EFFECTS OF NITROGEN AND PHOSPHORUS MICRO-DOSING ON MAIZE-PIGEON PEA INTERCROPS GROWN UNDER DIFFERENT SOIL MOISTURE MANAGEMENT PRACTICES

SNAL - SUA / O
063079 8

PAUL SABAS SAIDIA

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

11/06/19

2018

SNAL
DATE 11/11/201
SPECIAL COLLECTION

EXTENDED ABSTRACT

Declining soil fertility and moisture stress are among the serious constraints facing agriculture in most developing countries in the world. Tanzania inclusive. Continuous farming with none or low use of fertilizer accelerates nutrient mining in the soil. Average fertilizer use under smallholder farming systems is 16 - 19 kg/ha in sub Saharan Africa. Low fertilizer adoption by smallholder farmers are mainly due to inadequate knowledge on fertilizer usage. untimely availability of inorganic fertilizers and low affordability. Declining soil fertility may cause yield reduction of up to 50% when not addressed resulting into low food availability and poor income generation. Inadequate rainfall and uneven distribution results into prolonged dry spells. Low rainwater and poor runoff management practices under the flat cultivation increases water loss, moisture stress and soil erosion that affects plant nutrient availability and uptake. In both semi-arid and sub-humid areas. maize production is also limited by inadequate soil moisture due to fluctuation of rainfall regimes. A prolonged dry spell and change in rainfall pattern results into low crop yield and shrinkage of grazing land which increase conflicts between crop producers and pastoralist. Recommended N and P fertilizer rates have been developed in maize as the most limiting in different agro-ecological zones. However, only 12% of smallholder farmers use inorganic fertilizers due to poor capital and unavailability of fertilizer in their areas. Use of a fertilizer micro-dosing technology which is about 25% of the rate recommended, would enable farmers to start with the lowest-cost effective technology and gradually move to higher capital-intensive technologies as their resources increase. It is an entry point for resource poor farmers to use fertilizers. Inter-row rainwater harvesting practices

have been reported to increase crop yield in rain-fed farming and minimizes risks of crop failure in drought prone areas. The influence of micro-dosing fertilizer and soil moisture conservation through inter-row rainwater harvesting on maize and pigeon-pea cropping systems would increase crop productivity, maximize land use efficiency, increase financial return and nutritional quality. Most recommendations of technologies are from agronomic analysis with emphasis on maximum yield without economic analysis. As farmers do the economic analysis at farm level, profitability analysis is therefore important in recommending fertilizer micro-dosing rate along with rainwater harvesting practices and cropping system. Therefore, the objectives of this study were: i) To determine micro-dose rates of phosphorus and nitrogen for maize crop. ii) To evaluate the effect of nitrogen and phosphorus fertilizer micro-dosing on yields, resource utilization and nutritional quality of maize and pigeonpea cropping systems as influenced by soil moisture management through rainwater harvesting technique, and iii) To determine the profitability of the micro-dose rates in maize production, as well as profitability of inter-row rainwater harvesting and fertilizer use on maize and pigeonpea cropping systems.

To achieve the objectives of this study, two field experiments were conducted in Ilakala and Changarawe villages of Kilosa District in Morogoro Region Tanzania. The first experiment was laid out in split-plot involving three phosphate fertilizer types (Diammonium phosphate, Minjingu mazao and triple super phosphate), and micro-dose rates (12.5, 25, 50 and 75% of recommended N and P) with control and recommended rate (80 kg N and 40 kg P/ha). The second experiment was laid out

in split-split plot design. It involved rainwater harvesting practices (tie ridge, open ridge and flat cultivation), cropping systems (maize sole, pigeonpea sole and 1:1 maize-pigeonpea intercrop), and fertilizer use (control, micro-dosing and recommended rate).

Results indicated that Minjingu mazao fertilizer had significantly higher maize yield than DAP by 6.63% and TSP by 9.55%. Fertilizer micro dose rates at 12.5% (10 kg N and 5 kg P/ha) and 25% (20 kg N and 10 kg P/ha) increased the yield from 1012 kg/ha in control to 1928 kg/ha (90.5%) and 2394 kg/ha (137%), respectively. Tied ridges conserved soil moisture by 13.33% more than flat cultivation at 30 cm depth after ten days of rainfall. Ridges increased maize yield by 8 - 15% than flat cultivation, but decreased pigeon pea yield by 23% than flat cultivation. Fertilizer use increased maize yield by 93% at micro-dosing rates and 132% at recommended rate compared to control plot. Tie ridges and fertilizer use increased maize yield by 90% and pigeon pea yield by 20% than flat cultivation without fertilizer.

Land use efficiency was ranging from 28 to 100% higher in intercropping than sole crop. Financial return was high ranging from 2 to 4 million shillings from maize-pigeonpea intercrop applied with micro-dose and recommended fertilizer in both tied ridges and flat cultivation. Maize sole had more energy than pigeonpea under tied ridges, however the highest energy was between 60,000 and 70,000 kJ/ha from intercrops and recommended fertilizer. The highest protein ranging between 400 and 500 kg/ha was from intercropping applied with micro-dose and recommended fertilizer in both tied ridges and flat. Micro-dosing rate at 12.5% was more profitable than no fertilizer application and the profitability increased towards 25%

and 50% of recommended fertilizer rates and thereafter, decreased at recommended rate. Tied ridges and fertilizer micro-dose had higher gross margin than open ridges and flat cultivation in maize sole cropping. Pigeonpea sole cropping had higher gross margin in flat cultivation than tie and open ridges. Maize and pigeonpea intercropping under fertilizer micro-dosing had the highest gross margin above 4.5 million Tanzanian shillings. Intercropping maize and pigeonpea had high B/C ratio ranging from 6.1 to 15.6 in commercial farming and from 12 to 32 in subsistence farming. Adoption of micro-dosing fertilizer at 12.5% could be an entry point to fertilizer use and later on advance to 25% and 50% micro-dosing rates which are more profitable with better yield under smallholder farming systems in sub-humid tropics. Inter-row rainwater harvesting and fertilizer micro-dosing would increase food and nutritional security and optimize profit in both sole and intercropping systems of sub-humid tropical farming.

DECLARATION

I, **PAUL SABAS SAIDIA** do hereby declare to the Senate of Sokoine University of Agriculture, Morogoro, Tanzania, that this thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

Paul Sabas Saidia — 13.08.2018 Date

(PhD Candidate)

The above declaration is confirmed by;

Professor Cornel L. Rweyemamu — 14/09/2018 Date

(Supervisor)

Professor Johnson M.R. Semoka — 13/09/2018 Date

(Co-Supervisor)

Adjunct Professor Anthony A. Kimaro — 12/08/2018 Date

(Co-Supervisor)

COPYRIGHT

No part of this thesis may be reproduced, stored in any retrieval system, or transmitted in any form or by any means, without prior written permission of the author or Sokoine University of Agriculture in that behalf.

ACKNOWLEDGEMENTS

I am grateful to my supervisors Professor Cornel L. Rweyemamu from the Department of Crop Science and Horticulture at Sokoine University of Agriculture (SUA), Professor Johnson M.R. Semoka from the Department of Soil and Geological Sciences at SUA and Dr. Anthony A. Kimaro from International Center for Research in Agro-forestry (ICRAF) Country Office in Dar es salaam, Tanzania for their tireless assistance to accomplish my PhD study.

Special thanks to the Project Trans SEC (Innovating Strategies to safeguard Food Security using Technology and Knowledge Transfer: A people-centered Approach) Dr Stefen Sieber (Leader), Dr Frieder Graef (Scientific Coordinator) and the entire team at ZALF Germany, Dr Jorn Germer (Work Package 5.2 Leader), Prof Folkard Asch, Prof. Hermann Ludger and the entire team at University of Hohenheim Germany. Also, my thanks to Dr. Khamaldin Mutabazi (Project Coordinator, Tanzania), Prof. Frederck C. Kahimba (Co-Project Coordinator, Tanzania), Mr Bashir Makoko and Phlorentin Lagweni from ARI-Ilonga, Mr Elirehema Swai (ARI- Makutupora), my fellow PhD candidates from the Project and at the University.

I also wish to extend my appreciation to TARI-Ukiriguru and the Ministry of Agriculture for granting me study leave and encouragement for studies. Dr Geophrey J. Kajiru Assistant Director (Natural Resource Management) Ministry of Agriculture is appreciated for encouragement and linkages.

I am greatly indebted to my wife Honoratha Kachewa Saidia, my daughters Beatrice and Clarine, my mother (Alverina Lusale), my brothers (Gregory and others), sisters (Euphrazia, Bernadetha and others) and uncles (Dismus Lusale, Rev. Nemes Lusale, Norasco Lusale and others) for their encouragement, comfort and company during the period of my studies.

May the Almighty God bless all who contributed in one way or another towards the completion of this work. Amen.

DEDICATION

This work is dedicated to the Almighty God "I AM THE WAY THE TRUTH AND THE LIFE", praise, glory and honor be to Him alone.

To my parents my father the late Sabas Saidia who passed away on December 1st 1992 and my mother Alverina Lusale for laying the foundation of education. To my wife Mrs. Honoratha Kachewa Saidia and my children Beatrice and Clarine.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABREVIATIONS, ACRONYMS AND SYMBOLS

%	Percent
ANOVA	Analysis of variance
B	Boron
Ca	Calcium
CGR	Crop growth rate
CIMMYT	International Maize and Wheat Improvement Center
cm	Centimeter
cmol	Cent mole
Cu	Copper
CV	Coefficient of variation
DAP	Di-ammonium phosphate
DTMA	Drought tolerant maize for Africa
ESA	Eastern and Southern Africa
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
Fl	Flat
g	gram
GM	Gross margin
GR	Gross return
ha	Hectare
ICRAF	International Center for Research in Agroforestry
ICRISAT	International Center for Research in Semi-Arid Tropics
K	Potassium
KES	Kenya Shillings
kg	Kilogram

km	Kilometer
LA	Leaf area
LAI	Leaf area index
LER	Land equivalent ratio
m	Meter
MALF	Ministry of Agriculture Livestock and Fisheries
MF/FM	Micro-dosing fertilizer
Mg	Magnesium
mg	Milligram
MM	Minjingu mazao
mm	Millimeter
Mn	Manganese
N	Nitrogen
Na	Sodium
NAP	National Agricultural Policy
NBS	National Bureau of Statistics
NH_4	Ammonium
OC	Organic carbon
OPV	Open pollinated variety
OR	Open ridges
P	Phosphorus
R	Reproductive growth stages
RAE	Relative agronomic efficiency
RF/ FR	Recommended fertilizer
RWH	Rainwater harvesting
S	Sulphur

SEM	Standard error of mean
SM	Sole maize
SP	Sole pigeonpea
SSA	sub Saharan Africa
SSSA	Soil Science Society of America
SUA	Sokoine University of Agriculture
t	Tonne
TR	Tied ridges
TSP	Triple super phosphate
TVC	Total variable costs
TZS/ TSh	Tanzanian shillings
V	Vegetative growth stages
Zn	Zinc

ORGANIZATION OF THE THESIS

The thesis is designed in publishable paper format and there are six chapters as follows:

i. Chapter one gives the background of the thesis including problem statement and justification as well as the study objectives and hypothesis.

ii. Chapter two: paper 1 Effects of nitrogen and phosphorus micro-doses on maize growth and yield in a sub-humid tropical climate

iii. Chapter three: paper 2 Soil moisture management and fertilizer micro-dosing on yield and resource utilization indices of intercropping maize and pigeonpea in sub humid tropics

iv. Chapter four: paper 3 Profitability of nitrogen and phosphorus fertilizer micro-doses on maize production in sub-humid farming systems of Tanzania

v. Chapter five: paper 4 Profitability of maize-pigeonpea intercrops under soil moisture management options and fertilizer micro-dosing in sub-humid tropics

vi. Chapter six: Contains the conclusions of the thesis and recommendations

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Agriculture is very important in the world as a source of food. feed, employment and raw materials for industries (World Bank, 2008). It is the mainstay of economy in most of developing countries in the world (Bruinsma, 2003). In Tanzania, agriculture employs 65.5% of people, contributes 100% food when there is adequate rainfall and 29.1% of gross domestic product according to the Ministry of Agriculture Livestock and Fisheries (MALF, 2017).

About 11% of globe's land surface (13.4 billion ha) is used in crop production. Developing countries have 2.8 billion ha of land with a potential for rain-fed agriculture above a minimum acceptable level which is the suitability for a defined use of land in its present condition without major improvement, about 960 million ha are under cultivation. The remaining 1.8 billion ha is not used for agriculture but rather under forest, in protected areas, human settlements or considered as reserve and most of it is concentrated in few countries of South America and Sub Saharan Africa (SSA) (Bruinsma, 2003). In Tanzania total land is 94.5 million ha, about 44 million ha is arable land and less than 33% of arable land is under cultivation (NBS, 2012). Annual crop production growth is 2.5% with yield increase of 68% in SSA during 2015 – 2030 (Bruinsma, 2003).

Maize is the major cereal crop in SSA and Latin America, this crop is expected to grow at 2.2% per annum against 1.3% for wheat and 1.0% for rice (Bruinsma, 2003). Maize is grown for food and cash in SSA (Smale *et al.*, 2011). Maize as a food crop accounts for 50% of the calories and protein consumed in Eastern and Southern Africa (ESA) and 20% in West Africa (Macauley and Ramadjita. 2015). The estimated average consumption per person per year is 100 kg in Lesotho, Malawi, Zambia and Zimbabwe; 104 kg in South Africa (Smale *et al.*, 2011) and 128 kg in Tanzania (Suleiman and Rosentrater, 2015). About 85-90% of Tanzania's population have been reported to eat maize in different forms as unprocessed and processed products (Wilson and Lewis, 2015). Maize as cash crop generates about 50 % of rural cash income in SSA (Macauley and Ramadjita, 2015; Maziku, 2015). However, only 35% of household production in Tanzania is sold, but the exact quantity depends on quantity produced per respective season and domestic needs (Wilson and Lewis, 2015). Maize and pigeon pea inter-cropping accounts for about 70% of the cropped land area in Tanzania (Rusinamhodzi *et al.*, 2017). In Tanzania, smallholder farmers produce about 80% of maize (Wilson and Lewis, 2015).

1.1 Fertilizer Use and Rainwater Harvesting Technologies

1.1.1 Fertilizer

Fertilizer is any organic or inorganic material of natural or synthetic origin (other than liming materials) that is added to a soil to supply one or more plant nutrients essential to the growth of plants (SSSA, 1997). The trend of inorganic fertilizer use is 12 and 9 kg/ha during 1979/80, 14 and 15 kg/ha during 1991/92 (Mwangi, 1996), 16 kg/ha (Cameron *et al.*, 2017) and 19 kg/ha (MALF, 2017) during 2016/17 in SSA and Tanzania, respectively. The increase in fertilizer use has been due to various efforts from the Government such as fertilizer subsidy called the National Agricultural Input Voucher Scheme (NAIVS) from 2007/08 to 2014/15.

which subsidized half of the cost of fertilizer and seeds to smallholder farmers. The number of NAIVS beneficiaries increased from 0.7 – 2 million from 2008 to 2011 (Cameron *et al.*, 2017). The subsidy program provided 57% of 263,000 t used during 2010/11 and 68% of 500,000t required to achieve maize optimal yield during 2013/14 (IFDC, 2012; Cameron *et al.*, 2017). Later on, the system changed and from 2017 the Ministry of Agriculture introduced a new system: "bulk procurement" by reducing taxes and other importation charges to reduced market price of fertilizers and increased availability of fertilizer. Fertilizer DAP and urea were under this program (MALF, 2017).

1.1.2 Rainwater harvesting

Rainwater harvesting (RWH) is the process of concentrating, collecting and storing water for different uses such as agriculture or domestic at a later time (Nuhu and Mahoo, 2000). There are two types: *in-situ* and *ex-situ* RWH. *In-situ* RWH is also called water conservation that involves the use of methods that increase the amount of water stored in the soil profile by trapping or holding the rain where it falls (Yosef and Asmamaw, 2015). It is basically all the conventional approaches to soil and water conservation designed to enhance infiltration of rainwater into the soil (Nuhu and Mahoo, 2000). *Ex-situ* is the practice where rainwater is collected and stored for productive use (Nuhu and Mahoo, 2000; Yosef and Asmamaw, 2015). The basic components of a water harvesting system are catchment or collection area, the runoff conveyance system, storage and application area (Mekdaschi and Liniger, 2013). Forms of RWH commonly applied includes: roof top water harvesting, water harvesting for animal consumption, inter-row water harvesting.

micro-catchment water harvesting, medium sized catchment water harvesting, and large catchment water harvesting (Nuhu and Mahoo, 2000; Mekdaschi and Liniger, 2013). Choice of the RWH practice depends on the purpose for use and capital to establish infrastructure.

1.1.3 Intercropping systems

Intercropping is among the multiple cropping systems that involve the growing of two or more crops in proximity to promote interaction between them (Francis, 1986; Ofori and Stern, 1987). Spatial arrangement (rows, strips, mixed and relay), plant density, maturity dates of the crops being grown, and plant architecture should be considered to maximize cooperation and minimize competition (Mousavi and Eskandari, 2011). There are four groups of intercropping according to Ofori and Stern (1987) as follows: i) Row-intercropping as growing of two or more crops simultaneously where one or more crops are planted in regular rows, and crop or other crops may be grown simultaneously in row or randomly with the first crop. ii) Mixed-intercropping is the growing of two or more crops simultaneously with no distinct row arrangement. iii) Strip-intercropping is the growing of two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for crops to interact ergonomically. iv) Relay-intercropping is growing of two or more crops simultaneously during part of the life cycle of each; a second crop is planted after the first crop has reached its reproductive stage but before it is ready for harvest. Yield advantages and intercropping indices such as land equivalent ratio and monetary values have been reported as benefits of intercropping over sole or mono cropping (Kimaro *et al.*, 2009; Mousavi and Eskandari, 2011). Also, facilitative and competitive interactions under inter-cropping systems are modified by availability of resources such as nutrients supplied by fertilizers and soil moisture from rainwater harvesting practices (Kimaro *et al.*, 2009).

1.2 Problem Statement and Justification

1.2.1 Problem statement

Productivity of most food and cash crops is low. Maize yield is averaging 1.0 – 1.7 t/ha compared with potential of 5.0 – 7.5 t/ha (Cameron *et al.*, 2017) and pigeon pea is less than 1.0 t/ha compared with a potential of 2.5 – 3.0 t/ha.

Declining soil fertility and moisture stress are among the main factors causing low crop productivity under the current climate change effects. Continuous farming and low use of fertilizer accelerates nutrient mining in the soil. For instance, 12.0 - 15.67 kg N/ha, 2.67- 3.92 kg P/ha, 3.92- 5.42 kg K/ha, 1.25- 1.67 kg Mg/ha, 1.08- 1.33 kg S/ha and 22.42- 29.42 g Zn/ha are removed when 1.0 t/ha maize grains are harvested (Bender *et al.*, 2013). Fertilizer use by smallholder farmers is low averaging 16 kg/ha in SSA (Cameron *et al.*, 2017) and 19 kg/ha in Tanzania (MALF, 2017). This is less than 40% of the African Union's Abuja Declaration Commitment of 50 kg/ha fertilizer material (Cameron *et al.*, 2017). In SSA about 40% of fertilizer has been reported to be used on maize production (Smale *et al.*, 2011). Low fertilizer adoption by smallholder farmers are mainly due to inadequate knowledge on fertilizer usage (Druilhe and Barreiro-Hurlé, 2012), untimely availability of inorganic fertilizers and low affordability (MALF, 2017). Declining soil fertility may cause yield reduction of up to 50% when not addressed (Foth and

Ellis, 1997). Consequently, low crop productivity that results into low food availability and income insecurity.

Also, rainfall shortage and uneven distribution results into prolonged dry spell which is becoming a common problem to smallholder farmers causing low crop yields due to soil moisture stress. Rowhani *et al.* (2011) reported that 20% increase in intra-seasonal precipitation variability reduced yield by 4.2 % for maize. The mean annual rainfall varies from 500 to 2500 mm characterized by unpredictable patterns (Msaki *et al.*, 2015). Poor rainwater and runoff management practices under the conventional flat cultivation increases water loss, moisture stress, soil erosion and affect plant nutrient availability and uptake, which contribute to low yield. In both semi-arid and sub-humid areas, maize production is also limited by inadequate soil moisture due to fluctuation of rainfall regimes (NRSP, 2005). A prolonged dry spell and change in rainfall pattern results into low crop yield and shrinkage of grazing land which increase conflicts between crop producers and pastoralists.

1.2.2 Justification

Recommended N and P fertilizer rates have been developed in maize as the most limiting in different agro ecological zones (Marandu *et al.*, 2014). However, only 12% of smallholder farmers use inorganic fertilizers (NBS, 2012). Most of smallholder farmers do not afford to buy fertilizer at recommended rate due to poor capital and unavailability of fertilizer in rural areas. Micro-dose technology involves fertilizer placement with a rate of about a third to a fourth of the usual rate recommended by research or advisory services (Camara *et al.*, 2013). Micro-dose technology enables farmers to start with the lowest-cost effective technology and gradually move to higher capital-intensive technologies as their resources increase (Aune and Bationo, 2008; Aune and Coulibaly, 2015). This strategy has been widely used in semi-arid areas of West Africa and proven to be advantageous to smallholder farmers and even under the long-term application (Aune and Coulibaly, 2015; Adams *et al.*, 2016; Okebalama *et al.*, 2017). Fertilizer micro-dosing technology is potential to address most of constraints to fertilizer adoption because few resources are needed (only 25% of fertilizer), not knowledge intensive and can readily be comprehended by farmers by following time, quantity and type of fertilizer, promising crop productivity and good adaptation to wide range of climatic and agro-ecological conditions; and flexibility in purchasing farm inputs due to less fertilizer needed and less monetary investment (Camara *et al.*, 2013). Therefore, studies on fertilizer micro-dosing strategy are important under sub-humid farming systems.

