physicochemical properties of irrigation water at the study area, Kivulini Irrigation Scheme in the Kilimanjaro region of Tanzania

Sample ID	pH	EC (µs/cm)	Temp (^{0}C)	DO (%)	DO (mg L^{-})	ORP (mV)	Salinity (PSU)	NO$_3^-$ N (Mg L^{-})	P (Mg L^{-})	SO$_4^{2-}$ (Mg L^{-})	Cl$^-$ (Mg L^{-})	HCO$_3^-$ (Mg L^{-})	Na+ (Mg L^{-})	K+ (Mg L^{-})	Ca^{2+} (Mg L^{-})	Mg^{2+} (Mg L^{-})	B(Mg L^{-})
	Levels in field samples																
WS-1	7.36	662	21.8	80.2	6.47	24.2	0.28	1.2	0.18	6	0.1	310	11.69	2.05	55.08	26.24	1.2
WS-2	7.42	925	21.6	84.2	6.81	-3.5	0.39	1.1	0.21	3	0.1	460	22.8	4.71	69.09	31.59	0.4
WS-3	7.41	823	21.7	79.22	6.41	14.2	0.35	1.1	0.14	8	0.2	310	35.2	7.41	28.01	43.25	1.3
WS-4	7.35	670	21.2	81.3	6.64	0.1	0.28	0.4	0.24	0	0.1	230	7.41	1.41	34.93	33.53	3.9
WS-5	7.23	711	22.7	65.7	5.37	55.3	0.3	0.1	0.25	0	0.1	300	13.65	2.58	28.11	32.81	0.8
WS-6	6.93	958	24.6	71.12	5.09	37.3	0.4	0.3	0.57	7	0.1	260	19.77	3.06	65.91	39.37	0.8
WS-7	7.33	1132	21.9	63.3	5.09	19.6	0.54	0.3	0.82	0	0.2	290	56.2	3.76	28.83	31.59	0.8
WS-8	6.91	930	25.7	70.6	5.73	19.6	0.39	0.2	0.19	1	0.3	380	11.39	1.78	65.06	24.3	0.2
WS-9	6.9	923	25.9	73.6	5.74	21.9	0.39	0.0	0.17	7	0.1	300	15.31	2.05	80.3	30.62	9
WS-10	6.82	994	25.7	81.3	5.49	29.2	0.42	0.2	0.95	1	0.2	320	23.58	3.29	52.1	31.59	1.4
WS-11	7.28	1462	22.3	53.1	4.21	19.3	0.69	0.5	0.39	0	0.1	550	24.05	3.97	101.1	39.85	3.3
WS-12	6.58	1365	21.7	48.7	2.39	-80.1	0.65	0.5	0.82	0	0.2	460	25.48	3.35	52.61	75.33	0.2
WS-13	6.56	820	24.4	73.9	5.54	10.6	0.35	0.5	0.21	6	0.3	260	19.03	3.63	31.3	21.87	0.4
WS-14	6.27	836	23.5	53.3	4.15	45.1	0.35	1	0.24	5	0.1	210	16.87	3.21	28.14	24.3	2.5
WS-15	6.49	953	22.3	10.9	0.7	-64.7	0.4	0.1	0.23	8	0.2	360	13.09	2.49	70.7	31.59	3.7
WS-16	6.52	1053	23.38	37.9	1.91	-79.5	0.5	0.5	0.19	7	0.1	650	12.21	2.03	140.06	35.96	1.0