Inter-row water harvesting have been reported to restore the productivity of land that suffers from inadequate rainfall, it increases yields in rain-fed farming areas and minimizes risks in drought prone areas (Prinz, 1996). Thus, Inter-row rainwater harvesting would increase nutrient availability, uptake and fertilizer use efficient. The influence of micro-dose fertilizer application and soil moisture conservation through inter-row rainwater harvesting on maize and pigeon-pea intercropping system is currently inadequately documented in sub humid tropical conditions. Intercropping has been reported to increase land use by 66% in Nigeria (Dania *et al.*, 2014) and could reduce land use conflict compared to sole crop.

Therefore, maximizing land utilization by intercropping maize and pigeon pea and use of improved technologies such as fertilizers are becoming inevitable.

Due to increasing costs of production, smallholder farmers are becoming aware of financial return and other benefits before adopting a new technology (Kaliba *et al.*, 2000; Waddington *et al.*, 2007). Most recommendations of technologies are from agronomic analysis with emphasis on maximum yield without economic analysis (Limbu, 1999). It is important to supplement agronomic experiments with economic analysis (Kirway *et al.*, 2003). Net profit and benefit-cost ratio analyses are among the profitability analysis before recommending a new technology to farmers (Kirway *et al.*, 2003; Senkondo *et al.*, 2004). Thus, profitability analysis is important to recommend fertilizer micro-dosing rate along with rainwater harvesting practices and cropping system which is agronomically and economically acceptable.

Therefore, with the current situation in Kilosa district where agricultural productivity is declining due to climate change effects, soil degradation and increasing land conflicts between crop producers and livestock keepers, maximizing land utilization by use of improved technologies in crop production is becoming very vital.

1.3 Study Objectives

1.3.1 Overall objective

Establishment of integrated soil fertility and moisture conservation methods to improve productivity for smallholder farmers under maize and pigeon pea cropping systems

1.3.2 Specific objectives

i) To determine micro-dose rates of phosphorus and nitrogen for maize crop
ii) To evaluate the effect of nitrogen and phosphorus fertilizer micro-dosing on yields, resource utilization and nutritional quality of maize and pigeon-pea cropping systems as influenced by soil moisture management through rainwater harvesting techniques
iii) To determine the profitability of the micro-dose rates in maize production, as well as profitability of inter-row rainwater harvesting and fertilizer use on maize and pigeon-pea cropping systems.

1.4 Research Hypotheses

i. Application of micro-dose rate will not reduce yields significantly from the recommended rate.
ii. There are no differences in soil moisture conservation among the *in situ* rainwater harvesting practices
iii. Intercropping and sole cropping systems are not different in yields, land use efficiency, financial return and other indices
iv. There are no economic benefits of fertilizer micro-dosing and inter-row rainwater harvest on maize and pigeon pea cropping systems

1.5 References

Adams, A. M., Gillespie, A. W., Kar, G., Koala, S., Ouattara, B., Kimaro, A. A., et al. (2016). Long term effects of reduced fertilizer rates on millet yields and soil properties in the West-African Sahel. *Nutr Cycl Agroecosyst, 106*: 17- 29.

Aune, J. B. and Bationo, A. (2008). Agricultural intensification in the Sahel- The ladder approach. *Agricultural Systems, 98*: 119 - 125.

Aune, J. B. and Coulibaly, A. (2015). Microdosing of Mineral Fertilizer and Conservation Agriculture for sustainable agricultural intensification in Sub-Saharan Africa. In R. Lal, B. R. Singh, D. L. Mwaseba, D. Kraybill, D. O. Hansen, & O. L. Eik. *Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa.* Springer International Publishing Switzerland. pp. 223 - 234.

Bender, R. R., Haegele, J. W., Ruffo, M.L. and Below, F.E. (2013).Nutrient uptake, partitioning and remobilization in modern, transgenic insect-protected maize hybrids. Agronomy Journal 105 (1): 161 - 170.

Bruinsma, J. (2003). World Agriculture: Towards 2015/2030 UN FAO Perspective. Earthscan Publications Ltd, London. 444 pp.

Camara, B. S., Camara, F., Berthe, A. and Oswald, A. (2013). Micro-dosing of fertilizer- a technology for farmers' needs and resources. *International Journal of Agri Science, 3*(5): 387 - 399.

Cameron, A., Derlagen, C. and Pauw, K. (2017). *Options for reducing fertilizer prices for smallholder farmers in Tanzania*. Prepared for the Ministry of Agriculture, Livestock and Fisheries (MALF) United Republic of Tanzania. Policy Report. MAFAP (Monitoring and Analyzing Food and Agricultural Policies). FAO. Rome. 34pp.

Dania, S. O., Fagbola, O. and Alabi, R. A. (2014). The yield and farmer's economic advantage of maize – pigeon pea intercrop as affected by the application of organic base fertilizer. *Europian Scientific Journal* 10 (25): 357 - 374

Druilhe, Z. and Barreiro-Hurlé, J. (2012). *Fertilizer subsidies in sub-Saharan Africa*. ESA Working paper No. 12 – 04. Rome. FAO. 73pp.

Foth, H. D. and Ellis, B. G. (1997). *Soil Fertility* (Second ed.). Florida: CRC Press Inc. 290pp.

Francis, C.A. (1986). *Multiple Cropping Systems*. Macmillan Publishing Company, New York, USA. 383pp.

IFDC International Fertilizer Development Center. (2012). *Tanzania fertilizer assessment*. Alabama. 51pp.

Kaliba, A. R. M., Verkuijl, H. and Mwangi, W. (2000). Factors Affecting Adoption of Improved Maize Seeds and Use of Inorganic Fertilizer for Maize Production in the Intermediate and Lowland Zones of Tanzania. *Journal of Agricultural and Applied Economics* 32 (1): 35 – 47.

Kimaro, A. A., Timmer, V. R., Chamshama, S. A. O., Ngaga, Y. N. and Kimaro, D. A. (2009). Competition between maize and pigeonpea in semi-arid Tanzania: Effect on yields and nutrition of crops. *Agriculture, Ecosystems and Environment* 134: 115-125.

Kirway, T. N., Lema, N. M., Lyimo, S. D., Kilco, R. O., Kapange, B. W., Schouten, C. and Schrader, T. (2003). *Farming Systems Approaches Training Manual*, Volume 2. DRD/MAFS. Tanzania. 255pp.

Limbu, F. (1999). Agricultural Technology Economic Viability and Poverty Alleviation in Tanzania. Paper Presented at the Structural Transformation Policy Workshop held on 27- 30 June at Sarena Hotel, Nairobi, Kenya. Organized by the ECAPAPA, TEGEMEO Institute, and Michigan State University. 55pp.

Macauley, H. and Ramadjita, T. (2015). Cereal crops: Rice, maize, millet, sorghum and wheat. 36pp. [https://www.afdb.org /fileadmin/ uploads/ afdb/ Documents/Events/DakAgri2015/Cereal_Crops-_Rice__ Maize__ Millet__Sorghum__Wheat.pdf] visited 12th October 2017.

MALF Ministry of Agriculture Livestock and Fisheries. (2017). Budget Speech of the MALF 2017/18. Parliament of the United Republic of Tanzania. Dodoma Tanzania. 255pp.

Marandu, A. E., Mbogoni, J. D. and Ley, G. J. (2014). *Revised Fertilizer Recommendations for Maize and Rice in the Eastern, Southern Highlands and Lake Zones of Tanzania.* Department of Research and Development. Dar es salaam: Ministry of Agriculture Food Security and Cooperatives. 40pp.

Maziku, P. (2015). Market access for maize smallhlder farmers in Tanzania. Proceedings of the second Europina Academic Research Conference on Global Business, Economics, Finance and Banking (EAR15 Swiss Conference) ISBN: 978-1-63415-477-2 Zurich-Switzerland. 3-5 July, 2015 Paper ID: Z548.

Mekidaschi, S. R. and Liniger, H. (2013). *Water Harvesting: Guidelines to Good Practices.* Centre for Development and Environment (CDE), Bern; Rainwater Harvesting Implementation Network (RAIN). Amsterdam; MetaMeta, Wageningen. The International Fund for Agricultural Development (IFAD). Rome. 210pp.

Mousavi, S. R. and Eskandari, H. (2011). A general overview on intercropping and its advantages in sustainable agriculture. *Journal of Applied Environmental and Biological Sciences* 1(11): 482 – 486.

Msaki, M. M., Tambi, E. and Bangali, S. (2015). *State of knowledge on climate smart agriculture in Africa, case studie from Rwanda, Tanzania and Zambia.* Forum for Agricltural Research inAfrica, Accra, Ghana. 80pp.

Mwangi, W. (1996). *Low use of fertilizers and low productivity in Sub-Saharan Africa*. NRG Paper 96-05. Mexico, D.F.: CIMMYT. 26pp.

NBS (2012). *National sample census of Agriculture smallholder agriculture. Volume II: Crop sector- National Report*. National Bureau of Statistics (NBS), Dar es salaam Tanzania. 539pp.

NRSP Natural Resource Security Programme (2005). Reducing poverty through rainwater harvesting: Evidence from the semi-arid areas of Maswa and Same Districts, Tanzania. Soil water management research group. [http://www.nrsp. org.uk/database/ documents/2257.pdf] site visited 5th August 2014.

Nuhu, H. And Mahoo, H. F. (2000). *Rainwater Harvesting for Natural Resources Management: A planning guide for Tanzania*. Technical Handbook No.22. Published by Sida's Regional Land Management (RELMA) Unit. 156pp.

Ofori, F. and Stern, W. R. (1987). Cereal-legume intercropping systems. *Advance in Agronomy* 41: 41 – 90.

Okebalama, C. B., Ibrahim, A., Safo, E. Y., Yeboah, E., Abaidoo, R. C., Logah, V. and Monica, U. I. (2017). Fertilizer micro-dosing in West African low-input cereals cropping: Benefits, challenges and improvement strategies. *African Journal of Agricultural Research* 12 (14): 1169 – 1176.

Prinz, D. (1996). Water Harvesting: Past and Future. In: Sustainability of Irrigated Agriculture. *Proceedings, NATO Advanced Research Workshop* (Edited by Pereira, L. S.), 21 – 26 March 1994. Vimeiro. Balkema. Rotterdam, 135- 144pp.

Rowhan, P., Lobell, D. B., Linderman, M. and Ramankutty. N. (2011). Climate variabilty and crop production. *Agriculture and Forest Meteorology,* Volume 151: 449 – 460.

Rusinamhodzi, L., Makoko, B. and Sariah, J. (2017). Ratooning pigeonpea in maize-pigeonpea intercropping: Productivity and seed cost reduction in eastern Tanzania. *Field Crops Research* 203: 24 – 32.

Senkondo, E. M. M., Msangi, A. S. K., Xavery, P., Lazaro. E. A. and Hatibu, N. (2004). Profitability of Rainwater Harvesting for Agricultural Production in Selected Semi-Arid areas of Tanzania. *Journal of Applied Irrigation Science* 39 (1): 65 – 81.

Smale, M., Byerlee, D. and Jayne, T. (2011). *Maize Revolution in Sub-Saharan Africa: The Policy Research Working Paper 5659*, the World Bank Development Research Group of Agriculture and Rural Development Team. 34pp.

SSSA Soil Science Society of America. (1997). *Glossary of Soil Science Terms.* Madison, Wisconsin, USA. 134pp.

Suleiman, R. A., and Rosentrater, K. A. (2015). Current maize production, postharvest losses and the risk of mycotoxins contamination in Tanzania. *Agricultural and Biosystems Engineering Conference Proceedings and Presentations.7-2015.* St. Joseph, Michigan: Iowa State University.

Waddington, S. R., Mekuria, M., Siziba, S. and Karigwindi, J. (2007). Long-term Yield Sustainability and Financial Returns from Grain Legume - Maize Intercrop on a Sandy Soil in subhumid North Central Zimbabwe. *Expl Agric.* 43: 489 – 503.

Wilson, T. and Lewis, J. (2015). *The maize value chain in Tanzania: A report from the Southern Highlands food systems programme.* Food and Agriculture Organization of the United Natons (FAO). 60pp.

World Bank (2008). *World Development Report: Agriculture for Development.* The World Bank, Washington DC. 386pp.

Yosef, B. A. and Asmamaw, D. K. (2015). Rainwater harvesting: An option for dry land agriculture in arid and semi-arid Ethiopia. *International Journal of Water Resources and Environmental Engineering* 7(2): 17 – 28.

CHAPTER TWO

2.0 EFFECTS OF NITROGEN AND PHOSPHORUS MICRO-DOSES ON MAIZE GROWTH AND YIELD IN A SUB-HUMID TROPICAL CLIMATE

2.1 Abstract

Inadequate knowledge on fertilizer usage such as type, rate, time and method of application as well as poor financial resources are among the reasons for low maize productivity under small-scale farming. Fertilizer micro-dosing may increase food production by using low rates which are affordable by most resource poor farmers and have a high investment return. A two-year field experiment was conducted on sandy loam and sandy clay soils being typical representatives of sub-humid tropical agro-ecological zones to evaluate the effect of nitrogen and phosphorus micro-doses on maize growth performance and yield. A split-plot design involved di-ammonium phosphate (DAP), Minjingu mazao (MM) and triple super phosphate (TSP) as main plots and fertilizer micro-dose rates of 10kg N and 5kg P/ha, 20 kg N and 10 kg P/ha, 40 kg N and 20 kg P/ha, 60 kg N and 30 kg P/ha, recommended rate (80kg N and 40 kg P ha^{-1}), and control (no fertilizer application) as sub-plots. Among the phosphate fertilizers, MM produced the highest grain yield (2317 kg/ha), followed by DAP (2173 kg/ha) and TSP (2115 kg/ha). Fertilizer micro dose rates (10 kg N and 5 kg P/ha; 20 kg N and 10 kg P/ha) increased the yield from 1012 kg/ha in control to 1928 kg/ha (90.5%) and 2394 kg/ha (137%), respectively. Also, fertilizer rates of 40 kg N and 20 kg P/ha and 60 kg N and 30 kg P/ha produced average grain yields of 2629 and 2647 kg/ha while the recommended rate (80 kg N and 40 kg P/ha) produced 2601 kg/ha. The highest grain yield was 3910

kg/ha followed by 3573 kg/ha and 3543 kg/ha from MM at 40 kg N and 20 kg P/ha, TSP at 80 kg N and 40 kg P/ha, and MM at 60 kg N and 30 kg P/ha respectively. Considering the selected phosphate fertilizers. MM is agronomically effective than DAP and TSP. Also micro dose rates (10kg N and 5kg P/ha) and (20 kg N and 20 kg P/ha) are recommended as entry point to fertilizer use for resource poor farmers. However, endowed resource farmers are advised to use intermediate rates (40 kg N and 20 kg P/ha) and (60 kg N and 30 kg P/ha) for optimum productivity of maize in sub-humid tropical conditions.

Keywords: Di-ammonium phosphates, Fertilizer micro-dosing, growth analysis characteristics, minjingu mazao, recommended fertilizer, relative agronomic effectiveness, triple super phosphate

2.2 Introduction

Maize (*Zea mays* L.) is the most popular and important crop in Tanzania and other sub-Sahara African (SSA) countries and is grown for food and cash. The estimated average consumption, for instance in Tanzania is 128 kg per person per year (Suleiman and Rosentrater, 2015) but the average maize yield is 1.2 t/ha which is far less than its potential of 6 to 7.5 t/ha (NAP, 2013). The low yield leads to perpetual self-insufficiency in maize availability and inadequacy of food to meet the increasing population (NBS, 2013).

Low maize productivity is attributed mainly to declining soil fertility; climate changes especially rainfall and poor agronomic practices. Continuous farming and low or no use of fertilizer accelerates nutrient mining in the soil (Bender *et al.*, 2013). Only few farmers about 10% use inorganic fertilizers (IFDC, 2012; NBS, 2012) where the main nutrient supplied is nitrogen (N) followed by phosphorus (P) which are also the most limiting nutrients in maize farming (Marandu *et al.*, 2014).

Reasons for low fertilizer adoption in crop production by smallholder farmers are mainly inadequate knowledge on fertilizer usage such as type, rate, time, method and fertilizer benefits (Druilhe and Barreiro-hurle, 2012). Also, most smallholder farmers are resource poor, therefore they cannot afford to buy and apply fertilizers at recommended rates (Aune and Bationo, 2008; Camara *et al.*, 2013). This condition necessitates the need to introduce fertilizer micro-dose technology in Tanzania. Micro-dose technology involves fertilizer placement with a rate of about a third to a fourth of the usual rate recommended by research or advisory services (Camara *et al.*, 2013). Micro-dose technology enables farmers to start with the lowest-cost effective technology and gradually move to higher capital-intensive technologies as their resources increase (Aune and Bationo, 2008; Aune and Coulibaly, 2015). Fertilizer micro-dose also reduces the risk of crop failure and fertilizer poisoning in areas where rainfall is erratic and harsh weather conditions (Murendo and Wollni, 2015). A long term study on the use of fertilizer micro-dose in the Sahel suggests that sustainability of this technology on highly degraded soil is improved by combined application of organic matter (Aune and Coulibaly, 2015; Adams *et al.*, 2016; Okebalama *et al.*, 2017). There are positive effects on the use of fertilizer micro-dosing technology by smallholder farmers in West African Sahel (Hayashi *et al.*, 2008; Pale *et al.*, 2009; Adams *et al.*, 2016; Aune and

Coulibaly, 2015). These studies found that 125kg/ha of $N_{19}P_{19}K_{19}$ fertilizer was appropriate micro-dose rate in sorghum and millet cultivated under semi-arid conditions of Sahel. Recent studies reported 27 kg DAP and 27 kg Urea/ha in semi-arid Ethiopia (Sime and Aune, 2014), NPK ($N_{20}P_{40}K_{20}$ and $N_0P_{40}K_{20}$) in humid forest areas in Ghana (Okebalama *et al.*, 2016), 37.5 kg N and 13 kg P/ha in Kenya (Kisinyo and Palapala, 2016) as micro-dose fertilizer rates in maize. Studies to develop micro-dose rates for smallholder farmers in maize crop production sub-humid conditions have not been done. Therefore, this study will provide information about straight and multiple nutrients fertilizers and micro-dose rates in maize production under sub humid areas.

Field experiments were carried out in two case study villages in sub-humid Tanzania. Different micro-dose rates were compared against farmers' practices and nitrogen (N) and phosphorus (P) recommended application rates (Marandu *et al.*, 2014). The study involved use of different types of P fertilizers compared with blended fertilizers like Minjingu mazao (MM) so as to provide micro nutrients, which are increasingly becoming limiting in Tanzania (Amuri *et al.*, 2013). The study was conducted in the framework of a large participatory research project (Graef *et al.*, 2014). The focus here was to increase food production through fertilizer micro-dosing rates that would be affordable by most smallholder poor resource farmers and give high investment return. Objectives of the study were to determine the effectiveness of selected phosphate fertilizer types on maize growth and yield under different soil conditions and determine the optimum N and P micro-dose rates for maize.

2.3. Materials and Methods

2.3.1 Description of the study area

The study was conducted in Kilosa District, Morogoro Region during 2014/15 and 2015/16 cropping seasons. Rainfall pattern is bimodal where the short rain season starts in October and ends in January and the long rain season starts from mid-February and ends in May. The mean annual rainfall ranges between 800 and 1400 mm while the average ambient temperature is about 25°C (Kajembe *et al.*, 2013). The experiment was conducted in Changarawe village (06°54'55" South. 036°5710" East and 500 meter above sea level) in Masanze ward, and Ilakala village (07°08'39" South, 036°54'05" East and 605 meter above sea level) in Ullaya ward. The villages are located 25 km apart from each other.

2.3.2 Experimental design, treatments and management

Maize variety used was TMV1-OPV medium maturing (110 days) with white grains and flinty type (Lyimo *et al.*, 2014). Inorganic fertilizers applied were di ammonium phosphate (DAP) ($(NH_4)_2HPO_4$) with 18% N and 46% P_2O_5 (McClauley *et al.*, 2009), Minjingu Mazao (MM) containing 10% N and 20% P_2O_5, 25% CaO, 5% S, 1.5% MgO, 0.5% Zn and 0.1% B (Minjingu Mines and Fertilizers, 2014) and triple super phosphate (TSP) that contained 46% P_2O_5 and urea which had 46%N (FAO, 2000).

063079 8

Experiments were initiated in December 2014 and February 2015 in Ilakala and Changarawe villages, respectively. The field experiment was laid out as split-plot in a randomized complete block design (RCBD) (Montgomery, 2013). The main plot was phosphate fertilizers that were DAP, MM and TSP. The sub-plots were

SNAL DATE -------- SPECIAL COLLECTION

fertilizer application rates at 0 (no fertilizer use) as farmer practice; micro-dose rates (5kg P and 10kg N/ha; 10kg P and 20 kg N/ha); intermediate rates (20 kg P and 40 kg N/ha; 30 kg P and 60 kg N/ha); and recommended rates of 40 kg P and 80 kg N/ha (Marandu *et al.*, 2014). DAP and TSP fertilizers were applied by separate hole placement, MM was applied by broadcasting followed by incorporation into the soil because of low solubility (Prasad and Power. 1997). Urea was applied at fifth leaf collar visible (V5) (Camara *et al.*, 2013). The crop spacing used was 0.75 m by 0.30 m with 8 rows per plot and 10 plants per row giving plot size of 18 m^2. At Ilakala site, maize crop was sown on 25 January 2015 and 14 January 2016 while at Changarawe site sowing was done on 8 March 2015 and 20 January 2016 by dibbling method. Two seeds per hole were sown and thinning was done at seedling stage (V2). Agronomic practices and crop management included weeding three times, which were at seedling stage (V2), fifth leaf (V5) and tasseling (VT) stages of maize growth. Stalk borers, aphids and other insects were controlled by spraying insecticide KUNG FU 5 EC (50 g/liter Lambda-cyhalothrin) by mixing 20 ml of insecticide in 15 liter Knap sack sprayer (Kanyeka *et al.*, 2007).

2.3.3 Data collection

2.3.3.1 Soil sampling and laboratory analysis

Soils were sampled before establishing experiments and analysed as described by Soil survey staff (2014) where ten spots were sampled at depth of 0 – 15 cm and 15 – 30 cm. Quartering method was used to get composite soil sample which was transferred to Soil Laboratory for analysis. Soil analysis included particle size distribution for textural class by Hydrometer method, soil pH by pH meter in 1:2.5 soil-water, organic carbon by Walkley- Black Method, total nitrogen by micro-Kjedahl digestion method, available phosphorus by Bray and Kurtz 1. exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) by NH_4-acetate filtrates by Ammonium Acetate Saturation and available micronutrients (Zn, Cu, Mn and Fe) by the DTPA extraction method.

2.3.3.2 Rainfall data

At both sites, daily weather data on rainfall (mm) was recorded using standard rain gauges type that were installed in the experimental fields during the 2014/15 and 2015/16 cropping seasons.

2.3.3.3 Nutrient concentration and uptake in plants

Five plants were selected randomly at sixth leaf growth stage (V6) and cut at five centimetres above the ground as described by Hochmuth *et al.* (2012). Samples were oven dried at 80°C and plant tissue analysis was done in laboratory by nitric acid wet digestion method as described by Okalebo *et al.* (1993) and Fageria *et al.* (1997). The nutrients analysed include N, P, K, S and Zn. Furthermore, nutrient uptake was determined using the equation described by Fageria *et al.* (1997) with some modification that nutrient concentrations in percentage were changed into milligram per kilogram by multiplying by 10,000 and later on changed into g/kg and kg/kg of dry plant materials to get kg nutrient/ha as follows:

$$Nutrient\ uptake\ (kg/ha) = TDM\ (kg/ha)\ X\ Nutrient\ content\ in\ plant\ (kg/kg) \quad \text{............} (1)$$

2.3.3.4 Growth analysis and total dry matter

Growth analysis characteristics were determined by sampling five plants randomly at sixth leaf growth stage (V6), silking (R1) and dough growth stage (R4) as proposed by Ogoke *et al.* (2003). Length and width of leaves was measured using a ruler and leaf area (LA) was calculated from the equation described in Ogoke *et al.* (2003) as follows:

LA = Length of leaf (cm) x Maximum width of leaf (cm) x 0.75 (a constant factor for maize leaves)........... .... (2)

Total dry matter (TDM) was determined as from five sampled plants which were oven dried at 80°C to constant weight as described by CIMMYT (2013); dry weight was measured by using the Advanced Electronic Balance ENDEL™ K-3000BH. Crop growth rate (CGR) and leaf area index (LAI) were determined using the methods reported by Fageria *et al.* (1997) as follows:

$LAI = {LA}/{GA}$ .... (3)

$CGR = \frac{1}{GA} \times \frac{W2-W1}{T2-T1}$ $g/m^2/day$ .... (4)

Where, GA is ground area covered during sampling. LA is leaf area, T1 and T2 are time intervals at different growth stages, W1 and W2 are weights of dry matter at different growth stages.

Total dry matter (TDM) at sixth leaf growth stage (V6), silking (R1), dough stage (R4) and harvesting stage were determined by sampling five plants randomly and oven drying at 80°C to constant weight as described by CIMMYT (2013).

2.3.3.5 Yield components and grain yield

Maize was harvested seven days after attaining physiological maturity (R6) when husks dried up and were turning papery from harvesting spot of $3m^2$ area. Yield components determined included plant population at harvest, number of cobs per plant, the number of grains m^{-2} and seed size (g/100seeds). Yield involved the biological yield and grain yield per ha which was converted from grain yield in g m^{-2} at harvest maturity (CIMMYT, 2013).

2.3.4 Data analysis

Soils, rainfall and nutrient concentration data were subjected to descriptive statistics.

Crop growth and yield data were analysed using the analysis of variance (ANOVA) at $P \leq 0.05$ basing on the statistical model for the split-plot design as follows:

$$Y_{ijk} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{jk} + \varepsilon_{ijk} \quad (5)$$

Where: Y_{ijk}= Response level, μ = General effect or general error mean, β_i = Block effect, A_j = Main plot effect, δ_{ij} = the main plot random error (Error a), B_k = Sub-plot effect, AB_{jk}= Interaction effect between the main plot and the subject, and ε_{ijk}= Sub-plot random error effect (Error b).

Comparison of means was done with Tukey's test at $p \leq 0.05$ as described by Montgomery (2013). Coefficient of determination (R^2 or r^2) and correlation coefficient (r) analysis for micro-dose fertilizer rates vs. yield was performed as described by Gomez and Gomez (1984) and Montgomery (2013).

Relative agronomic effectiveness for MM fertilizer as a test fertilizer and standard fertilizer (DAP or TSP) was calculated using the equation described in Muhawish and Razaq (2009) as follows:

$$\text{Relative agronomic effectiveness (RAE)} = \left(\frac{\text{Yield from test fertilizer} - \text{Control yield}}{\text{Yield of standard fertilizer} - \text{Control yield}} \times 100\%\right) \ldots (6)$$

2.4 Results

2.4.1 Soil and rainfall description

Soil characteristics at the study sites are shown in Table 2.1. Soils at Ilakala study site were sandy loam and sandy clay at 0 – 15 cm and 15 30 cm, respectively. Soil pH was neutral (6.6 - 7.3) with low total nitrogen (0.10 - 0.20%), medium organic carbon (1.26 - 2.50%) and phosphorus (7 - 20 mg/kg). Exchangeable cations were medium to high except sodium which was low. Micronutrients determined were medium to high except for zinc which was low in both sites. Soils at Changarawe study site were sandy clay loam and sandy loam at 0 – 15 cm and 15 – 30 cm, respectively, soil pH was medium acidic (5 - 6.0). Total nitrogen (N), organic carbon (OC) and phosphorus (P) were very low.

Table 2. 1: Soil characteristics at Ilakala and Changarawe study sites

Soil characteristics	Ilakala (0-15cm)	Ilakala (15-30cm)	Chanagarawe (0-15cm)	Changarawe (15-30cm)
Sand (%)	66.24	69.52	62.24	77
Clay (%)	26.48	26.48	30.48	14
Texture class	Sandy Loam	Sandy Clay	Sandy Clay Loam	Sandy Loam
Soil pH	6.92 [neutral]	7.10 [neutral]	5.52 [strongly acid]	5.33 [strongly acid]
Total nitrogen (%)	0.10 [L]	0.20 [L]	0.06 [VL]	0.04 [VL]
Organic carbon (%)	2.09 [M]	2.00 [M]	0.93 [L]	0.80 [L]
P- Bray 1 (mg/ kg)	19.77 [M]	10.21 [M]	2.86 [L]	2.75 [L]
Exchangeable potassium (cmol +/ kg)	1.15 [H]	0.64 [M]	0.80 [M]	0.72 [M]
Exchangeable magnesium (cmol +/ kg)	0.75 [M]	0.70 [L]	1.89 [H]	1.72 [H]
Exchangeable calcium (cmol +/ kg)	13.77 [VH]	15.23 [VH]	3.89 [M]	3.89 [M]
Exchangeable sodium (cmol +/ kg)	0.10 [L]	0.09 [VL]	0.24 [L]	0.26 [L]
Copper (mg/ kg)	0.36 [M]	0.26 [M]	0.24 [M]	0.26 [M]
Zinc (mg/ kg)	0.58 [L]	0.34 [L]	0.91 [M]	0.58 [L]
Iron (mg/ kg)	20.73 [H]	13.45 [H]	38.76 [H]	41.68 [H]
Manganese (mg/ kg)	43.30 [H]	36.70 [H]	42.80 [H]	47.50 [H]

Letters in superscript represent abbreviation for remarks according to Landon (1991) where H = high, L = low, M= medium, VH= very high, VL= very low.

Rainfall results for 2014/15 and 2015/16 cropping seasons are presented in Figure 2.1. At Ilakala total rainfall was 496 mm in 2014/15 cropping season whereas it was 805 mm in 2015/16. There was inter- as well as intra-seasonal variations in rainfall amount. Distribution was not even during both cropping seasons. In 2015. there were no rains which coincided with seedling and sixth leaf growth stages (3 5 weeks after planting) while at booting and tasseling there was high rainfall (7 – 9 weeks after planting). From silking (11 week after planting) to dough stage (13 week after planting) there was moderate amount of rainfall (30 50mm) and well distributed rainfall pattern. In 2016, rainfall increased from 25 mm at emergence to 110 mm at fourth leaf stages and decreased to 34.5 mm at booting and tasseling stage (7 to 9 weeks after planting). From milk stage to maturity (11 to 15 weeks after planting) rainfall amount was very high (90 mm and above).

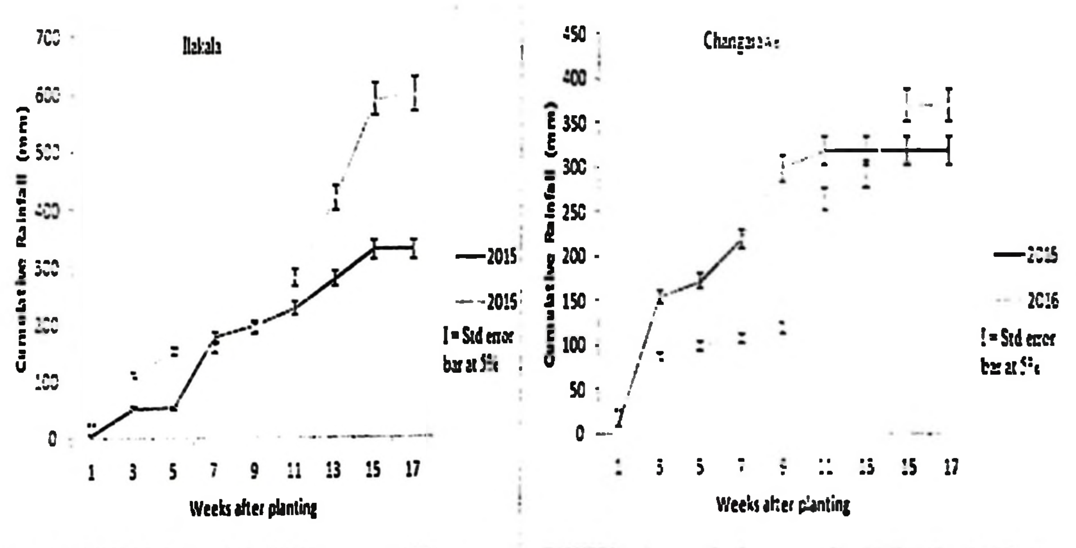


Figure 2. 1: Rainfall amount and distribution during main season after planting maize

In Changarawe, total amount of rainfall received was 349.5 mm during 2014/15 cropping season and 579.3 mm in 2015/16. During 2014/15 cropping season, there was low rainfall at emergence growth stage of 8 mm followed by high amount of rains amounting to 154.6 mm at seedling and fifth leaf (1^{st} and 3^{rd} week after planting), respectively. From booting to milk stages (7 to 11 weeks after planting) there was high amount of rainfall which decreased towards dough and maturity stage. In 2015/16, amount of rainfall increased from sowing to third week after planting (26.5 to 86.0 mm) and decreased rapidly to about 10 mm between sixth leaf and silking stage (5^{th} and 9^{th} week after planting).

2.4.2 Nutrient concentrations in maize plants

Different fertilizer types and micro-dose rates affected nutrients concentrations differently at Ilakala study site during 2015 and 2016 (Table 2.2). Nitrogen (N) concentration increased from control to different fertilizer rates with maximum at recommended rate during 2015 while during 2016 the maximum N was at intermediate rates. Phosphorus (P) concentration increased from control to fertilizer rates and reached maximum at both intermediate and recommended rates during 2015 and 2016 years. Concentration of potassium (K) increased from control to different fertilizer rates and reached maximum at micro-dose, intermediate and recommended rates during 2015 and 2016. Sulphur (S) concentration increased from control to micro-dose rates and decreased towards recommended rate in DAP, MM and TSP plots. Zinc (Zn) concentration was increasing from control to micro-dose rates and decreased towards recommended rate in MM, however the trend of

Zn decreased from control to higher fertilizer rates in DAP and TSP plots and was dependent on season.

Table 2. 2: Nutrient concentration in maize plants at Ilakala site

Treatment	N (%) 2015	N (%) 2016	P (%) 2015	P (%) 2016	K (%) 2015	K (%) 2016	S (%) 2016	Zn (ppm) 2015	Zn (ppm) 2016
Control (1)	1.26	1.89	0.15	0.21	1.39	1.32	0.17	5.85	20.41
DAP2	1.26	2.38	0.33	0.24	1.96	2.38	0.22	11.17	15.96
DAP3	1.61	2.10	0.28	0.24	1.87	2.55	0.24	5.85	21.68
DAP4	1.68	2.66	0.31	0.26	1.83	2.67	0.26	11.17	19.53
DAP5	1.89	2.45	0.39	0.23	1.86	2.27	0.15	7.18	14.89
DAP6	1.96	2.52	0.26	0.26	1.66	2.36	0.16	4.52	14.13
Mean	1.61	2.33	0.29	0.24	1.76	2.26	0.20	7.62	17.77
Range	0.70	0.77	0.24	0.05	0.57	1.35	0.11	6.65	7.55
SD	0.30	0.29	0.08	0.02	0.21	0.48	0.05	2.87	3.17
Control (1)	1.26	1.89	0.15	0.21	1.39	1.32	0.17	5.85	20.41
MM2	1.47	2.17	0.23	0.27	1.70	2.56	0.17	8.51	18.84
MM3	1.55	2.45	0.25	0.27	1.67	2.44	0.17	9.84	17.25
MM4	1.45	2.73	0.21	0.22	1.57	2.30	0.22	9.84	15.77
MM5	1.55	2.10	0.22	0.23	1.95	2.02	0.26	8.51	21.84
MM6	1.75	2.17	0.43	0.28	1.53	2.65	0.23	4.52	19.67
Mean	1.51	2.25	0.25	0.25	1.64	2.22	0.20	7.85	18.96
Range	0.49	0.84	0.28	0.07	0.56	1.33	0.09	5.32	6.07
SD	0.16	0.29	0.10	0.03	0.19	0.49	0.01	2.19	2.19
Control (1)	1.26	1.89	0.15	0.21	1.39	1.32	0.17	5.85	20.41
TSP2	1.71	2.24	0.17	0.22	1.39	2.52	0.19	3.19	19.61
TSP3	1.65	2.31	0.19	0.23	1.68	2.61	0.21	4.52	19.61
TSP4	1.78	2.17	0.23	0.27	2.13	2.49	0.18	5.85	18.82
TSP5	1.96	2.10	0.21	0.23	1.53	3.30	0.16	3.19	18.84
TSP6	1.96	2.52	0.23	0.28	1.54	2.70	0.17	7.18	19.62
Mean	1.72	2.21	0.20	0.24	1.61	2.49	0.18	4.96	19.48
Range	0.70	0.63	0.08	0.07	0.74	1.98	0.05	3.99	1.59
SD	0.26	0.21	0.03	0.03	0.28	0.65	0.02	1.61	0.59

DAP is di ammonium phosphate, MM is Minjingu mazao and TSP is triple super phosphate; control (farmers not applying fertilizer) while fertilizer rates numbered 2 to 6 are 10 and 5, 20 and 10, 40 and 20, 60 and 30, 80 and 40 kg N/ha and P/ha, respectively. Data were subjected to descriptive statistical analysis.

Nutrient concentrations at Changarawe study site were affected by fertilizer types and rates (Table 2.3). Nitrogen increased from control to fertilizer rates and reached a maximum at micro-dose rates in DAP, recommended rate in MM and intermediate rate in TSP during 2015 and 2016. Phosphorus increased from control to different fertilizer rates and reached maximum at recommended rate during 2015 while in 2016 the maximum P was at micro-dose and intermediate rates. Potassium concentration increased from control to different fertilizer rates with a maximum K at micro-dose, intermediate and recommended rates inconsistently during 2015 and 2016. Concentration of sulphur increased with fertilizer rates from different fertilizer types with a maximum at TSP4 during 2016. Concentration of zinc was not consistent and was decreasing with increased fertilizer rate and was dependent on season.

Table 2. 3: Nutrient concentration in maize plants at Changarawe site

Treatment	N (%) 2015	N (%) 2016	P (%) 2015	P (%) 2016	K (%) 2015	K (%) 2016	S (%) 2016	Zn (ppm) 2015	Zn (ppm) 2016
Control (1)	1.93	1.50	0.09	0.10	3.75	2.57	0.11	51.52	38.49
DAP2	2.07	1.54	0.10	0.12	3.95	2.86	0.22	37.82	32.99
DAP3	2.35	1.96	0.11	0.12	3.43	2.86	0.23	31.41	28.65
DAP4	2.17	1.89	0.10	0.12	3.90	3.39	0.20	22.53	35.46
DAP5	1.99	1.89	0.10	0.20	3.63	2.63	0.21	33.42	23.54
DAP6	2.14	1.70	0.12	0.16	4.68	2.62	0.14	32.36	24.33
Mean	2.11	1.75	0.10	0.14	3.89	2.82	0.19	34.84	30.58
Range	0.42	0.46	0.03	0.10	1.25	0.82	0.12	28.99	14.95
SD	0.15	0.20	0.01	0.04	0.43	0.31	0.05	9.58	6.08
Control (1)	1.93	1.50	0.09	0.10	3.75	2.57	0.11	51.52	38.49
MM2	2.14	1.82	0.11	0.14	4.48	2.70	0.23	54.04	20.77
MM3	2.10	1.75	0.12	0.17	3.03	2.66	0.22	42.39	30.65
MM4	2.59	1.54	0.12	0.13	5.49	2.35	0.22	47.84	26.46
MM5	2.24	1.68	0.10	0.19	4.60	2.62	0.19	43.15	21.84
MM6	2.76	2.03	0.13	0.16	5.33	3.15	0.21	50.64	26.92
Mean	2.29	1.72	0.11	0.15	4.45	2.68	0.20	48.26	27.52
Range	0.83	0.53	0.04	0.09	2.46	0.80	0.12	11.65	17.72
SD	0.32	0.20	0.01	0.03	0.94	0.26	0.01	4.70	6.47
Control (1)	1.93	1.50	0.09	0.10	3.75	2.57	0.11	51.52	38.49
TSP2	2.45	1.40	0.11	0.19	5.33	2.60	0.22	56.16	23.54
TSP3	2.35	1.82	0.10	0.19	5.17	2.55	0.22	47.94	25.18
TSP4	2.45	1.68	0.10	0.14	4.15	2.49	0.27	45.47	21.97
TSP5	2.56	1.89	0.12	0.21	4.03	2.59	0.25	48.81	21.97
TSP6	2.38	1.82	0.12	0.19	4.11	2.74	0.21	46.62	25.95
Mean	2.35	1.69	0.11	0.17	4.42	2.59	0.21	49.42	26.18
Range	0.63	0.49	0.03	0.11	1.58	0.25	0.16	10.69	16.52
SD	0.22	0.20	0.01	0.04	0.66	0.08	0.06	3.90	6.25

DAP is di ammonium phosphate, MM is Minjingu mazao and TSP is triple super phosphate; control (farmers not applying fertilizer) while fertilizer rates numbered 2 to 6 are 10 and 5, 20 and 10, 40 and 20, 60 and 30, 80 and 40 kg N and P/ha respectively. Data were subjected to descriptive statistical analysis.

Phosphorus uptake at Ilakala and Changarawe was affected by fertilizer type, fertilizer rate and cropping season (Figure 2.2). Ilakala had higher P uptake than Changarawe in all treatments. The nutrient uptake was 3 to 29 kg P/ha and 1 to 5.4 kg P/ha in the first year while in the second year the range was 16 to 37 kg P/ha and 1 to 5.3 kg P/ha at Ilakala and Changarawe respectively. At Ilakala, control had the lowest uptake in both cropping seasons, the first year had low P uptake in all fertilizer types and rates compared to the second year. Phosphorus uptake from DAP increased up to DAP5 (30 kg P/ha) during 2015 and DAP3 (10 kg P/ha) during 2016, and thereafter decreased. The P uptake in MM and TSP increased with increasing fertilizer rates up to the recommended 40 kg P/ha during 2015 while during the second year the trend decreased after MM3 and TSP4. At Changarawe, control plot had the lowest uptake in both cropping seasons. The second year had the lowest P uptake in all fertilizer types and rates compared to the first year. The P uptake increased with increasing fertilizer rate from 0 to 40 kg P/ha.