WS-17	6.33	1198	29.3	35.7	2.42	-24.9	0.57	0.5	0.22	0	0.4	650	39.98	12.46	122.55	30.38	1.8
WS-18	6.5	1085	28.28	30.1	2.1	29.6	0.51	1.2	0.19	0	0.2	300	26.6	6.78	34.07	43.25	1.6
WS-19	6.28	953	28.5	18.6	1.33	-18.1	0.4	0.5	0.19	0	0.5	360	13.09	3.09	65.53	23.09	1.3
WS-20	6.33	891	28.4	5.27	0.36	-21.5	0.37	0.5	0.19	2	0.1	390	19.66	4.34	72.9	27.95	2.9
WS-21	6.27	823	22.6	78.6	6.21	23.6	0.35	1.3	0.16	8	0.1	260	9.41	4.45	25.45	66.58	1.4
WS-22	6.25	820	23.75	79.3	6.3	49.7	0.34	1.3	0.2	8	0.2	310	3.61	4.82	51.5	27.22	0.5
WS-23	6.23	979	29.7	7.9	0.12	-17.6	0.41	0.5	0.11	0	0.1	390	4.36	5.48	64.13	34.02	0.8
WS-24	6.3	976	28	65.4	4.28	-31.2	0.41	0.2	0.22	3	0.4	330	3.41	4.02	52.1	35.48	1.7
WS-25	6.25	975	26.9	66.4	4.85	12.9	0.41	0.1	0.33	0	0.1	290	23	6.66	15.49	34.02	1.0
WS-26	6.43	1159	21.7	24.1	1.92	-81.4	0.35	0.3	0.17	0	0.1	420	5.43	4.47	58.5	39.37	0.3
WS-27	6.63	1515	20.5	4.9	0.4	-112.5	0.74	0.4	0.76	1	0.4	620	28.9	2.57	82.1	52.25	0.1
WS-28	6.55	1027	20.4	34.3	2.8	-78.9	0.49	0.4	0.22	1	0.1	460	23.38	4.81	57.28	39.37	0.3
WS-29	6.8	862	20.4	59.3	4.89	-85.9	0.36	0.0	0.21	1	0.1	360	16.99	2.33	60.12	30.13	0.5
WS-30	6.75	990	21.6	73.5	5.95	-18.2	0.41	0.3	0.21	1	0.2	310	16.09	2.21	38.33	30.13	1.1
WS-31	6.62	1169	22.2	27.6	2.12	-64.2	0.55	1.2	0.22	1	0.1	500	11.63	2.05	68.09	23.09	0.4
WS-32	6.54	1369	21.7	1.5	0.11	-77.1	0.64	1.0	0.31	2	0.1	490	9.2	1.36	76.15	52.97	1.8
WS-33	6.4	656	21.03	83.9	6.85	-13.2	0.27	0.2	0.51	3	0.1	320	15.66	3.25	68.12	24.3	3.7
WS-34	6.85	705	22.8	90.1	7.14	-17.9	0.3	1.9	0.36	3	0.2	310	11.53	2.39	16.54	44.96	0.5
WS-35	6.33	658	21.7	80.3	6.49	22.1	0.28	0.2	0.22	4	0.1	250	9.67	2.28	44.09	23.09	1.8
WS-36	6.27	669	23.8	67.8	4.13	18.9	0.28	0.6	0.21	1	0.1	300	8.85	1.75	40.73	28.19	0.6
WS-37	6.33	786	21.7	68.3	5.4	28.4	0.33	0.1	0.25	2	0.1	440	12.59	1.66	84.88	34.99	2.4