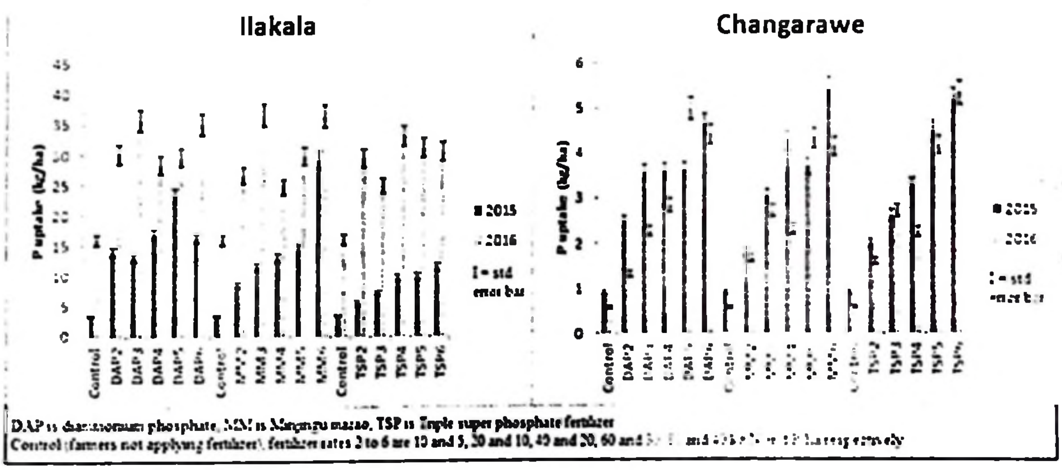
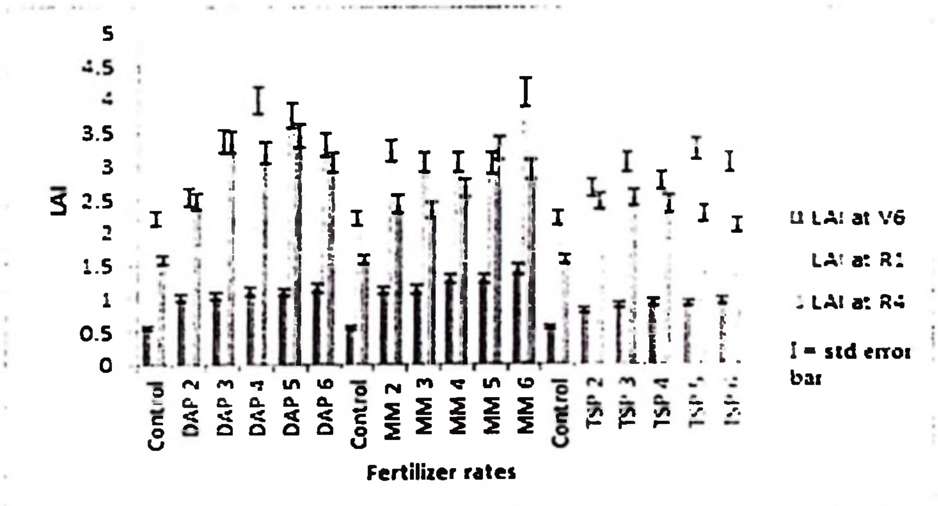


Figure 2. 2: Phosphorus uptake in maize plants at sixth leaf growth stage (V6)

2.4.3 Effects of fertilizer type and rates on crop growth

The effect of fertilizer type and micro-dose rates on leaf area index (LAI) is shown in Figure 2.3. Fertilizer application significantly improved LAI compared to the control (P= 0.001) at sixth leaf growth stage (V6) and silking growth stage (R1).

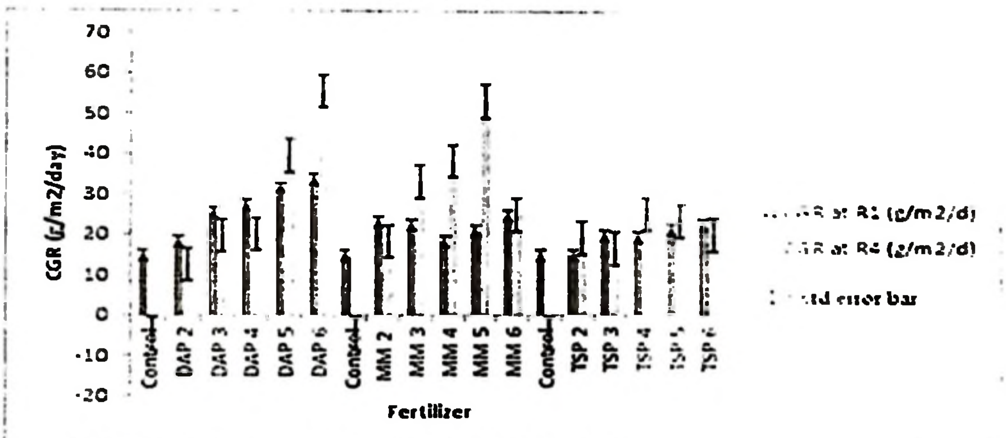
There was no significant increase in LAI at R1 and dough growth stage (R4) after addition of DAP4 and TSP4 (40 kg N and 20 kg P/ha). However, addition of MM3 (20 kg N and 10 kg P/ha) improved LAI similar to MM4 (40 kg N and 20 kg P/ha) and MM5 (60 kg N and 30 kg P/ha). At V6 growth stage, LAI was very low about 0.56 in control while the highest was 1.43 in Minjingu mazao fertilizer at the recommended rate (80 kg N and 40 kg P/ha). At R1 growth stage, the lowest LAI was 2.2 in control plots while the highest value was 4.1 in MM6. At R4 growth stage, the lowest LAI was 1.58 in control plots while the highest was 3.44 in DAP5. LAI was low at V6 and reached maximum at R1 and decreased slightly at R4.



DAP is diammonium phosphate, MM is Minjingu mazao, TSP is triple super phosphate. Control (farmers not applying fertilizer), fertilizer rates 2 to 6 are 10 and 5, 20 and 10, 40 and 20, 60 and 30, 80 and 40 kg N and P/ha respectively

Figure 2. 3: Leaf area index (LAI) at vegetative and reproductive stages under different fertilizer types and rates

Crop growth rate (CGR) under different fertilizer types and micro-dose rates is shown in Figure 2.4. Between sixth leaf growth stage (V6) and silking (R1) the rate of growth was generally low about 14.7 in control plot and very high 33.8 g m^{-2} day^{-1} in di-ammonium phosphate fertilizer at recommended rate (DAP6). While between silking (R1) and dough stage (R4), the rate of crop growth was increasing at decreasing rate of 4.7 in control plots while in micro-dose fertilizer rates the CGR increased up to 55.6 g m^{-2} day^{-1} in DAP6. Generally. CGR increased in all plots except control at reproductive growth stages which decreased rapidly by -4.7 g m^{-2} day^{-1}.



DAP is diammonium phosphate, MM is Minjingu mazao, TSP is triple super phosphate Control (farmers not applying fertilizer), fertilizer rates 2 to 6 are 10 and 5, 20 and [illegible] and 20, 60 and 30, 80 and 40 kg N and P ha respectively

Figure 2. 4: Crop growth rate (CGR) under different fertilizer types and rates

2.4.4 Effect of fertilizers on yield components, grain and total dry matter

The influence of fertilizer types and rates on yield components and yield at Ilakala site is shown in Table 2.4. In 2015 number of grains, 100 grain weight and grain yield were significantly higher in MM than DAP and TSP. Plant population at harvest was between 3.84 and 3.99 in 2015 while 2016 was between 3.9 and 4.1 plants m^{-2}. The number of grains were significantly higher in MM ($P= 0.003$) than DAP and TSP fertilizers during 2015. Also, fertilizer rates had highly significant effects on number of grains ($P= 0.001$) which increased from control to micro-doses and decreased slightly towards 6 (recommended rate). The weight of hundred grains was significantly influenced by fertilizer rates ($P= 0.001$) and increased with fertilizer application. Fertilizer types and rates had significant effects on grain yield ($P \leq 0.01$), the yield increased significantly with fertilizer application from control to rates three (3) and four (4) depending on season. Biological yields increased with fertilizer rates up to rate 5 and 6.

Table 2. 4: Effects of fertilizer types and rates on yield components and yields at Ilakala site

Treatment	2015 Plant (# m⁻²)	Grains (# m⁻²)	100 Grain wt (g)	Grain yield (kg/ha)	TDM at harvest (gm⁻²)	2016 Plant (# m⁻²)	Grains (# m⁻²)	100 Grain wt (g)	Grain yield (kg/ha)	TDM at harvest (gm⁻²)
Fertilizer										
DAP	3.83a	679.1a	34.69a	2373a	511.3ab	4.05a	1584a	32.59a	2596a	827.2a
MM	4.03a	754.5b	35.51a	2707b	539.9 b	4.16b	1580a	33.01a	2635a	841.4a
TSP	3.86a	680.2a	35.00a	2396a	488.1 a	3.98a	1671a	33.58a	2721b	846.1a
Mean	3.91	704.6	35.07	2492	513.10	4.06	1612	33.06	2651	838
CV (%)	3.40	3.12	5.92	3.00	1.90	0.43	19.5	6.9	1.20	16.7
SEM	0.05	16.91	0.74	2.20	14.38	0.028	74.00	0.539	1.52	32.9
P value	0.06	0.003	0.731	0.001	0.003	0.025	0.622	0.436	0.01	0.915
Rates										
1	3.99 a	409.1a	28.20a	1152a	313.0 a	4.12a	992a	29.3a	1492a	496.8a
2	3.89a	586.1b	35.42b	2064b	424.8 b	4.03a	1470b	33.07b	2394b	855.0b
3	3.90a	775.7c	37.62b	2888c	578.9 c	4.01a	1782b	33.12b	2590c	841.8b
4	3.84a	829.3c	35.87b	2930c	587.2 c	3.99a	1798b	34.24b	2938d	900.2b
5	3.93a	803.3c	36.90b	2938c	596.1 c	4.08a	1840b	34.25b	3229e	953.2b
6	3.92a	824.0c	36.38b	2980c	578.5 c	4.07a	1787b	34.40b	3264e	982.6b
Mean	3.91	704.60	35.07	2492	513.10	4.06	1612	33.06	2651	838.00
CV (%)	2.6	3.12	5.92	3.80	1.90	1.40	19.50	6.90	1.10	16.70
SEM	0.048	23.91	1.04	3.12	20.24	0.042	104.6	0.763	2.02	46.6
P value	0.38	0.001	0.001	0.001	0.001	0.429	0.001	0.001	0.001	0.001

Where: 1 = 0 and 0, 2 = 10 and 5, 3= 20 and 10, 4=40 and 20, 5 = 60 and 30, and 6 = 80 and 40 kg N and P/ha respectively. Numbers in same column followed by same letter(s) do not differ significantly at $P \leq 0.05$ according to Tukey's test.

At Changarawe site, effects of fertilizer types and rates on yield components and yield are shown in Table 2.5. In 2015, the number of grains and grain yields were significantly higher in MM than DAP and TSP. The number of plant at harvest was between 3.8 and 4.03 plants m^{-2}. The number of grains increased significantly in fertilizer types and rates ($P= 0.001$) during 2015 and 2016 at $P = 0.019$ and 0.001 for fertilizer types and rates respectively. The weight of hundred grains was highly significant in fertilizer rates ($P= 0.001$) with the lowest weight in rate 1. Grain yield was highly significant in fertilizer types and rates (P < 0.01) in both cropping seasons. The grain yields increased with fertilizer rates up to intermediate rates (4 and 5) and decreased at recommended rate. The yield increase was highly influenced by seasons where higher yields averaged 2572 kg/ha during 2015 while during 2016 yields were low averaging 1089 kg/ha. Biological yields increased with fertilizer rates to two folds in rates 5 and 6.

Table 2. 5: Effects of fertilizer types and rates on maize yield components and yields at Changarawe

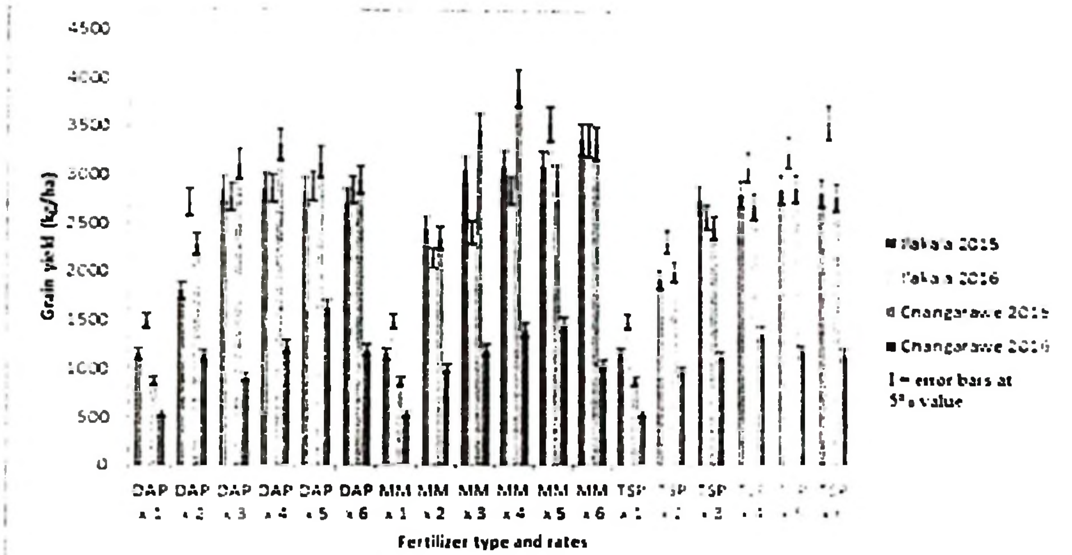
	2015					2016				
Treatment	Plant (#m^{-2})	Grains (# m^{-2})	100 Grain wt (g)	Grain yield (kg/ha)	TDM at harvest (gm^{-2})	Plant (# m^{-2})	Grains (# m^{-2})	100 Grain wt (g)	Grain yield (kg/ha)	TDM at harvest (gm^{-2})
Fertilizer (a)										
DAP	3.86a	853.7b	30.33a	2615b	859.4a	3.95ab	378.3b	29.15a	1107b	813.8b
MM	4.03b	946.2c	29.41a	2819c	897.6a	3.99b	366.0ab	29.80a	1105b	625.8a
TSP	3.89a	745.7a	30.16a	2287a	861.0a	3.89a	349.9a	29.75a	1056a	628.9a
Mean	3.924	849.00	29.97	2572	872.7	3.95	364.7	29.57	1089.3	689.5
CV (%)	2.90	6.60	1.40	6.60	2.50	2.10	3.60	2.20	3.60	10.3
SEM	0.030	29.10	0.812	9.17	21.44	0.024	4.01	0.231	0.752	12.92
P value	0.001	0.001	0.485	0.01	0.147	0.018	0.019	0.199	0.005	0.001
Rates (b)										
1	3.86a	352.5a	24.84a	874a	512.9a	3.90a	218.8a	24.55a	530a	454.0a
2	3.96a	729.0b	30.71b	2215b	717.8b	3.95a	376.4b	27.97b	1037b	601.8b
3	3.91a	957.5c	31.67b	3023cd	879.1c	3.89a	354.3b	30.48c	1076bc	662.0b
4	3.88a	1095.7d	30.65b	3309d	1000.8d	3.98a	433.1c	31.04c	1336d	808.0c
5	3.96a	988.9cd	30.55b	2992c	1067.7d	4.02a	441.9c	32.36d	1428e	792.4c
6	3.99a	967.7c	31.39b	3029cd	1057.6d	3.94a	364.0b	31.01c	1130c	818.9c
Mean	3.92	849.0	29.97	2572	872.7	3.95	364.7	29.57	1089.3	689.5
CV (%)	1.70	6.60	1.40	8.0	2.50	1.70	2.50	1.70	1.50	10.3
SEM	0.034	41.10	1.148	6.47	30.32	0.034	8.84	0.279	1.736	18.27
P value	0.065	0.001	0.001	0.001	0.001	0.088	0.001	0.001	0.001	0.001

Where: 1 = 0 and 0, 2 = 10 and 5, 3= 20 and 10, 4=40 and 20, 5 = 60 and 30. and 6 = 80 and 40 kg N and P/ha respectively. Numbers in same column followed by same letter(s) do not differ significantly at P≤ 0.05 according to Tukey's test.

2.4.5 Interaction effects of fertilizer types and rates on grain yield

The interaction effect between fertilizer types and rates was highly significant (P < 0.001) in grain yield in both first and second year (Figure 2.5). There was a positive increase from control to fertilizer rate 4 and 5 in DAP, MM and TSP fertilizer and thereafter yield decreased towards recommended rate in Ilakala and

Changarawe. Similar trend was observed during the second cropping season in both villages.



DAP is diammonium phosphate, MM is Minjingu mazao, TSP is triple super phosphate fertilizer. Rate 1 is control (farmers not applying fertilizer), rates 2 to 6 are 10 and 5, 20 and 10, 40 and 20, 60 and 30, and 80 and ... and ... P ha, respectively

Figure 2. 5: Interaction effects of fertilizer types and rates on grain yield (kg/ha)

The results indicated a high effect of the fertilizer rates on grain yield in both seasons and at both sites as presented in Figure 2.6. The Coefficient of determination (R^2 or r^2) denoting a ratio or percent of the explained variation to the total variation were 0.96 and 0.97 at Ilakala and 0.94 and 0.92 at Changarawe for the 2015 and 2016 seasons respectively.

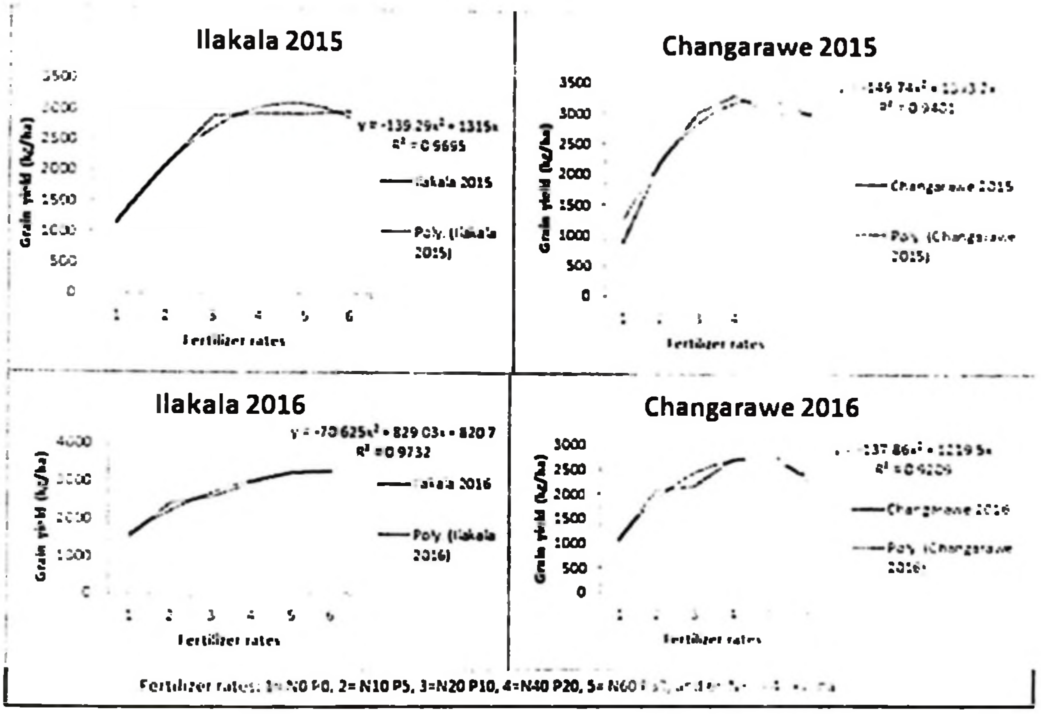


Figure 2. 6: Relationship between N and P rates and maize yield at Ilakala and Changarawe

2.4.6 Agronomic effectiveness of fertilizers used

Relative agronomic effectiveness (RAE) of Minjingu mazao (MM) fertilizer against DAP and TSP as standard fertilizers is shown in Table 2.6. At Ilakala site, during 2015 cropping season RAE of MM was 36.5% and 29.4% above the standard fertilizers DAP and TSP respectively. During 2016 cropping season, RAE for MM as a test fertilizer was 2% above DAP and 9.14% below the TSP as standard fertilizer. At Changarawe site, RAE in MM during 2015 was 11.10% and 38.5% above the standard fertilizers DAP and TSP respectively while during 2016 RAE was 7.2% and 9.2% above the standard fertilizers DAP and TSP respectively.

Table 2. 6: Relative agronomic effectiveness (RAE) of Minjingu mazao against DAP and TSP fertilizers

	Ilakala		Changarawe	
Fertilizer type	RAE (%) 2015	RAE (%) 2016	RAE (%) 2015	RAE (%) 2016
DAP	100	100	100	100
MM	136.5	102.0	111.1	107.2
CV (%)	27.14	40.05	11.53	38.6
SEM	16.57	18.27	5.73	18.50
TSP	100	100	100	100
MM	129.4	90.86	138.5	109.2
CV (%)	16.69	16.17	18.87	19.44
SEM	9.66	6.67	11.68	9.50

Data were subjected to descriptive statistics

2.5 Discussion

2.5.1 Soil characteristics and weather condition

Soils at Ilakala site were characterized by sandy loam and sandy clay with a neutral pH that was within the range suitable by most crops (Landon, 1991). Soils were characterized by low nitrogen mainly due to nature of the soil that is highly weathered and leached as reported by Szilas *et al.* (2005). Medium soil phosphorus levels was probably due to the medium soil pH which was between 6 and 7.5 which was ideal for P availability as reported by Foth and Ellis (1997) and Landon (1991). Zinc was below a critical level of 1 mg/kg required for crop production according to Landon (1991) probably was caused by soil pH in Ilakala (Landon, 1991; Foth and Ellis, 1997).

In Changarawe, soils texture was sandy clay loam and sandy loam with strongly acidic soil reaction due to leaching of basic cations caused by high rains in the area as observed by Foth and Ellis (1997). Nitrogen and phosphorus were very low mainly due to highly weathered and leached soils. Low pH values (<5.5) in soils probably reduced bacterial activities and nitrification of organic matter contributing to low N as reported by Landon (1991) and Prasad and Power (1997); also phosphate ions probably combined with iron and aluminium to form P-compounds not readily available (Landon, Op. cit). Low zinc in the soil below a critical level of 1 mg/kg required for crop production (Landon, Op. cit) was due to highly weathered acidic soil in Changarawe. These findings are in agreement with Amuri *et al.* (2013) who also worked in the same agro-ecological zone.

Variations in rainfall amount and distribution between Ilakala and Changarawe during the seasons are due to their distance from each other and differences in geographical locations. Ilakala site is hilly and surrounded by mountains and characterized by high vegetation cover such as forests contrary to Changarawe. There was a change in rainfall pattern between the two cropping seasons characterized by unexpected onset and erraticness as previously reported in Manyoni, Tanzania (Mary and Majule, 2009) and Accra, Ghana (Germer *et al.*, 2011). This inter- and intra-seasonal variation of rainfall could have been influenced by the impact of climate change (Kijazi *et al.*, 2012).

2.5.2 Nutrient concentration in maize crop

The deficiency of N during 2015 and 2016 (Table 2 and 3) reflected poor soil fertility (Table 2.1). However, soil N was improved by fertilizer application. Nitrogen concentration improved to sufficient range during 2016 at Ilakala and during 2015 at Changarawe due to good rainfall pattern (Figure 2.1) from seedling to sixth leaf growth stage indicating that availability and uptake was affected by soil moisture (Fageria *et al.*, 1997). Hochmuth *et al.* (2012) reported that soil N levels of 3 - 4% are adequate for maize production. Nitrogen concentration increased from control to fertilizer application in similar trend reported by Mourice *et al.* (2014).

Phosphorus was within adequate range of 0.3 – 0.5% reported by Hochmuth *et al.* (2012) in most fertilizer treatments (Table 2.2) for both cropping years due to fertilizer application in the soil with soil pH that was in the range ideal for P availability and uptake by plants as reported by Landon (1991) and Foth and Ellis (1997). However, at Changarawe site P was deficient in plants (Table 2.3) reflecting poor soil fertility status (Table 2.1). Also, excessive precipitation (Figure 2.1) in 2016 February, increased nutrient loss and reduced nutrient uptake due to poor aeration and death of root hairs (Fageria *et al.*, 1997).

Potassium was deficient in 2015 while 2016 the concentration increased to adequate range in Ilakala (Table 2.2) while in Changarawe K was adequate (Table 2.3) as reflected in soil fertility (Table 2.1) possibly due to the effect of other nutrients such as nitrogen and phosphorus concentration as well as precipitation during early vegetative stage (V1- V6) which promoted root growth and expansion for nutrient absorption from the soil which had adequate potassium (Fageria *et al.*, 1997). Hochmuth *et al.* (2012) reported that concentration of 2.5-4% K is adequate for optimum maize production.

Concentration of sulphur was deficient (<0.4%) (Hochmuth *et al.*, 2012) in all treatments at Ilakala (Table 2.2) and Changarawe (Table 2.3). However, N to S ratio was below 18: 1 indicating that S was in the range suitable for protein development. Zinc was deficient in plants at Ilakala (Table 2.2) while at Changarawe (Table 2.3) Zn was adequate (30-40 ppm) in both cropping years (Hochmuth *et al.*, 2012) due to increasing acidity in the soil as reported by Landon (1991) and moisture regime in the soil.

The phosphorus (P) uptake in maize plant at Ilakala was higher than Changarawe site because the experimental site at Ilakala had medium P while Changarawe had very low P in the soil. The results of P uptake in this study at Ilakala site are in the range reported by Muhawish *et al.* (2009) 24 to 45 kg P/ha in slightly alkaline soils with medium P. At Ilakala, P uptake was higher at micro-dose rates (10, 20 and 30 kg P/ha) than at recommended rate (40 kg P/ha) due to medium soil P which probably needed only small rates for maximum P uptake unlike the soil with low P status. The trend of P uptake at Ilakala was higher in the second year (2016) than first year (2015) due to high amount and good distribution of rainfall between seedling and sixth leaf growth stages in the second year unlike the first year which was characterized by prolonged dry spell (Figure 2.1) which affected nutrient uptake. The opposite was true for Changarawe which had higher nutrient uptake in the first year (2015) than the second year, probably caused by a dry spell from third week to sixth week after planting (Figure 2.1) which coincided with seedling and sixth leaf growth stage and affected nutrient uptake due to moisture stress as observed by Fageria *et al.* (1997). Therefore, nutrient uptake especially P was highly affected by moisture stress in the soil, initial soil P as well as P fertilizer sources and rates.

2.5.3 Crop growth, yield and yield components

As expected LAI was low (1.43) at sixth leaf growth stage but increased to maximum (4.1) at silking growth stage and thereafter decreased gradually to 3.44 at dough growth stage (Figure 2.3). Such results are documented by Portes and de Melo (2014). LAI was the lowest in control plots; this reflects the importance of applying fertilizer which supplies nitrogen in the soil with low fertility status (Table 2.1) for crop growth and development as stated by Fageria *et al.* (1997). The reports by Nguy-Robertson *et al.* (2012) and Fageria *et al.* (1997) indicate that optimum LAI is between 3 and 5 for optimum growth. Some plots treated with fertilizer had LAI below the optimum (<3) , such results could be due to dry spell at boot (V13), tasseling (VT) and silking (R1) growth stages (Figure 2.1).

Crop growth rate (CGR) increased from sixth leaf growth stage (V6) to silking (R1) following the same trend as LAI due to increased photosynthesis which is influenced by leaf surface area. The increasing trend of LAI (Figure 2.3) resulted into more dry matter accumulation and crop growth rate (Figure 2.4) as significant positively correlated ($r = 0.94^*$) by Portes and de Melo (2014). Such results were also reported by Sani *et al.* (2014) ranging between 11 and 16.7 g $m^{-2}day^{-1}$ in Nigeria and Adepo and Olaoye (2010) between 28 and 41 g $m^{-2}day^{-1}$ at tasseling. In control treatment the rate of growth was decreasing from silking (R1) to dough stage (R4) due to loss of leaves and decreased photosynthetic activity as reported by Hokmalipour and Darbandi (2011).

Fertilizer types and rates applied increased total dry matter (TDM) production averaging 5.13 – 8.72 t/ha, comparable results have also been reported by Kisetu *et al.* (2014) and Mourice *et al.* (2014) also working in Morogoro Region. The results indicate that even under unreliable rainfall conditions farmers could still get TDM for livestock feed and other uses as observed by De Groote *et al.* (2013) in Tanzania and Aune and Coulibaly (2015) in West Africa. Grain yield at both sites indicate that Minjingu mazao (MM) was the best fertilizer for use under farmers' conditions. The MM fertilizer produced on average 2317 kg/ha which was 6.6% and 9.6% more than DAP and TSP, respectively. This could be due to multiple nutrient content and ability to supply both macro-nutrients (N, P, Mg, S, Ca) and micro-nutrients (B, Zn) (Minjingu Mines and Fertilizers, 2014) which improved nutrient concentration in plants (Table 2.2 and 2.3), nutrient uptake (Figure 2.2) and LAI (Figure 2.3). Fertilizer micro-dose rates at 2 (10kg N and 5 kg P/ha) and 3 (20 kg N/ha and 10 kg P/ha) increased yield by 912-1736, 902-1098 kg/ha in Ilakala; 1341-2149, 507-546 kg/ha in Changarawe during 2015 and 2016 cropping seasons, respectively. The trend of yield increase reported in this study is similar to that observed by Mourice *et al.* (2014) and Amuri *et al.* (2013). However, at Changarawe village during 2016 results were highly affected by drought from 3rd to 9th week after planting (Figure 2.1). Fertilizer rates (40 kg N and 20 kg P/ha) and (60 kg N and 30 kg P/ha) performed almost the same as recommended rate. Our study was carried out in only two locations; however, we consider the sites highly representative for large sub-humid tropical regions with sandy loam and sandy clay soils typical for this agro-ecological zone (IUSS Working Group WRB, 2015).

2.5.4 Fertilizer affordability by smallholder farmers

It is suggested that the reported rates 50% (40 kg N and 20 kg P/ha) and 75% (60 kg N and 30 kg P/ha) from this study be recommended to replace the current recommendation of 80 kg N and 40 kg P /ha for the Eastern zone including Kilosa in these areas (Marandu *et al.*, 2014). Further, the current results from micro dosing rates of N and P are in agreement with rates suggested by J.M.R Semoka (2017, Personal Communication). In most Agro shops found in Tanzania, MM is sold at Tsh 35,000 – 40,000/= per bag of 50 kg while DAP and TSP are sold at 60,000 - 90, 000/= per 50 kg bag during 2014/15 and 2015/16 cropping seasons. The relative agronomic effectiveness (RAE) indicated that Minjingu mazao (MM) fertilizer had RAE more than 100% (Table 2.6), suggesting that MM was superior to DAP and TSP used as standard fertilizers in this study. Therefore, MM fertilizer is an affordable source of P with higher RAE. This result is in agreement with Muhawish *et al.*(2009) who reported that phosphate rock fertilizers with low and medium P solubility had higher RAE (113% <) than higher solubility fertilizers such as TSP.

The results reported on grain in this study are slightly higher than those reported by DTMA (2014) and other researchers who have worked under Tanzania's farmers' field conditions. Such results could have been contributed by relatively large grain size reported in this study that ranged from 29.57 to 35.07 g/ 100 grains. The grain weight reported in this study was also found to be significantly correlated to grain yield (r = 0.913* to 0.964**).

2.6 Conclusions and Recommendations

Minjingu mazao fertilizer performed better than DAP and TSP in this study. Micro-dosing fertilizer increased yield by 90.5% and 136.5% at 10 kg N and 5 kg P/ha (12.5% of recommended rate) and 20 kg N and 10 kg P/ha (25% of recommended rate) than control, respectively. Intermediate fertilizer rates produced more grain yield by 1.0% and 1.1% at 40 kg N and 20 kg P/ha (50% of recommended rate) and 60 kg N and 30 kg P/ha (75% of recommended rate) compared to recommended rate (80 kg N and 40 kg P/ha), respectively.

A combination of fertilizer rates of 10 kg N and 5 kg P ha^{-1} (12.5% of recommended rate) as well as 20 kg N and 10 kg P ha^{-1} (25% of recommended rate) are the appropriate micro-dose fertilizer rates for maize production in the study site and other areas with similar conditions. The fertilizer micro-doses recommended from this study will improve crop productivity under smallholder farming systems in sub-humid tropical regions. Also, intermediate rates of 40 kg N and 20 kg P ha^{-1} (50%of recommended rate) as well as 60 kg N and 30 kg P ha^{-1} (75%of recommended rate) are recommended to replace 80 kg N and 40 kg P/ha

(Marandu *et al.*, 2014) for resource endowed farmers who can afford higher application rates. Also, fertilizer package has to include lower amount such as 5, 10, 20 and 25 kg bag to accommodate micro-dose strategy and affordability to resource poor farmers who can rarely afford to buy a 50 kg bag package. It is important to avail locally produced cheap fertilizers if they have a lower market price and good agronomic effectiveness.

2.7 Acknowledgement

This work is a product of the Trans SEC project for food security in Africa, funded by the Germany Federal Ministry of Education and Research (BMBF) and the Germany Federal Ministry for Economic Cooperation and Development (BMZ).

2.8 References

Adams, A. M., Gillespie, A. W., Kar, G., Koala, S., Ouattara, B., Kimaro, A. A., et al. (2016). Long term effects of reduced fertilizer rates on millet yields and soil properties in the West-African Sahel. *Nutr Cycl Agroecosyst. 106*: 17 - 29.

Adepo, F. A., and Olaoye, G. (2010). Growth indices and Grain Yield Attributes in Six Maize Cultivars Representing Tow Era of Maize Breeding in Nigeria. *Journal of Agricultural Science. 2*(3): 218 - 228.

Amuri, N., Semoka, J. M., Ikera, S., Kulaya, I., and Msuya-Bengesi, C. P. (2013). Enhancing Use of Phosphorus Fertilizers for Maize and Rice Production in Small Scale Farming in Eastern and Northern Zones, Tanzania. *The 27th Soil Science Society of East Africa- 6th African Soil Science Society Conference*. Nakuru, Kenya: Soil Science Society of East Africa. 1 12pp.

Aune, J. B., and Bationo, A. (2008). Agricultural intensification in the Sahel- The ladder approach. *Agricultural Systems* 98: 119 - 125.

Aune, J. B., and Coulibaly, A. (2015). Microdosing of Mineral Fertilizer and Conservation Agriculture for sustainable agricultural intensification in Sub-Saharan Africa. In: *Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa*. (Edited by R. Lal, B. R. Singh, D. L. Mwaseba, D. Kraybill, D. O. Hansen, and O. L. Eik), Springer International Publishing Switzerland. pp. 223 - 234.

Bender, R. R., Haegele, J. W., Ruffo, M. L. and Below, F. F. (2013). Nutrient uptake, partitioning and remobilization in modern transgenic insect-protected maize hybrids. *Agronomy Journal* 105(1): 161 - 170.

Camara, B. S., Camara, F., Berthe, A. and Oswald, A. (2013). Micro-dosing of fertilizer- a technology for farmers' needs and resources. *International Journal of Agri Science* 3(5): 387 - 399.

CIMMYT (2013). *Yield and yield components: A practical guide for comparing crop management practices.* Mexico: International Maize and Wheat Improvement Center. 28pp.

De Groote, H., Dema, G., Sonda, G. B., and Gitonga, Z. M. (2013). Maize for food anf feed in East Africa- The farmers' perspective. *Field Crops Research* 153: 22 - 36.

Druilhe, Z., and Barreiro-hurle, J. (2012). *Fertilizer subsidies in sub- Saharan Africa. ESA Working paper No. 12-04.* Rome: FAO. 73 pp.

DTMA. (2014). *Drought Tolerant Maize for Africa. Quarterly Report.* [http://dtma.cimmyt.org/] site visited 20th November 2016.

Fageria, N. K., Baligar, V. C., and Jones, C. A. (1997). *Growth and Mineral Nutrition of Field Crops.* New York: Marcel Dekker Inc. 624 pp.

FAO (2000). *Fertilizers and their use: A pocket guide for extension officers* (Fourth edition ed.). Rome, Italy: Food and Agriculture Organization of the United Nations International Fertilizer Industry Association. 34pp.

Foth, H. D., & Ellis, B. G. (1997). *Soil Fertility.* Second Edition. Florida: CRC Press Inc. 290 pp.

Germer, J., Addai, S., and Sauerborn, J. (2011). Response of grain sorghum to fertilisation with human urine. *Field Crop Research* 122: 234 - 241.

Gomez, K. A., and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research.* Laguna, Philippines: John wiley and Sons. 680 pp.

Graef, F., Sieber, S., Mutabazi, K., Asch, F., Biesalki, H. K., Bitegeko, J., et al. (2014). Framework for participatory food security research in rural food value chains. *Global Food Security* 3: 8 - 15.

Hayashi, K., Abdoulaye, T., Gerard, B. and Bationo, A. (2008). Evaluation of application timing in fertilizer micro-dosing technology on millet production in Niger, West Africa. *Nutr Cycl Agroecosyst* 80: 257 - 265.

Hochmuth, G., Maynard, D., Vavrina, C., Hanlon, E., and Simone, E. (2012). *Plant tissue analysis and interpretation for vegetable crops in Florida.* Institute of Food and Agricultural Sciences Univeristy of Florida, The Horticultural Sciences. Florida: Florida Cooperative Extension Service. 48pp.

Hokmalipour, S., and Darbandi, M. H. (2011). Physiological Growth Indices in Corn (Zea mays L.) Cultivars as Affected by Nitrogen Fertilizer Levels. *World Applied Sciences Journal* 15(12): 1800 - 1805.

IFDC (2012). *Tanzania Fertilizer Assessment.* Alabama. USA: International Fertilizer Development Center. 51 pp.

IUSS Working Group WRB. (2015). *World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps.* World Soil references Reports no. 106. FAO, Rome. 203 pp.

Kajembe, G. C., Silayo, D. A., Mwakalobo, A. B., and Mutabazi, K. (2013). *The Kilosa Disrtict REDD Pilot Project, Tanzania: A Socioeconomic baseline study.* London, UK: International Institute for Environment and Development (IIED). 50 pp.

Kanyeka, E., Kamala, R., and Kasuga, R. (2007). *Improved agricultural technologies recommended in Tanzania.* First Edition. Dar es salaam, Tanzania: Department of Research and Development in the Ministry of Agriculture Food Security and Cooperatives. 144 pp.

Kijazi, A. L., Chang'a, L. B., Liwenga, E. T., Kanemba, A. and Nindi, S. J. (2012). The use of indigenous nowledge in weather and climate prediction in Mahenge and Ismani Wards, Tanzania. *Proceedings of the first Climate Change Impacts, Mitigation and Adaptation Programme Scientific Conference.* Dar es salaam: The Climate Change Impacts, Adaptation and Mitigation (CCIAM) Programme. pp. 42 - 48.

Kisetu, E., Lily, S., Temba, W. J., and Rwebangila, A. P. (2014). Effect of nitrogen and phosphorus on performance of maize planted at the varying soil depths. *International Journal of Agricultural Policy and Research* 2(3): 090 - 097.

Kisinyo, P. O. and Palapala, V. A. (2016). Maize response to micro dose inorganic inputs on acid smallholder farm in Kenyan Midland. *Journal of Agricultural Science and Food Technology* 2(8): 125 132.

Landon, J. R. (1991). *Booker Tropical Manual. A handbook of soil survey and agricultural land evaluation in the tropical and subtropical.* Longman. 474 pp.

Lyimo, S., Mduruma, Z., and De Groote, H. (2014). The use of improved maize varieties in Tanzania. *African Journal of Agricultural Research* 9 (7): 643 - 657.

Marandu, A. E., Mbogoni, J. D., and Ley, G. J. (2014). *Revised Fertilizer Recommendations for Maize and Rice in the Eastern, Southern Highlands and Lake Zones of Tanzania.* Department of Research and Development. Dar es salaam: Ministry of Agriculture Food Security and Cooperatives. 40 pp.

Mary, A. L., and Majule, A.E. (2009). Impacts of climate change, variability and adaptation strategies on agriculture in semi arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania. *African Journal of Environmental Science and Technology* 8 (3): 206-218.

McClauley, A., Jones, C. and Jacobsen, J. (2009). Commercial Fertilizers and Soil Amendments. In M. S. Extension, *Nutrient Management Module* (Vol. Module No.10). Montana: Montana State University. 1 20 pp.

Minjingu Mines and Fertilizers (2014). *Developing indigenous Resources for Fertilizer Production in Africa.* Minjingu Mines and Fertilizer Ltd. 20 pp.

Montgomery, D. C. (2013). *Design and analysis of experiments.* Eighth edition. New York, USA: John Wiley and Sons, Inc. 757 pp.

Mourice, S. K., Rweyemamu, C. L., Nyambilila, A. A. and Tumbo, S. D. (2014). Narrowing Maize Yield Gaps Under Rain-fed conditions in Tanzania: Effect of small Nitrogen Dose. *Tanzania Journal of Agricultural Sciences* 12(2): 55-65.

Muhawish, N. M. and Razaq, I. B. (2009). Agronomic Effectiveness of a New Formula of Phosphate Fertilizer I- Initial Agronomic Effectiveness. *Journal of tikrit university for Agricultural Sciences* 9(2): 617 - 625.

Murendo, C. and Wollni, M. (2015). *Ex-post impact assessment of fertilizer microdosing as aclimate-smart Technology in Sub-Saharan Africa.* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 27pp.

NAP (2013). *National Agricultural Policy.* Dar es salaam, Tanzania: Ministry of Agriculture Food Security and Cooperatives. 51pp.

NBS (2012). *National Sample Cencus of Agriculture 2008* (Vol. Ve). Dar es salaam, Tanzania, Morogoro. National Bureau of Statistics. 353 pp.

NBS. (2013). *The 2012 Population and Housing Census. Population distribution by Administrative Areas* . Dar es salaam. Tanzania: National Bureau of Statistics. 264 pp.

Nguy-Robertson, A., Gitelson, A., Peng, Y., Vina, A.. Arkebauer, T., and Rundquist, D. (2012). Green Leaf Area Index Estimation in Maize and Soybean: Combining vegetation indices to Achieve Maximal Sensitivity. *Agronomy Journal 104*(5): 1336 - 1347.

Ogoke, I. J., Egesi, C. N., and Obiefuna, J. C. (2003). A Review of some non-destructive linear measurement procedures for leaf area determination in crops. *Int. J. Agricu. Rural dev.1 4*: 74-80.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. (1993). *Laboratory methods of soil and plant analysis: A working manual.* Tropical Soil Biology and Fertility Programme (TSBF), Soil Science Society of East Africa (SSSEA) Technical Publication No.1, Nairobi, Kenya. 88pp.

Okebalama, C.B., Safo, E.Y., Yeboah, E., Abaidoo. R.C. and Logah, V. (2016). Fertilizer micro-dosing in humid forest zone of Ghana: An efficient strategy for increasing maize yield and income in smallholder farming. *Soil Sci. Soc. Am. J.* 80(5): 1254 – 1261.

Okebalama, C.B., Ibrahim, A., Safo, E.Y., Yeboah. E., Abaidoo, R.C., Logah. V. and Monica, U.I. (2017). Fertilizer micro-dosing in West African low-input cereals cropping: Benefits, challenges and improvement strategies. *African Journal of Agricultural Research* 12 (14): 1169 – 1176.

Pale, S., Mason, S. C., and Taonda, S. J. (2009). Water and fertilizer influence on yield of grain sorghum varieties produced in Burkina Faso. *S. Afr. J. Plant Soil, 26*(2): 91-97.

Portes, T. d., and de Melo, H. C. (2014). Light interception. leaf area and biomass production as a function of the density of maize plants analyzed using mathematical models. *Acta Scientiarum. Agronomy 36*(4): 457- 463.

Prasad, R., and Power, J. F. (1997). *Soil Fertility Management for Sustainable Agriculture.* New York, USA: CRC Press. Lewis Publishers. 356pp.

Sani, B. M., Abubakar, I. U., Falaki, A. M., Mani. H., and Jaliya, M. M. (2014). Agro Physiological characteristics of quality protein maize genotypes as influenced by irrigation and plant population in semi arid Region of Nigeria. *African Journal of Agricultural Research. 9*(5): 527- 532.

Sime, G. and Aune, J. B. (2014). Maize response to fertilizer dosing at three sites in the Central Rift Valley of Ethiopia. *Agronomy* 4 (3): 436 – 451.

Soil survey staff (2014). *Soil survay field and laboratory methods manual.* (R. Burt, & Soil survey staff, Eds.) USA: Department of Agriculture. Natural Resource Conservation Service. 487pp.