Appendix 2: Results for concentration of selected heavy metals and metalloids in irrigation water samples collected in the study area, Kivulini Irrigation Scheme of Kilimanjaro region, Tanzania. Total number of samples, N = 37

Sample ID	As (mg L^{-1})	Cd (mg L^{-1})	Mo (mg L^{-1})	Zn^{2+} (mg L^{-1})	Mn^{2+} (mg L^{-1})	Fe (mg L^{-1})	Ni (mg L^{-1})	Pb^{2+} (mg L^{-1})	Cr^{2+} (mg L^{-1})	Al3^{+} (mg L^{-1})	Cu^{2+} (mg L^{-1})
	Levels in field samples										
WS-1	BDL[a]	BDL	0.01	0.22	BDL	2.01	0.11	0.12	0.01	1.1	0.01
WS-2	BDL	BDL	BDL	0.29	BDL	0.96	0.06	0.34	0.08	1.2	0.01
WS-3	BDL	BDL	0.01	0.22	BDL	0.28	0.07	0.35	0.03	0.91	0.03
WS-4	BDL	BDL	0.01	0.87	0.07	1.34	0.1	0.42	0.05	0.82	0.08
WS-5	BDL	BDL	0.01	0.85	0.02	1.24	0.08	1.45	0.04	1.12	0.01
WS-6	0.02	BDL	BDL	0.91	BDL	0.59	0.05	1.54	0.01	1.23	0.02
WS-7	0.01	BDL	BDL	1.61	BDL	0.35	0.05	1.82	0.01	0.52	0.06
WS-8	BDL	BDL	BDL	1.05	0.03	0.82	0.03	0.64	0.01	0.82	0.01
WS-9	BDL	BDL	BDL	0.17	BDL	0.27	0.04	0.85	0.02	1.23	0.01
WS-10	BDL	BDL	BDL	0.23	0.06	0.62	0.04	1.68	0.02	1.5	0.01
WS-11	BDL	BDL	0.01	0.14	BDL	0.96	0.01	2.24	0.02	1.21	0.01
WS-12	BDL	BDL	0.01	0.12	BDL	1.25	0.02	0.84	0.02	0.51	0.01
WS-13	BDL	BDL	BDL	0.58	0.09	1.33	0.06	0.75	0.05	0.62	0.01
WS-14	BDL	BDL	0.01	0.79	0.11	1.07	0.05	1.26	0.03	0.18	0.01
WS-15	BDL	BDL	0.01	0.81	0.08	0.80	0.02	1.87	BDL	0.26	0.01
WS-16	BDL	BDL	BDL	1.18	0.05	0.72	0.07	1.83	BDL	0.16	0.01
WS-17	BDL	BDL	BDL	0.12	0.07	0.56	0.05	0.74	BDL	0.29	0.04
WS-18	BDL	BDL	BDL	0.13	0.06	0.13	0.08	0.53	BDL	0.85	0.12
WS-19	BDL	BDL	BDL	0.02	0.05	0.35	0.04	1.84	BDL	0.96	0.14
WS-20	BDL	BDL	BDL	0.26	0.04	0.54	0.04	1.34	0.04	1.09	0.01
WS-21	BDL	BDL	BDL	0.24	0.04	0.67	0.05	1.5	0.03	1.02	0.09
WS-22	BDL	BDL	BDL	0.16	0.07	0.61	0.04	1.73	0.04	0.97	0.06
WS-23	BDL	BDL	BDL	0.31	0.05	0.61	0.09	1.25	BDL	0.12	0.04
WS-24	BDL	BDL	BDL	0.28	0.07	1.90	0.04	1.63	0.03	0.15	0.01
WS-25	BDL	BDL	BDL	0.11	0.08	1.28	0.04	1.27	0.02	0.08	0.03
WS-26	0.02	BDL	BDL	0.12	0.01	0.56	0.02	1.91	0.01	0.05	0.02
WS-27	BDL	BDL	BDL	0.12	0.08	0.14	0.02	0.97	0.01	0.63	0.02
WS-28	BDL	BDL	BDL	0.96	0.04	0.23	0.01	1.27	0.04	0.52	0.01
WS-29	BDL	BDL	BDL	1.08	0.05	0.32	0.01	1.81	0.02	1.43	0.01
WS-30	BDL	BDL	BDL	1.19	0.07	0.26	0.14	0.96	0.02	1.59	0.03
WS-31	BDL	BDL	BDL	0.88	0.07	0.87	0.07	0.53	0.04	1.45	0.04
WS-32	BDL	BDL	BDL	0.72	0.04	0.91	0.1	0.52	0.04	2.08	0.09
WS-33	BDL	BDL	BDL	0.42	0.07	1.34	0.02	0.45	0.03	1.57	0.06
WS-34	BDL	BDL	BDL	0.10	0.08	2.19	0.03	0.36	0.02	0.96	0.04
WS-35	BDL	BDL	BDL	0.61	0.01	1.98	0.06	0.42	0.04	0.85	0.04
WS-36	0.01	BDL	BDL	0.37	0.07	1.53	0.10	0.73	0.02	0.89	0.05
WS-37	BDL	BDL	0.01	0.61	0.11	1.63	0.07	0.36	0.02	0.54	0.01

[a] BDL = levels were below detection limit

Appendix 3: Results for soil samples physico-chemical analyses for a total of 61 samples collected at a study area in Kivulini Irrigation Scheme, Kilimanjaro, Tanzania