Suleiman, R. A., and Rosentrater, K. A. (2015). Current maize production, postharvest losses and the risk of mycotoxins contamination in Tanzania. *Agricultural and Biosystems Engineering Conference Proceedings and Presentations.7-2015.* St. Joseph, Michigan: Iowa State University. An ASABE Annual International Meeting Paper Number 152189434. 127 pp.

Szilas, C., Moberg, J. P., Borggaard, O. K., and Semoka. J. M. (2005). Mineralogy of Characteristic well-drained soils of sub-humid to humid Tanzania. *Acta Agriculturae Scandinavica, Section B- Soil and Plant Science* 55(4): 241 - 251.

CHAPTER THREE

3.0 EFFECTS OF SOIL MOISTURE MANAGEMENT AND FERTILIZER MICRO-DOSING ON YIELD AND RESOURCE UTILIZATION INDICES OF INTERCROPPING MAIZE-PIGEON PEA IN SUB HUMID TROPICS

3.1 Abstract

Declining soil fertility and moisture stress are among the main causes of low crop productivity resulting into scarcity of food and income insecurity. Nitrogen and phosphorus fertilizer micro-dosing along with inter-row rainwater harvesting practices may improve land use efficiency, monetary value and nutritional quality of maize intercropping. A two year field experiment was conducted on sandy loam soils at two sites in sub humid Tanzania using a 3x3x3 split-split plot design. The main plots were tied ridges, open ridges and flat cultivation: sub-plots were sole maize, sole pigeon-pea and 1:1 maize-pigeon pea intercropping and sub-sub plots were no fertilizer, fertilizer (N and P) application at micro-dose level and recommended rate of fertilizer. Tied ridges conserved soil moisture 13.33% more than flat cultivation at 30 cm depth after ten days of rainfall. Ridges increased maize yield by 8 – 15% compared to flat cultivation. Fertilizer increased maize yield by 93 % at micro-dosing and 132% at recommended rates compared to control. Tied ridges and fertilizer increased maize yield by 90% and pigeon pea yield by 20% than flat cultivation without fertilizer. Land use efficiency was 28-100% higher in intercropping than sole crop. The highest monetary value was 2 – 4 million shillings per hectare under maize-pigeon pea intercropping + fertilizer. Tied ridges conserved more soil moisture than flat cultivation which enhanced

fertilizer use efficiency that improved crop yield and land equivalent ratio under intercropping. This strategy could increase food availability and income generation under smallholder farming systems of the sub-humid tropics.

Key words: Cropping systems, fertilizer micro-dosing, land utilization, rainwater harvesting

3.2 Introduction

Maize (*Zea mays* L.) is the most important cereal crop in Sub-Saharan Africa (SSA) grown for both food and cash (Smale *et al.*, 2011; Sulc *et al.*, 2014; Suleiman and Rosentrater, 2015). Current smallholders' maize productivity is low averaging 1.0-1.5 t/ha compared with potential of 5.0 to 7.5 t/ha (Cameron *et al.*, 2017). Intercropping maize and pigeon-pea create a win-win situation during crop management. Pigeon-pea (*Cajanus cajan* L.) is among the pulses which is a source of protein (Janila *et al.*, 2016) and the yield in smallholders' farms is 0.5 – 0.7 t/ha, which is only 20 - 26% of its potential.

Declining soil fertility and moisture stress are among the main factors causing low crop productivity, food insufficiency, poor nutrition and income insecurity. Fertilizer use by smallholder farmers is low, averaging 16 kg/ha in SSA (Cameron *et al.*, 2017) and 19 kg/ha in Tanzania (MALF, 2017). This is less than 40% of the African Union's Abuja Declaration Commitment to increase fertilizer use to 50 kg/ha (Cameron *et al.*, 2017). Also, inadequate rainfall and poor distribution results into prolonged dry spells which are becoming a common problem to smallholder farmers causing low crop yields mainly due to soil moisture stress. Rowhani *et al.*

(2011) reported that 20% increase in intra-seasonal precipitation variability reduced yield by 4.2 % for maize. Most of SSA is characterized by unpredictable pattern and distribution of rainfall among months (Msaki *et al.*, 2015) due to climate change. Low rainfall and poor runoff management practices under flat cultivation commonly used by smallholder farmers increase water loss, moisture stress, soil erosion and affect plant nutrient availability and uptake (NRSP, 2005). A prolonged dry spell and changes in rainfall pattern results into low crop yield and shrinkage of grazing land, which increase conflicts between crop producers and pastoralist (Cabot, 2017; Roseline and Amusain, 2017; Walwa, 2017). Research results have shown that inter-row water harvesting techniques restore land productivity and increase crop yields in rain-fed farming areas and minimize risks in drought prone areas (Prinz, 1996). To mitigate rainfall shortage problem in some seasons there is a need to use inter-row rainwater harvesting methods.

Low fertilizer adoption by smallholder farmers are mainly due to inadequate knowledge on fertilizer usage (Druilhe and Barreiro-Hurlé, 2012), untimely availability of inorganic fertilizers and low affordability (MALF, 2017). Hence, fertilizer micro-dosing technology may address the problem of no fertilizer usage by applying small amounts of 25 – 33 % of the rates recommended by advisory services in SSA (Camara *et al.*, 2013). This application rate is an entry point to fertilizer use in sub-humid tropical areas and it has proven to be advantageous in semi-arid and arid conditions of Africa in countries such as Mali, Niger, Ethiopia, Burkina Faso and Zimbabwe (Aune and Coulibaly, 2015; Adams *et al.*, 2016). Research results have shown that inter-row water harvesting techniques such as tie ridging restore land productivity and increases crop yields in rain-fed farming areas and minimizes risks in drought prone areas (Prinz, 1996). Inter-row rainwater harvesting traps, holds and conserves water in a soil profile (Nuhu and Mahoo, 2000); this increases nutrient availability and fertilizer use efficiency. The influence of micro-dose fertilizer rates and soil moisture conservation through inter-row rainwater harvesting on maize and pigeon-pea intercropping system is still inadequately documented in sub humid Tropical conditions.

In SSA, most smallholder farmers grow pigeon-pea under mixed or intercropping system together with other cereal crops such as maize in semi-arid Tanzania (Kimaro *et al.*, 2009) and sub-humid Tanzania (Myaka *et al.*, 2006), pigeon-pea with maize and sorghum in Guinea Savanna Nigeria (Egbe and Adoko, 2012), pigeon-pea and sorghum in Eritrea (Weldeslassie *et al.*, 2016). Maize and pigeon-pea are intercropped for food, cash, soil fertility improvement through nitrogen fixation and organic matter, fodder and firewood production, yield advantages under water stress conditions and suppression of weeds and other pests (Sharma *et al.*, 2011). Growing two or more crops in proximity promote interactions that might be facilitative or competitive or complementary on capture and use of growth resources such as light, water and nutrients (Francis, 1986; Zhang and Li, 2003; Kimaro *et al.*, 2009). Intercropping has been reported to increase land use efficiency by 66% in Nigeria (Dania *et al.*, 2014) and could reduce land use conflict compared to sole crop. Therefore, maximizing land utilization by intercropping maize and pigeon-pea and use of improved technologies such as fertilizers are becoming very vital.

The objectives of this study were to examine the influence of inter-row rainwater harvesting methods as well as nitrogen and phosphorus micro-dosing on yield, land use efficiency and financial returns of maize and pigeon-pea sole and intercropping systems in the sub-humid tropical areas of Tanzania.

3.3 Materials and Methods

3.3.1 Location

Field experiments were conducted at Ilakala village in Ulaya ward and Changarawe village in Masanze ward, Kilosa District in Morogoro Region of Tanzania. Ilakala study site is located at 07°08′07″ South, 036°55′12″ East and 599 m above sea level, while Changarawe site is at 06°54′55.5″ South, 036°57′11.5″ East and 502 m above sea level. Rainfall in this sub-humid area is usually bimodal where the short annual rain season ("*Vuli*") starts in November and ends in January while the long rain season ("*Masika*") starts in February or early March and ends in late May. However, inter-seasonal and intra-seasonal variations are common in the area (Rowhani *et al.*, 2011). Rainfall during the long season ranges from 400 - 800 mm. The overall annual rainfall ranges between 800 and 1400 mm while average temperature is about 25°C (Kajembe *et al.*, 2013) which is typical of sub humid tropical conditions. Soils in Ilakala and Changarawe are categorized as Haplic Acrisols and Mollic Fluvisols (Trans SEC Project, 2017).

The study site in Ilakala was previously grown with pigeon-pea and the remaining part was under local vegetation. The average slope at the site is 9.7% determined as shown in Equation 1.

$$Slope = \frac{Height\ (m)}{Horizontal\ (m)} X\ 100\% \text{ .... equation 1}$$

The study site in Changarawe had been under fallow from 2011 - 2013 and in 2013/14 season, the site was used for sesame (*Sesamum indicum* L.) production. The slope of the Changarawe trial site was 11.5%.

3.3.2 Materials

Maize variety "*TMV1*"was used. The variety is medium maturing (110 days) and is an open pollinated variety (OPV) which is commonly grown in the study areas (Kanyeka *et al.*, 2007). Pigeon-pea "*Babati white*" variety is commonly used in the area (Myaka *et al.* 2006).This is a long maturing variety which takes about nine months to mature (Saxena *et al.*, 2010). Fertilizers used were di-ammonium phosphate DAP $(NH_4)_2HPO_4$) a granulated solid fertilizer (18% N and 46% P_2O_5) (McCauley *et al.*, 2009) and urea (46% N).

3.3.3 Methods

One experiment in each village was laid out in split-split plot under randomized complete block design (RCBD) as described by Montgomery (2013). The main plot was moisture management options: tied ridges, open ridges and flat cultivation. While the sub- plot treatment was cropping systems: maize sole crop, pigeon-pea sole crop and 1:1 intercropping of maize with pigeon-pea as described by Natarajan (1990). The sub- sub plot treatment was fertilizer application rates: control (0 kg P and 0 kg N/ha), micro-dosing rate (10 kg P and 20 kg N/ha in maize; 10 kg P and 9 kg N/ha in pigeon-pea) and recommended rates of 40 kg P/ha and 80 kg N/ ha for maize (Marandu *et al.*, 2014) and 20 kg P/ha (Kumar Rao *et al.*, 1995) and18 kg N/ha for pigeon-pea.

Ridges were 75 cm apart with 20 cm height; the distance between ties was 150 cm as recommended by Edje and Ossom (2010). Phosphate fertilizer (DAP) was applied at planting by banding method of placing fertilizer in holes and covering by soil on both maize and pigeon-pea crops. Spacing for maize was 75 cm x 30 cm and 75 cm x 50 cm for pigeon pea resulting into one plant per hill. Urea was applied in maize at fourth leaf vegetative stage (V4) as recommended by Kanyeka *et al.* (2007).

3.3.4 Data collection

3.3.4.1 Soil and rainfall data

Soils were sampled and analyzed as described by Soil Survey Staff (2014) at a depth of 0 – 15 cm and 15 – 30 cm. Soil analysis included particle size distribution for textural class by Hydrometer method, soil pH by pH meter in 1:2.5 soil-water, organic carbon by Walkley- Black Method, total nitrogen by Kjedahl digestion method, available phosphorus by Bray and Kurtz 1, exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) in NH_4-acetate filtrates by Ammonium Acetate saturation and available micronutrients (Zn, Cu, Mn and Fe) by the DTPA extraction method. Soil moisture content was determined using a Delta T device Moisture Meter type HH2 in percentage (% Vol) as described by Delta T Devices Ltd (2013). Daily rainfall data were collected from the study sites where rain gauges were installed during the 2014/15 and 2015/16 cropping seasons.

3.3.4.2 Yields of maize and pigeon-pea

Crops were harvested at maturity from a harvest area of 3 m^2 and grain yields were collected, measured and converted into kg/ha following the procedures described by CIMMYT (2013) for maize and pigeon-pea as proposed by ICRISAT (1992) in both sole and intercropping plots.

3.3.4.3 Prices of crops

The current prices of maize and pigeon-pea after harvest were collected in the village from 15 key informants that included extension officers, project research assistants and farmers growing the crops. The currency used was Tanzanian shillings (TZS), exchange rate was between 2150 and 2282 TZS to one US dollar from 2016 to 2018 (XE Corporation, 2018).

3.3.4.4 Monetary values

The monetary values of crops were calculated from yield and price data as described by Federer (1993) and shown below:

$V = K1Y1 + K2Y2$.. equation 2

Where: *K1* and *K2* are yields of maize and pigeon pea respectively while *Y1* and *Y2*are prices of the respective crops; *V* is the financial return value.

3.3.5 Data analysis

Data collected and calculated financial values were subjected to analysis of variance (ANOVA) basing on the statistical model for the split-split-plot design as follows:

$Y_{ijkm} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \omega_{ijk} + C_m + AC_{jm} + BC_{km} + ABC_{jkm} + \varepsilon_{ijkm}$.

equation 3

Where: Y_{ijkm}= Response level, μ = general mean, β_i block effect, A_j = main plot effect, δ_{ij} = the main plot random error (Error a). B_k sub-plot effect. AB_{jk}= interaction effect between the main plot and the sub-plot. ω_{ijk} subject error (Error b), C_m = sub-subplot effect. ABC_{jkm} = the three way (Factors A* B* C), and ε_{ijkm}= sub-sub-plot random error effect (Error c) was used to test the treatment effects on the indices calculated.

Comparison of means was done using Tukey's test at $p < 0.05$ as described by Montgomery (2013).

Land equivalent ratio (LER) is the relative land area under sole crops that is required to produce the yields achieved by intercropping. It is an index of biological advantage used to compare the effectiveness of the intercropping system used in the study as proposed by Federer (1993) where yields from intercrop and sole crop of each crop were used as follows:

$$LER = \frac{Xi}{Xs} + \frac{Yi}{Ys} \quad \text{.......... equation 4}$$

Where X and Y are the component crops namely maize and pigeon-pea in the sole (s) and intercrop (i).

3.4 Results

3.4.1 Soil characteristics and weather conditions

Soil characteristics at Ilakala and Changarawe study sites are presented in Table 3.1. Soil texture was sandy loam at both sites. Soil pH was medium acidic to neutral (6.6- 7.3) at Ilakala and medium acidic to strongly acidic at Changarawe. Total nitrogen (TN), organic carbon (OC) and phosphorus (P) were low. Exchangeable cations were low except sodium (Na) at Ilakala was medium.

magnesium at Changarawe was high and potassium (K) was high at both sites. Micronutrients such as copper (Cu), iron (Fe) and manganese (Mn) were medium to high except zinc (Zn) which was low at both sites.

Table 3. 1 Soil characteristics at Ilakala and Changarawe study sites

Soil characteristics	Ilakala (0 - 15 cm)	Ilakala (15 - 30 cm)	Chanagarawe (0 - 15 cm)	Changarawe (15 - 30 cm)
Sand (%)	81	73	79	77
Silt	5	7	9	9
Clay (%)	14	20	12	14
Texture class	SL	SL	SL	SL
Soil pH	6.8^{neutral}	$6.0^{\text{medium acidic}}$	$5.8^{\text{medium acidic}}$	$5.3^{\text{strongly acidic}}$
Total nitrogen (%)	0.05^{VL}	0.05^{VL}	0.06^{VL}	0.04^{VL}
Organic carbon (%)	0.68^{L}	0.8^{L}	0.60^{L}	0.43^{VL}
P- Bray 1 (mg/ kg)	4.72^{L}	1.32^{L}	1.84^{L}	3.07^{L}
Exchangeable potassium (cmol +/ kg)	0.41^{H}	0.23^{M}	0.67^{H}	0.51^{H}
Exchangeable magnesium (cmol +/ kg)	0.11^{VL}	0.11^{VL}	1.89^{H}	1.72^{H}
Exchangeable calcium (cmol +/ kg)	0.48^{L}	0.48^{L}	3.89^{L}	3.89^{L}
Exchangeable sodium (cmol +/ kg)	0.52^{M}	0.52^{M}	0.24^{L}	0.16^{L}
Extractable sulphur (mg/kg)	19.39^{H}	26.48^{H}	21.97^{H}	22.62^{H}
Copper (mg/ kg)	0.37^{M}	0.50^{M}	0.24^{M}	0.50^{M}
Zinc (mg/ kg)	0.43^{L}	0.60^{L}	0.89^{M}	0.31^{L}
Iron (mg/ kg)	19.78^{H}	25.62^{H}	38.76^{H}	41.68^{H}
Manganese (mg/ kg)	72.42^{H}	52.36^{H}	42.81^{H}	47.59^{H}

Letters in superscript represent abbreviation for remarks according to Landon (1991) where H= high, L = low, M= medium, VH= very high, VL= very low; SL = sandy loam.

Rainfall results during 2014/15 and 2015/16 cropping seasons are shown in Figure 3.1. Total amount of rainfall was 489.8 and 891.5 mm at Ilakala while at Changarawe rainfall was 358.4 and 694.3 mm during 2014/15 and 2015/16 seasons, respectively. At Ilakala, only December, January, March and April received rainfall above 50mm with dry spell in February during 2014/15 cropping season. During 2015/16, Ilakala site received more rainfall than 2014/15 characterized by excess rains in April 2016. Likewise, Changarawe site received more rains during 2015/16 than 2014/15 cropping season with floods in March 2015, January and April 2016.

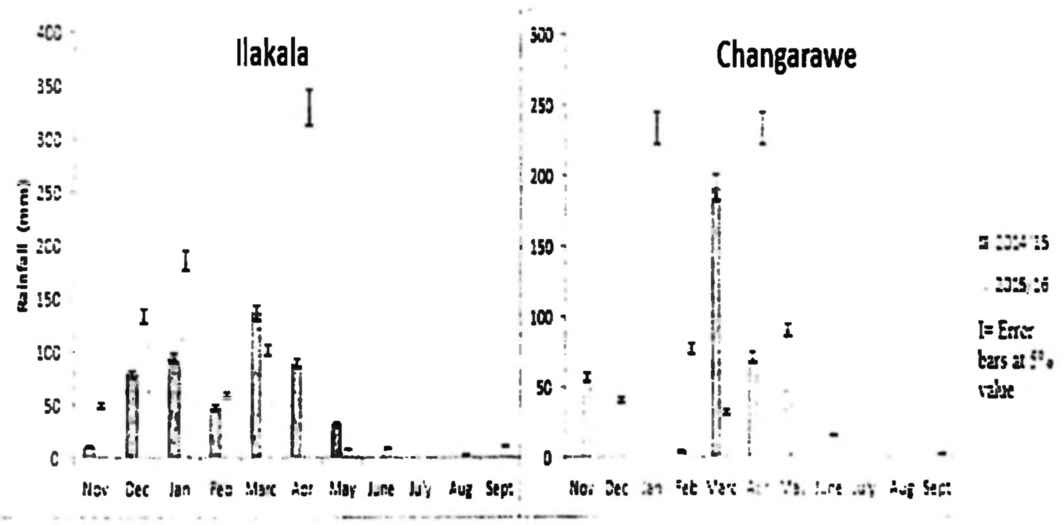


Figure 3. 1: Amount of rainfall during 2014/15 and 2015/16 cropping seasons

3.4.2 Soil moisture management practices

Soil moisture retention varied with rainwater harvesting (RWH) practices as shown in Figure 3.2. Flat cultivation, open ridges and tied ridges at 5cm soil depth had no significant differences (P≤0.05) in moisture conservation at 0.5 days (12 hours) after rainfall. Soil moisture content decreased with soil depth after 0.5 days (12 hours) and two days after rainfall from flat cultivation while in open and tied ridge plots moisture increased from 5 cm to 30 cm depth. Two days after raining, soil at 5 cm depth had 15% moisture content while 15 and 30 cm depth had 20% for ridge treatment. Ten days after rainfall, soil at 5 cm depth had 6% under flat cultivation while under tied ridges the soil had 8%. At 15 cm soil depth, moisture content was 11% in flat cultivation treatment and 12% in open ridge treatment and 14% under tie ridges plots. The soil at 30 cm depth had 14% moisture content in flat plots and 15% in open ridge while the tied ridged plots had 17% moisture content. On average, soil moisture content was 20-22% after 12 hours, 16 20% after two days and 7 – 15% ten days after rainfall.

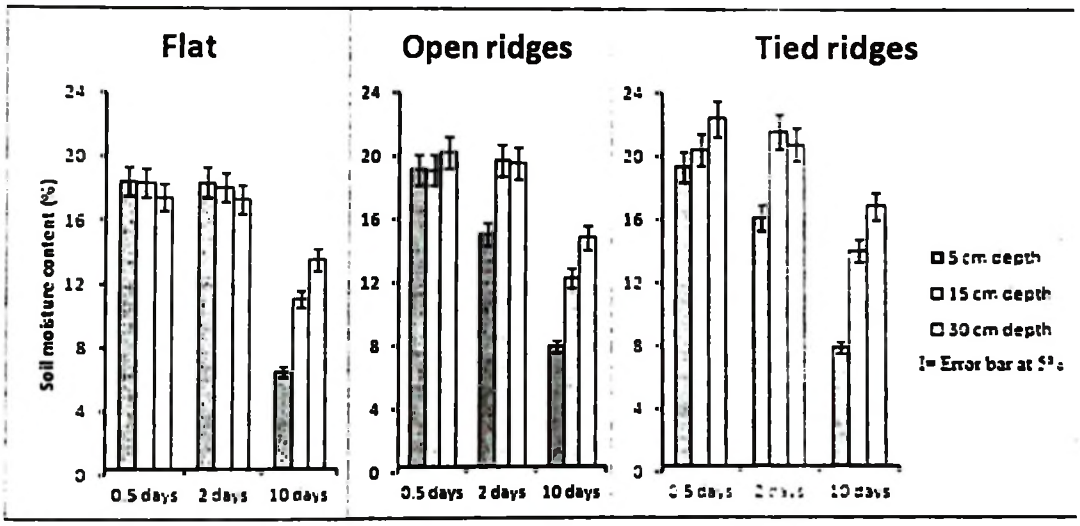


Figure 3. 2: Soil moisture as influenced by rainwater harvesting practices at different soil depths and duration after rainfall

3.4.3 Effects of inter-row rainwater harvesting practices and fertilizer use on yield

Maize yield was significantly affected by rainwater harvesting practices (Table 3.2). Tied ridges had the highest yield at Ilakala and Changarawe in both cropping seasons with the exception of Changarawe during 2015, where flat cultivation had higher yield than ridges. Sole maize produced very significantly higher yield than intercropping at both sites during 2015 and 2016 seasons. Fertilizer application increased maize yield very significantly (P = 0.001) from control to micro-dosing and recommended fertilizer at Ilakala and Changarawe in both seasons.

Table 3. 2: Main effects of inter-row rainwater harvesting cropping systems and fertilizer use on maize yield (kg/ha)

Treatment	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016
RWH (a)				
Tied ridges	1885 b	3000 b	1763 a	2098 b
Open ridges	1864 b	2628 a	1820 a	2051 b
Flat	1661 a	2601 a	1864 a	1950 a
SEM	46.8	19.72	40.4	11.33
P Value	0.018	0.001	0.26	0.001
CV (%)	5.8	1.6	5.0	1.2
Cropping system (b)				
Sole crop	1861 b	3066.1 b	2019 b	2220.3 b
Intercrop	1746 a	2420.1 a	1613 a	1845.8 a
SEM	13.1	14.92	26.6	14.05
P Value	0.001	0.001	0.001	0.001
CV (%)	2.8	2.1	5.7	2.7
Fertilizer use (c)				
Control	958 a	1794 a	914 a	1126 a
MF	2049 b	3058 b	1893 b	2254 b
RF	2403 c	3377 c	2640 c	2719 c
SEM	23.3	13.11	27.6	11.91
P Value	0.001	0.001	0.001	0.001
CV (%)	7.1	2.6	8.3	3.2

Means followed by same letter (s) in the same column were not significantly different according to Tukey's Test at $P \leq 0.05$. CV is the coefficient of variation, and SEM is a standard error of mean.

Interaction effects of inter-row rainwater harvesting, cropping systems and fertilizer use on maize yield were significant ($P \leq 0.05$) at both sites and seasons (Figure 3.3). The highest yield was 3776 kg/ha from TR + SM + RF followed by TR + SM + MF (3760 kg/ha), OR + SM + RF (3643 kg/ha) and Fl + SM + RF (3534 kg/ha) from maize sole crop.

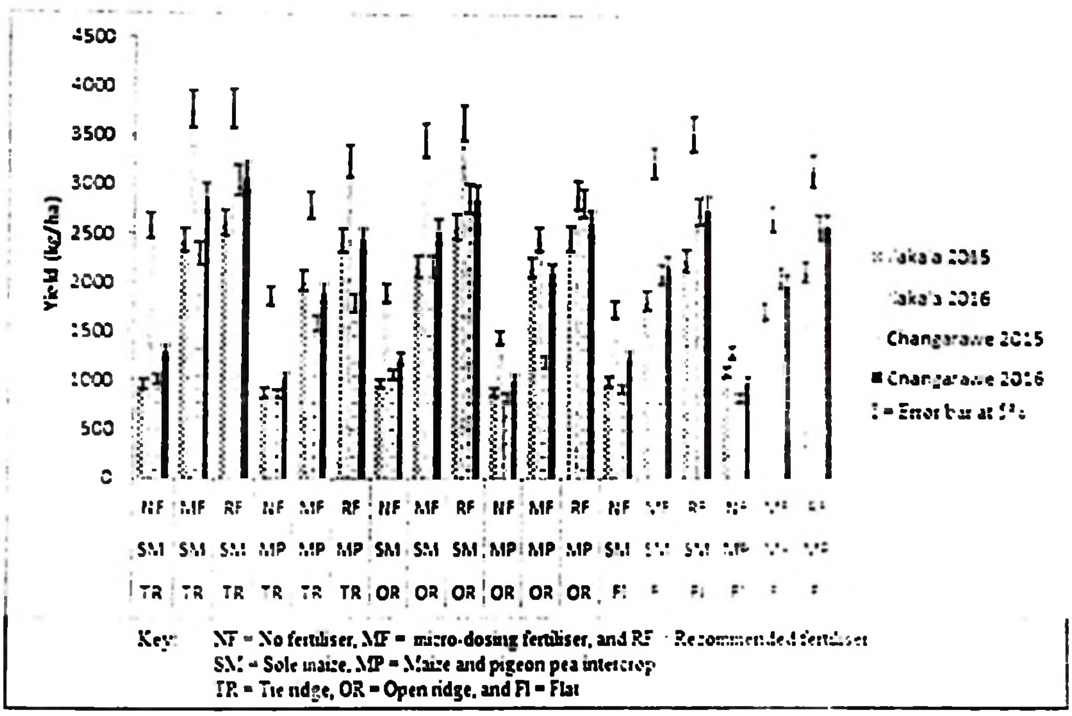


Figure 3. 3: Interaction effects of rainwater harvest, cropping system and fertilizer use on maize yield

Pigeon pea yield was significantly influenced by rainwater harvesting practices, cropping systems and fertilizer use (Table 3.3). Flat cultivation had significantly higher grain yield ($P \leq 0.015$) than ridges at both villages during 2015 and 2016 cropping seasons. Pigeon pea sole crop had significantly higher yield ($P = 0.001$) than intercrop at both sites during 2015 cropping season while the following year it did not have significant yield differences. Fertilizer micro-dosing and recommended rate increased yield very significantly (P 0.001) compared to control.

Table 3. 3: Main effects of inter-row rainwater harvesting cropping systems and fertilizer use on pigeon pea yield (kg/ha)

Treatment	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016
RWH (a)				
Tied ridges	492.6 a	1037 ab	522.5 a	852.3 a
Open ridges	581.7 ab	947 a	573.4 b	856a
Flat	611.9b	1095ab	782.9c	1091.9b
SEM	22.67	21.7	12.11	12.92
P Value	0.015	0.008	0.001	0.001
CV (%)	9.0	4.7	4.3	3.1
Cropping system (b)				
Sole crop	700.7b	1035a	683.9b	934.1a
Intercrop	423.4a	1017a	568.5a	932.7a
SEM	16.48	17.4	17.40	8.36
P Value	0.001	0.49	0.001	0.90
CV (%)	11.4	6.6	10.8	3.5
Fertilizer use (c)				
Control	512.0a	769a	594.9a	796.6a
MF	581.4b	1188c	602.3a	1038.3c
RF	592.8b	1122b	681.5b	965.2b
SEM	11.11	17.9	16.58	11.43
P Value	0.001	0.001	0.001	0.001
CV (%)	10.8	9.5	14.5	6.7

Means followed by same letter (s) in the same column were not significantly different according to Tukey's Test at P≤0.05. CV is the coefficient of variation, and SEM is a standard error of mean.

Interaction effects of inter-row rainwater harvesting, cropping systems and fertilizer use on pigeon pea yield was significant ($P < 0.05$) as shown in Figure 3.4. The highest pigeon pea yield was 1302 kg/ha from TR + SP + RF followed by TR + SP + MF (1296 kg/ha), Fl + SP + MF (1283 kg/ha) and Fl + MP + MF (1273 kg/ha).

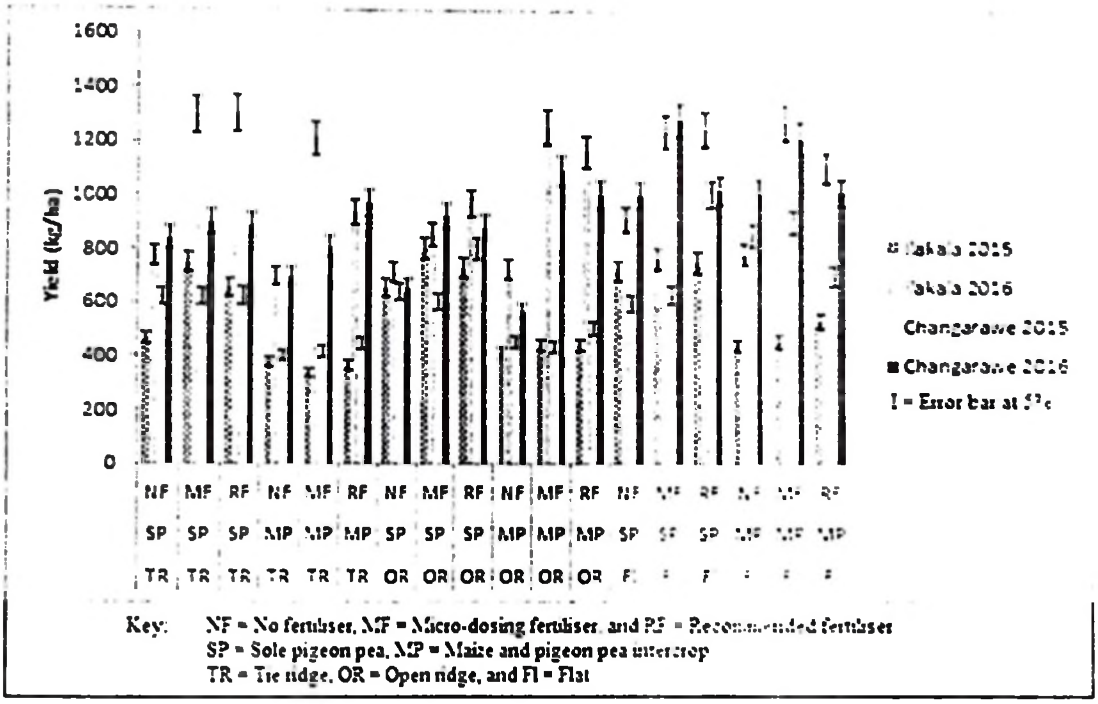


Figure 3. 4: Interaction effects of rainwater harvesting (RWH) practices, cropping systems and fertilizer use on pigeon pea yield

3.4.4 Land use efficiency of cropping systems under rainwater harvesting (RWH) practices and fertilizer use

Land equivalent ratios (LER) were used to describe land use efficiency in maize and pigeon-pea cropping systems as shown in Table 3.4. The LER values ranged between 1.46 and 1.99 at Ilakala and from 1.34 to 2.05 at Changarawe for soil moisture conservation through RWH. Tie ridged plots had the lowest (1.34 – 1.68) and flat plots had the highest (1.62 - 2.05). Under fertilizer use treatments, the control had the highest LER (1.64 - 1.76) during 2015 while in 2016 the recommended rate had the highest LER of 1.95. Tied ridges without fertilizer application had higher LER (1.51 – 1.72) than micro-dose and recommended fertilizer used during 2015 at both sites. Fertilizer application under tied ridges resulted into higher LER of 1.68 and 1.88 during 2016 at Ilakala and Changarawe, respectively. Open ridges combined with fertilizer application at the recommended rate had highest LER of 1.55 – 1.61 during 2015 at both sites. However, during 2016 the micro-dose rate under open ridges had the highest LER of 2.17 at Ilakala. Plots under flat cultivation without fertilizer had higher LER (1.71) at Ilakala during 2015 than micro-dose and recommended fertilizer. Micro-dose fertilizer under flat plots had the highest LER of 1.85 at Ilakala during 2016 and 2.42 at Changarawe during 2015.

Table 3. 4: Land equivalent ratios in maize and pigeonpea intercrops grown under different rainwater harvesting (RWH) practices and fertilizer levels

Treatment	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016
RWH				
Tied ridges (1)	1.46	1.62	1.34	1.68
Open ridge (2)	1.55	1.99	1.47	1.95
Flat (3)	1.61	1.88	2.05	1.88
Fertilizer use				
Control (1)	1.64	1.66	1.76	1.72
Micro-dose(2)	1.45	1.86	1.68	1.79
Recommended (3)	1.57	1.76	1.51	1.95
RWH x Fertilizer				
1 x 1	1.72	1.62	1.51	1.63
1 x 2	1.28	1.68	1.36	1.56
1 x 3	1.49	1.58	1.30	1.88
2 x 1	1.54	1.78	1.48	1.68
2 x 2	1.54	2.18	1.26	2.02
2 x 3	1.56	1.99	1.61	2.06
3 x 1	1.71	1.61	2.34	1.81
3 x 2	1.53	1.85	2.41	1.86
3 x 3	1.66	1.78	1.64	1.93

Indices not subjected to inferential statistical analysis

3.4.5 Monetary value for maize and pigeon pea cropping systems under different moisture conservation practices and fertilizer use

Effects of soil moisture conservation practices, cropping systems and fertilizer use on monetary value of maize and pigeon pea crops are shown in Table 3.5. Soil moisture conservation practices had highly significant effects ($P = 0.001$) on monetary values of the crops at both Ilakala and Changarawe sites during the 2015 and 2016 seasons with exception of Ilakala site during 2015 ($P = 0.08$). Average values were 1.78 and 1.69 million Tanzania Shillings (TShs) during 2015 and 2.67 and 2.15 million TShs during 2016 at Ilakala and Changarawe, respectively. The highest monetary values at Changarawe were 2.17 and 2.26 million TShs obtained from flat cultivation during both seasons. At Ilakala, the highest monetary values were 1.84 and 2.83 million TShs from ridges during 2015 and 2016 seasons, respectively. Cropping systems had very high significant effects ($P = 0.001$) with the highest monetary values 2.28 - 3.70 million TShs from maize-pigeon pea intercrops. During 2015 season, pigeon pea had higher financial return (1.7 million) than maize that had 1.3 – 1.4 million TShs. However, during 2016 season maize had more financial return of 2.0 to 2.7 million than pigeon pea which had 1.4 – 1.5 million. Fertilizer use resulted into higher significant effects ($P = 0.001$), where the highest monetary values were from 2.09 to 3.14 million TShs at recommended fertilizer rate followed by 1.89 – 3.02 million TShs from micro-dose fertilizer rate and 1.30 – 1.84 million TShs under control plots.

Table 3. 5: Effects of rainwater harvesting practices (RWH), cropping systems and fertilizer use on monetary value (TSh/ha) of maize and pigeon pea

Treatment	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016
RWH (a)				
Tied ridges (1)	1700447 a	2836628 c	1693723 a	2110833 a
Open ridge (2)	1839528 a	2524163 a	1804872 a	2086666 a
Flat (3)	1794972 a	2655131 b	2174602 b	2262076 b
P value	0.088	0.001	0.001	0.001
SEM	38798.1	22594.5	29233.6	11709.1
CV (%)	4.9	2.0	3.50	1.2
Cropping system (b)				
Maize (1)	1302712 a	2759529 b	1413332 a	1998248 b
Pigeon pea (2)	1751761 b	1552374 a	1709633 b	1401142 a
Maize-Pigeon pea Intercrop (3)	2280475 c	3704018 c	2550232 c	3060185 c
P value	0.001	0.001	0.001	0.001
SEM	40985.3	27145.0	39210.0	21586.9
CV (%)	8.9	3.9	8.0	3.9
Fertilizer use (c)				
Control (1)	1300155 a	1845035 a	1429100 a	1472333 a
Micro-dose(2)	1944226 b	3023393 b	1894058 b	2390915 b
Recommended rates (3)	2090567 c	3147494 c	2350039 c	2596326 c
P value	0.001	0.001	0.001	0.001
SEM	21219.0	18371.0	31130.1	12754.8
CV (%)	8.0	4.6	11.0	4.0

Means followed by same letter (s) in the same column were not significantly different according to Tukey's Test at P≤0.05. CV is the coefficient of variation, and SEM is a standard error of mean.

Interaction effects between soil moisture conservation practices, cropping systems and fertilizer use for monetary value of maize and pigeon-pea crops were significant at P <0.05 as presented in Figure 3.5. At Ilakala site, the highest monetary values were between 2.0 and 3.0 million TZS during 2015; 4.0 and 4.5 million TZS/ha during 2016 from maize-pigeon pea intercrops under micro-dose and recommended rates in ridges and flat cultivations. Maize sole crop had higher monetary values of 3.0 – 3.5 million TZS in 2016 under fertilizer micro-dose and recommended rates than pigeon-pea. At Changarawe site, the highest monetary values were 3.0 – 4.0 million TZS/ha maize-pigeon pea intercrop under recommended fertilizer rate, maize sole crop had higher money value at recommended fertilizer rate than pigeon-pea.

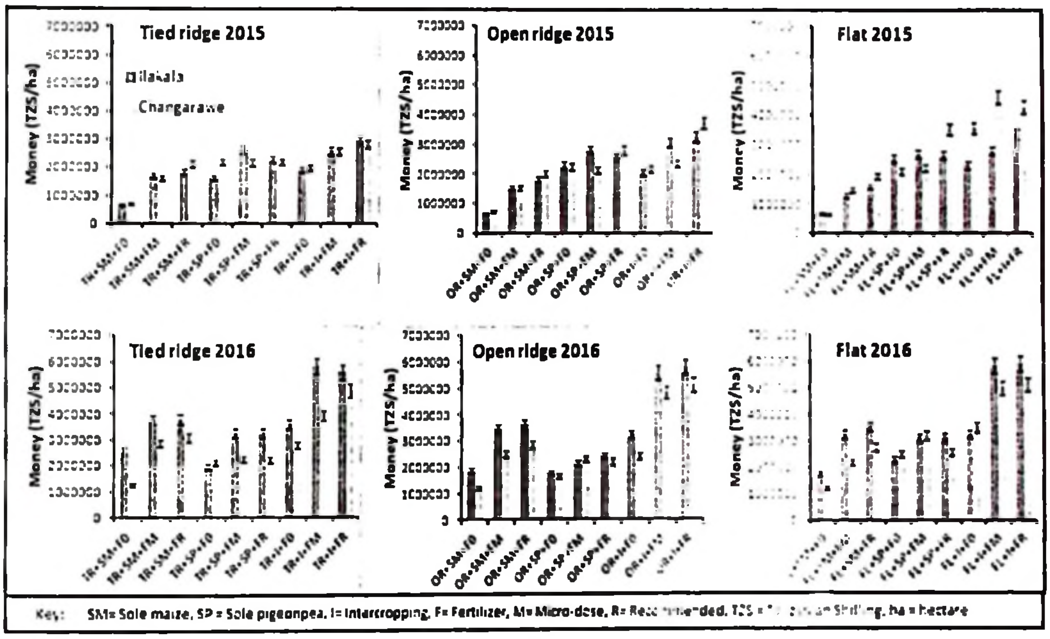


Figure 3. 5: Interaction effect of soil moisture conservation, cropping systems and fertilizer use on monetary value of maize and pigeon pea crops

3.5 Discussion

3.5.1 Soils and weather conditions

Soils at both study sites were sandy loam characterized by strongly acidic (5.3) to neutral (6.8) pH conditions that are suitable for most crops (Landon, 1991). Sandy loam is among medium textured soils which are ideal for the most crop growth (Birkas *et al.*, 2014). Low total nitrogen values recorded at both sites may have been the results of leaching and erosion which are common under tropical conditions as reported by Weier (1994) and Foth and Ellis (1997). Also, low total nitrogen is related with low organic matter in the soil (Lal, 2015). The very low P recorded could have been due to facts reported by Jeng (2014) highly weathered soils, unavailability of inherent soil P, fixation of P and poor management of on-farm organic resources. Therefore, application of fertilizer especially N and P would be important to increase crop productivity and maintain nutrients in the soil. The rainfall fluctuation in terms of amount, intensity, distribution and pattern experienced at Ilakala and Changarawe sites could have been influenced by the impact of climate change observed by Augustino *et al.* (2012).

3.5.2 Effects of rainwater harvesting and fertilizer on yield

Higher maize yield of up to 3000 kg/ha under tied ridges than under flat cultivation recorded in this study were due to reduced runoff, increased water infiltration and moisture conservation (Figure 3.2). However, during 2015 Changarawe site was exceptional due to extremely low amount rainfall (358 mm) characterized by flood in March and prolonged dry spells in April and May (Figure 3.1) which confined runoff in ridges and increased surface evapo-transpiration than flat cultivation (Karuma *et al.*, 2016) that affected yield negatively under the current climate changes (Augustino *et al.*, 2012).

Yield of up to 3066 kg/ha under maize sole cropping system was due to low inter-specific competition for resources such as light, nutrients, moisture and space compared with intercrop as also reported by Karuma *et al.* (2016). Inter-specific competition for moisture, nutrients and solar radiation reduced maize yield under intercropping, however the yield advantage of two crops under this system is advantageous for food, nutritional and income security to small scale farmers.

Significant increase in maize yield from micro-dose and recommended rates indicated the importance of applying fertilizer under the low soil nitrogen and phosphorus (Table 3.1) as reported by Amuri *et al.* (2013) and Masunga and Kazumba (2017). The highest maize yield 3600 – 3700 kg/ha were due to combined effects of inter-row rainwater harvest using ridges and fertilizer application under the current changes of rainfall distribution (Figure 3.1). Pigeon pea had higher yield (1091 – 1095 kg/ha) under flat cultivation than under ridges. due to deep tap root system and tolerance to drought (ICRISAT. 1992). Sole pigeon pea had highest yield up to 1035 kg/ha due to low competition for light, nutrients and space compared to intercropping system (Karuma *et al.*, 2016). The increased pigeon pea yield up to 1188 kg/ha from fertilizer application reflected the need to apply phosphorus and nitrogen in the soil with low fertility status (Table 3. 1). However, tied ridges increased fertilizer use efficiency and produced pigeon pea yield up to 1300 kg/ha due to interaction effects of soil moisture conservation and fertilizer nutrient availability and uptake.

3.5.3 Land utilization in cropping systems

High land equivalent ratios (LER) of 1.5– 2.4 were recorded in this study. These values were within the range of 1.66 – 2.79 recorded by Dania *et al.* (2014) in Nigeria. Higher LER above 1.0 indicated that maize-pigeon pea intercropping system was more efficient on land utilization than sole crop system (Federer, 1993). Maximization of land use efficiency by 50 – 140% under intercropping system was a result of interaction effects of nutrient application and soil moisture conservation through inter-row rainwater harvesting practices. Tied ridges had the lowest LER during 2015 cropping season in both sites due to low amount of rainfall and uneven distribution (Figure 3.1), which affected yields negatively due to moisture stress under prolonged dry spell of more than two weeks in sandy loam soils. However, during 2016 ridges improved crop growth and had higher LER than flat cultivation due to soil moisture conservation under short-term dry spells of a week and not more than two weeks.