Sample ID	EC (μs cm^{-1})	pH	OC (%)	K (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	P (mg kg^{-1})	N (mg kg^{-1})
	Levels in field samples							
S1	930	7.63	1.3	13.13	8.32	98.13	125.372	1340
S2	195	7.51	1.6	13.67	6.61	110.23	127.122	1379
S3	776	7.92	1.5	18.46	5.92	76.95	234.388	690
S4	247	7.66	2.4	11.01	61.73	204.09	230.852	1552
S5	387	7.61	2.4	12.13	3.84	15.18	172.307	2069
S6	240	9.48	2.3	12.09	4.27	39.54	235.174	2155
S7	404	7.58	2.2	20.12	5.51	90.17	142.446	1465
S8	236	7.59	2.3	11.70	13.19	128.20	178.201	1983
S9	323	7.65	2.4	13.48	3.28	72.42	159.341	2069
S10	338	7.71	2.3	11.37	15.92	35.41	355.014	2069
S11	320	8.23	2.3	11.34	5.01	83.36	227.709	1983
S12	380	7.94	2.1	13.14	3.86	70.91	234.781	1810
S13	346	7.77	1.2	14.26	4.13	68.37	198.371	1780
S14	546	6.49	0.9	11.54	7.01	15.97	116.120	776
S15	498	7.27	1.2	10.73	17.18	43.84	182.523	172
S16	390	6.89	1.6	13.48	14.97	21.57	199.026	1379
S17	523	7.45	1.5	15.48	43.55	23.01	125.943	1293
S18	564	7.76	2.1	18.49	4.88	148.17	136.159	1810
S19	303	7.33	2.3	13.90	3.64	35.54	129.479	1896
S20	220	7.69	2.1	12.028	10.81	48.72	170.736	1810
S21	322	6.81	0.3	11.604	169.49	49.52	133.016	1983
S22	480	7.41	0.2	11.543	4.84	67.90	678.952	1509
S23	296	6.31	0.1	13.812	9.48	12.78	136.159	86
S24	395	8.14	1.3	16.182	4.43	17.97	166.807	690
S25	511	7.41	1.3	11.543	4.84	67.90	122.407	1509
S26	636	6.31	1.2	11.694	22.88	169.74	481.533	1034
S27	542	8.14	1.5	12.240	3.76	44.33	234.781	1293
S28	1925	7.85	0.7	16.433	169.49	94.65	946.547	603
S29	513	8.04	0.9	16.433	5.00	94.65	433.990	603
S30	573	7.82	1.6	24.073	14.90	109.01	410.415	1379
S31	373	10.09	1.3	15.107	3.42	39.94	384.875	1121
S32	353	7.72	1.5	11.374	2.66	51.12	373.874	1293
S33	265	7.91	1.6	15.110	5.95	22.36	397.449	1983
S34	398	7.22	0.9	15.919	3.28	5.59	423.381	776
S35	307	8.66	1.2	15.264	5.47	5.37	396.381	572
N1	285	8.23	1.4	22.750	11.26	8.78	168.771	578
N2	488	8.1	0.5	14.538	58.83	37.14	173.486	431
N3	320	7.95	0.5	13.863	42.47	35.39	171.027	376
N4	582	8.03	1.2	13.772	4.26	13.98	166.807	517
N5	600	8.1	1.6	49.855	35.82	26.36	156.591	1379
N6	306	7.48	1.6	9.970	7.40	20.77	117.692	1552
N7	930	8.03	1.7	15.408	6.85	28.75	136.945	1896
N8	195	7.14	1.4	12.773	8.12	25.56	109.048	1034
N9	776	8.05	1.2	13.372	9.13	27.37	113.352	132
N10	247	7.44	1.2	17.627	24.45	63.50	136.945	1034
N11	387	8.87	1.5	8.899	154.85	146.18	144.410	1293
N12	240	7.01	1.4	15.373	7.89	5.48	386.447	862
N13	404	7.14	1.4	12.438	16.64	18.37	151.090	1207
N14	236	6.75	1.4	9.181	21.19	8.39	108.262	1422
BG1	323	8.2	1.6	9.036	16.90	15.27	116.298	1450
BG2	338	7.77	1.8	9.027	7.80	42.27	142.522	1270
BG3	320	7.74	1.5	9.082	4.30	46.73	151.483	1164
BG4	380	7.79	1.2	10.724	7.29	36.27	165.922	1030
BG5	346	7.72	1.0	11.642	34.78	20.37	184.488	862
BG6	546	8.14	1.3	10.528	3.42	29.95	199.419	1034
BG7	498	8.02	1.1	10.289	3.98	41.14	190.382	948
BG8	390	7.89	1.0	8.830	3.49	12.65	233.209	1552
BG9	523	7.66	1.1	12.865	16.51	23.56	177.808	948
BG10	564	7.7	0.9	11.119	11.38	71.09	280.359	1621
BG11	303	7.49	0.6	10.375	7.93	3.99	134.980	776
BG12	220	7.84	0.8	15.373	11.38	5.48	54.785	862

RESEARCH OUTPUTS

Publication paper

Mpanda, F. M., Rwiza, M. J., & Mtei, K. M. (2021). A survey of irrigation water and soil quality that likely impacts paddy rice yields in Kilimanjaro, Tanzania. *Discover Water*, *1*(1), 1-24.

Poster Presentation

A survey of irrigation water and soil quality that likely impacts paddy rice yields in Kilimanjaro, Tanzania.