Differences in crop growth above and below architecture of maize and pigeon-pea reduced inter-specific competition and enhanced resource use efficiency. This is complementary facilitative interaction effects of maize and pigeon-pea intercropping systems which increased LER (Zhang and Li. 2003; Kimaro *et al.*, 2009). Pigeon pea has a tap root system that has ability to penetrate down to 2 m deep extracting more water and nutrients from both top and deep soil layers (ICRISAT, 1992) than maize which is shallow rooted. Also, pigeon pea (Babati white variety) grew slowly during the first two months and flowered 6 - 7 months after sowing while maize growth was faster and reached tasselling two months after sowing. The addition of 10 and 20 kg P/ha in form of DAP at planting increased LER (Table 3.2) indicating the importance of applying N as starter dose and P for root development and enhanced nitrogen fixation in low soil N and P (Table 3.1). Rao *et al.* (1987) also reported similar trend of LER under flat cultivation in sorghum and pigeon-pea intercrops when nitrogen and phosphorus were applied. Therefore, maize-pigeon pea intercropping under inter-row rainwater harvesting and fertilizer use would reduce land use conflict between farmers and pastoralists in Africa as reported by Cabot (2017), Roseline and Amusain (2017) and Walwa (2017).

3.5.4 Cropping systems and financial return

Monetary values (0.7 – 4.5 million TZS) were highly dependent on quantity produced and market price for each crop under the tested cropping system. Maize and pigeon pea values were significantly influenced by soil moisture management practices and fertilizer applications in the same cropping system. The highest values from intercropping system was influenced by a combination of two crops having different yield and market price values indicating its importance on income generation (Sharma *et al.*, 2011). Maize performed better under tied ridges with fertilizer application due to increased soil moisture conservation (Figure 3.2) and nutrient uptake than under flat cultivation in low soil fertility environments (Table 3.1) and erratic rainfall (Figure 3.1). However, pigeon pea performance did not follow the maize trend because of the crop being able to tolerate drought and biologically fix nitrogen (Njira, 2016). In Tanzania, pigeon pea had very high market price (2000 – 3000 TZS/kg) compared to maize which had low market price (700- 1500 TZS/kg). Pigeon pea is usually cultivated primarily for sale (cash crop) while maize is a basically grown for food as reported by Amare *et al.* (2012). Monetary values reported in this study were above those reported by Matere *et al.* (2016) of 1.03 - 3.75 million TZS (48100 – 174641 KES) obtained from maize-pigeon pea intercropping system under terraces in neighboring semi-arid Kenya.

3.6 Conclusions and Recommendations

There was great inter- and intra-seasonal variation of amount and distribution of rainfall at both sub-humid study sites leading to soil moisture stress. Tied ridges conserved more soil moisture than flat cultivation up to ten days dry spell and increased soil water infiltration instead of surface runoff. Maize production was better under tied ridges than pigeon. Intercropping system had better land use efficiency and monetary value than sole crop. It reduced the risk of crop failure due to drought and diversified food than sole cropping system. Fertilizer micro-dosing increased maize yield by twice than control while recommended rate maximized maize yield. Fertilizer increased pigeon pea yield by a quarter than control. Inter-row rainwater harvest using tied ridges and fertilizer use produced more yield and income.

Tie ridging is the best strategy in the sub-humid tropical areas where water stress from drought is becoming common and the main rain season is experiencing shortage of rainfall especially in cereal crops, which are sensitive to dry spells even short-term of a week. Adoption of micro-dose rate at 10 kg P/ha to promote land productivity and financial return under maize-pigeon pea intercrops is encouraged as an entry point for small-scale farmers. The strategy of intercropping under inter-row rainwater harvesting and fertilizer micro-dose is encouraged to increase food and income security in smallholder farming systems of sub-humid tropical conditions.

3.7 Acknowledgement

Thanks to Trans-SEC project for food security in Africa. funded by the Germany Federal Ministry of Education and Research (BMBF) and the Germany Federal Ministry for Economic Cooperation and Development (BMZ) for sponsoring this study.

3.8 References

Adams, A. M., Gillespie, A. W., Kar, G., Koala, S., Ouattara, B., Kimaro, A. A., et al. (2016). Long term effects of reduced fertilizer rates on millet yields and soil properties in the West-African Sahel. *Nutrient Cycling in Agro-ecosystems* 106: 17-29.

Amare, M., Asfaw, S. and Shiferaw, B. (2012). Welfare impacts of maize-pigeonpea intensification in Tanzania. *Agricultural Economics* 00: 1-17.

Amuri, N., Semoka, J. M., Ikerra, S., Kulaya, I. and Msuya-Bengesi, C. P. (2013). Enhancing Use of Phosphorus Fertilizers for Maize and Rice Production in Small Scale Farming in Eastern and Northern Zones, Tanzania. In: *The 27th Soil Science Society of East Africa- 6th African Soil Science Society Conference*. Nakuru, Kenya: Soil Science Society of East Africa. pp. 1 12.

Augustino, S., Makonda, F. B. S., Shemdoe, R. S., Ishengoma, R. C., Gillah, P. R. and Migunga, G. A. (2012). Climate Change Impacts and Adaptation: Preliminary Observations from Forest Adjacent Communities in Kilombero Disrtict, Tanzania. In: *Proceedings of the first Climate Change Impacts, Mitigation and Adaptation Programme Scientific Conference*, 2 - 3 June 2012. Blue Pearl Hotel in Dar es Salaam, Tanzania. 118 – 130pp.

Aune, J. B. and Coulibaly, A. (2015). Micro-dosing of Mineral Fertilizer and Conservation Agriculture for sustainable agricultural intensification in Sub-Saharan Africa. In: *Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa*. (Edited by R. Lal, B. R. Singh, D. L. Mwaseba, D. Kraybill, D. O. Hansen, and O. L. Eik,), Springer International Publishing Switzerland. pp. 223-234.

Birkas, M., Jug, D. and Kisic, I. (2014). *Book of Soil Tillage*. Published by SzentIstvan University Press. 322pp [http://ljesnjak.pfos. hr/~j danijel/literatura/Book_of_Soil_Tillage.pdf] site visited 26th June 2017.

Cabot, C. (2017). Climate change and farmer – herder conflicts in West Africa. *Climate Change, Security Risks and Conflict Reduction in Africa*, Hexagon series on Human and Environmental Security and Peace 12, DOI 10.1007/978-3-642-29237-8_2.Springer-Verlag, Berlin Heidelberg. 35pp.

Camara, B.S., Camara, F., Berthe, A. and Oswald. A. (2013). Micro-dosing of fertilizer a technology for farmers' needs and resources. *International Journal of Agri. Science* 3 (5): 387- 399.

Cameron, A., Derlagen, C. and Pauw, K. (2017). *Options for reducing fertilizer prices for smallholder farmers in Tanzania*. Prepared for the Ministry of Agriculture, Livestock and Fisheries (MALF) United Republic of Tanzania. Policy Report. MAFAP (Monitoring and Analyzing Food and Agricultural Policies). FAO. Rome. 34pp.

CIMMYT (2013). *Yield and yield components: A practical guide for comparing crop management practices.* Mexico: International Maize and Wheat Improvement Center. 28pp.

Dania, S. O., Fagbola, O. and Alabi, R. A. (2014). The yield and farmer's economic advantage of maize–pigeon pea intercrop as affected by the application of organic base fertilizer. *Europian Scientific Journal* 10 (25): 357 - 374

Delta T Devices Ltd (2013). User Manual for the Moisture Meter type HH2. Version 4.0.1. Burwell, Cambridge, UK. 124pp.

Druilhe, Z. and Barreiro-Hurlé, J. (2012). *Fertilizer subsidies in sub-Saharan Africa*. ESA Working paper No. 12 - 04. Rome. FAO. 73pp.

Edje, O. T. and Ossom, E. M. (2010).Effects of tied ridges for rainwater harvesting on maize yields in Swaziland. In: *Second RUFORUM Biennial Meeting* 20- 24 September 2010, Entebbe, Uganda. 739 – 742pp.

Egbe, M. O. and Idoko, J. A. (2012). Evaluation of pigeon pea genotypes for intercropping with maize and sorghum in Southern Guinea Savanna: Economic benefits. *International Journal of Agriculture and Forestry* 2(1): 108 – 114.

Federer, W.T. (1993). *Statistical Design and Analysis for Intercropping Experiments*. Volume I: Two Crops. Springer Series in Statistics. Springer-Verlag New York, United States of America. 298pp.

Foth, H. D and Ellis, B. G. (1997). *Soil fertility*. Second Edition, CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton. Florida 33431 United States of America. 290pp.

Francis, C. A. (1986). *Multiple Cropping Systems*. Macmillan Publishing Company, New York, USA. 383pp.

ICRISAT (1992). Pigeonpea Botany and Production Practices: Skill Development Series no.9. Human Resource Development Program of the International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh 502 324. India. 41pp.

Janila. P., Rupavatharam, S., Sameer Kumar, C. V.. Samineni. S.. Gaur. P. M. and Varshney, R. K. (2016). Technologies for Intensification of Production and Uses of Grain Legumes for Nutritional Security. *Proc Indian Nat. Sci. Acad.* 82: 1541-1553.

Jeng, A. S. (2014). Securing crop phosphorus availability in the humid Tropics: Alternative sources and improved management options- A review. In: *Challenges and opportunities for agriculture intensification of the humid highland systems of Sub-Saharan Africa.* (Edited by Vanlauwe B., VanAsten P., Blomme G.). Springer. Cham. pp 51 66.

Kajembe, G. C., Silayo, D. A., Mwakalobo, A. B.. and Mutabazi. K. (2013). *The Kilosa Disrtict REDD Pilot Project. Tanzania: A Socioeconomic baseline study.* London, UK: International Institute for Environment and Development (IIED). 50 pp.

Kanyeka, E., Kamala, R. and Kasuga, R. (2007). *Improved agricultural technologies recommended in Tanzania.* First edition. Published by the department of Research and Training. Ministry of Agriculture Food Security and Cooperatives Dar es salaam. Tanzania. 144pp.

Karuma, A. N., Gachene, C. K. K., Gicheru, P. T.. Mtakwa. P. W. and Amuri, N. (2016). Effects of tillage and cropping systems on maize and beans yield and selected yield components in a semi-arid areas of Kenya. *Tropical and Subtropical Agroecosystems* 19: 167 - 179.

Kimaro, A. A., Timmer, V. R., Chamshama, S. A .O., Ngaga. Y. N. and Kimaro, D. A. (2009). Competition between maize and pigeonpea in semi-arid Tanzania: Effect on yields and nutrition of crops. *Agriculture, Ecosystems and Environment* 134: 115-125.

Kuma Rao, J. V. D. K., Johansen, C. and Usha Kiran. M. (1995). Nitrogen requirements at different growth stages of short-duration pigeonpea (*Cajanus cajan* L. Millsp). *Journal of Agronomy and Crop Science* 175: 15- 28.

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

Landon, J. R. (1991). *Booker Tropical Manual. A handbook of soil survey and agricultural land evaluation in the tropical and subtropical.* Longman. 474pp.

MALF (2017). Budget Speech: The Ministry of Agriculture Livestock and Fisheris. Parliament Budget for 2017/ 18. Dodoma Tanzania. 255p. [http://www.kilimo.go.tz/index.php/en/resources/category/budget-speeches] site visited on 9th October 2017.

Marandu, A. E. T., Mbogoni, J. D. J. and Ley, G. J. (2014). *Revised Fertilizer Recommendations for Maize and Rice in the Eastern, Southern Highlands and Lake Zones of Tanzania.* Ministry of Agriculture, Food Security and Cooperatives, Department of Research and Development, Dar es salaam, Tanzania. 40pp.

Masunga, S. L. and Kazumba, S. (2017). Assessment of soil fertility of Morogoro District and response of maize (*Zea mays*) to applied nitrogen, phosphorus and sulphur. *Asian Journal of Advances in Agricultural Research* 1 (3): 1 – 9.

Matere, S. J., Mbatia, O. L. E., Nzuma, J. M. and Nyamwaro, S. O. (2016). Financial benefit-cost analysis in maize-pigeon pea intercrop in semi-arid areas of Kenya. *Journal of Agriculture and Environmemntal Sciences* 5 (1): 140 148.

McClauley, A., Jones, C. and Jacobsen, J. (2009). Commercial Fertilizers and Soil Amendments. In: *Nutrient ManagementModule No. 10.* Montana State University Extension. pp. 1- 20.

Montgomery, D. C. (2013). *Design and analysis of experiments* (Eighth edition ed.). New York, USA: John Wiley and Sons. Inc. 757pp.

Msaki, M. M., Tambi, E. and Bangali, S. (2015). *State of knowledge on climate smart agriculture in Africa, case studie from Rwanda, Tanzania and Zambia.* Forum for Agricltural Research inAfrica. Accra, Ghana. 80pp.

Myaka, F. M., Sakala, W. D., Adu-Gyamfi, J. J., Kamalongo, D., Ngwira, A., Odgaard, R., Nielsen, N. E. and Hogh-Jensen, H. (2006). Yields and accumulations of N and P in farmer-managed intercrops of maize-pigeonpea in semi-arid Africa. *Plant Soil* 285: 207 - 220.

Natarajan, M. (1990). Spatial Arrangement of the Component Crops in Developing Intercropping Systems: Some Concepts and Methodologies. In: *Proceedings of a workshop on Research Methods for Cereal/Legume Intercropping in Eastern and Southern Africa.* Mexico, D. F.: CIMMYT. 68-73 pp.

Njira, K.O.W. (2016). Biological nitrogen fixation in legume-legume and legume-cereal intercrops: Effects on yields of subsequent maize crop in Central Malawi. A PhD dissertation in soil water management of Sokoine University of Agriculture, Morogoro. Tanzania. 182pp.

NRSP (2005). Reducing poverty through rainwater harvesting: Evidence from the semi-arid areas of Maswa and Same Districts. Tanzania. Soil water management research group. [http://www.nrsp. org.uk/ database/ documents/2257.pdf] site visited 5th August 2014.

Nuhu, H. And Mahoo, H. F. (2000). *Rainwater Harvesting for Natural Resources Management: A planning guide for Tanzania.* Technical Handbook No.22. Published by Sida's Regional Land Management (RELMA) Unit. 156pp.

Prinz, D. (1996). Water Harvesting: Past and Future. In: *Proceedings of Sustainability of Irrigated Agriculture, NATO Advanced Research Workshop.* (Edited by Pereira, L. S.), Vimeiro, 21 26 March 1994, Balkema, Rotterdam. 135 - 144pp.

Rao, M. R., Rego. T. J. and Willey, R. W. (1987). Response of cereals to nitrogen in sole cropping and intercropping with different legumes. *Plant and Soil*, 101: 167 - 177.

Roseline, O. and Amusain, O. (2017). Effect of Fulani herder's intrusion on the economic livelihood of crop farmers in Yagba East Local Government Area of Kogi State, Nigeria. *International Journal of Agricultural Policy and Research*, 5 (3): 80 85.

Rowhan, P., Lobell, D. B., Linderman, M. and Ramankutty, N. (2011). Climate variabilty and crop production. *Agriculture and Forest Meteorology*, 151: 449 – 460.

Saxena, K. B., Ravishankar, K., Vijaya Kumar, R., Sreejith, K. P. and Srivastava, R. K. (2010). *Vegetable Pigeonpea a High Protein Food for all Ages*. Information Bulletin No. 83. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 124 pp.

Sharma, S., Agarwal, N. and Verma, P. (2011). Pigeon pea (*Cajanus cajan* L.): A hidden treasure of regime nutrition. *Journal of Functional and Environmental Botany* 1 (2): 91- 101.

Smale, M., Byerlee, D. and Jayne, T. (2011). *Maize Revolution in Sub-Saharan Africa*: The Policy Research Working Paper 5659. the World Bank Development Research Group of Agriculture and Rural Development Team. 34pp.

Soil survey staff (2014). *Soil survay field and laboratory methods manual.* Department of Agriculture, Natural Resource Conservation Service. USA. 487pp.

Sule, E. I., Umoh, V. J., Whong, C. M. Z., Abdullahl, I. O. and Alabi, O. (2014). Chemical and nutritional value of maize and maize products obtained from selected markets in Kaduna State, Nigeria. *African Journal of Food Science and Technology* 5 (4): 100- 104.

Suleiman, R. A. and Rosentrater, K. A. (2015). Current maize production, postharvest losses and the risk of mycotoxins contamination in Tanzania. *Agricultural and Biosystems Engineering Conference Proceedings and Presentations.7-2015.* St. Joseph, Michigan: Iowa State University.

Trans SEC Project (2017). Tanzania Food and Land Productivity Information System: Map showing soils of Masanze and Ullaya wards in Kilosa. [http://sua.terragis.net/tsecgis/land_evaluation tool.html] site accessed 19 September 2017.

Walwa, W. J. (2017). Land use plans in Tanzania: repertoires of domination or solutions to rising farmer – herder conflicts?. *Journal of Eastern African Studies* 11 (3): 408 – 424.

Weier, K. L. (1994). Nitrogen use and losses in agriculture in Sub Tropical Australia. *Fertilizer research* 39 (3): 245 257.

Weldeslassie, T., Tripathi, R. P. and Ogbazghi, W. (2016). Optimizing tillage and irrigation requirements of sorghum in sorghum-pigeonpea intercrop in Hamelmaalo Region of Eritrea. *Journal of Geoscience and Environmental Protection* 4: 63 – 73.

XE Corporation (2018). XE Currency Charts: US Dollar to Tanzanian Shilling Chart. [https://www.xe.com/currencycharts/?from=USD&to=TZS] site visited 18th August 2018.

Zhang, F. and Li, L. (2003). Using competitive and facilittatvie interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant and Soil* 248: 305 - 312.

CHAPTER FOUR

4.0 PROFITABILITY OF NITROGEN AND PHOSPHORUS FERTILIZER MICRODOSES ON MAIZE PRODUCTION IN SUB-HUMID FARMING SYSTEMS OF TANZANIA

4.1 Abstract

Despite a high productivity potential for many best bet agricultural technologies, there is a low adoption. Recommendations of improved technologies such as fertilizer use basing on agronomic data without economic analysis contributes to low adoption. The purpose of this study was to evaluate the profitability of selected fertilizer types and rates in maize production in a sub humid farming system. A field experiment was conducted to investigate costs and revenue of fertilizer types and rates on maize. The phosphate fertilizers were local Minjingu mazao (MM), di-ammonium phosphate (DAP) and triple super phosphate (TSP), urea was used to supply nitrogen. Fertilizer rates were micro-doses at 12.5, 25, 50 and 75% compared to control and recommended. Local MM at 75% micro-dosing produced the highest net benefit 3.0 – 3.5 million Tanzania Shilling per hectare (TSh/ha) followed by 2.7 – 2.9 million TSh/ha from TSP at recommended and DAP at 75% micro-dose rate under subsistence farming. Micro-dosing fertilizer at 25 and 50% produced the highest benefit cost ratio under both commercial and subsistence farming conditions. Micro-dosing rate at 12.5% was more profitable than control and the profitability increased towards 25% and 50% and thereafter, decreased at recommended rate. Adoption of micro-dosing fertilizer at 12.5% could be an entry point to fertilizer use and later on advance to 25% and 50% micro-dosing rates which are more profitable under smallholder farming systems in sub-humid tropics.

Key words: Benefit/Cost ratio, Fertilizer use, Gross margin, Revenue

4.2. Introduction

Agriculture is the backbone of the economy in most of the developing countries in the world as it provides the main source of food, feed, employment, raw materials for industry and foreign exchange earnings. In Tanzania, agriculture employs 65.5% of people, contributes 100% to the national food supply when there is adequate rainfall and 29.1% of gross domestic product (MALF, 2017). Cereals such as maize and rice are most important crops grown for food and cash in sub-Saharan Africa (SSA) countries, including Tanzania (NAP, 2013). Maize accounts for 50% of the calories and protein in Eastern and Southern Africa and generates about 50% of rural cash income in Sub Saharan Africa (Macauley and Ramadjita, 2015).

Despite a high productivity potential for many best bet agricultural technologies there is a low adoption. This results into low productivity of most food and cash crops about 30% of potential (Shao, 2007). Low maize yields, for instance 1.0 - 1.7 t/ha in Tanzania compared to potential 5.0 - 7.5 t/ha is attributed mainly to declining soil fertility caused by very low fertilizer application averaging 19 kg/ha (MALF, 2017), that is 38% of African Union's Abuja Declaration (Cameron *et al.*, 2017). N and P fertilizers have been recommended for various parts of Tanzania Marandu *et al.* (2014). Fertilizer micro-dosing a technology of a reduced application by 25 – 75% of recommended rate (Camara *et al.*, 2013) has been reported to increase crop yields in semi-arid conditions of West Africa (Adams *et al.*, 2016). In Sub Saharan sub-humid and semi-arid agro-climates the maize yield increase with micro-dosing was found to attain twice the amount compared with no fertilizer application (Germer *et al.*, 2017). Recommendations of improved fertilizer application technologies normally target on an optimum production rate while fertilizer purchase economically may not be feasible to poor farmers.

Economic analysis therefore, is very important and enhances the usefulness of biophysical research results (Kirway *et al.*, 2003). Smallholder farmers are much aware on the prices of labour, inputs such as seeds, fertilizers and pesticides. Hayashi *et al.* (2008) reported more profit from farmers applying inorganic fertilizers than without fertilizer in millet cropping. However, Bachmann *et al.* (2016) reported that lower net profit of micro-dosing fertilizer as compared to recommended rates in maize production might limit its adoption. Lessons on the economy of the fertilizer micro-dosing technology can further be drawn from the different countries (Camara *et al.*, 2013) as more contributions are still needed to the debate on how soil fertility can be revitalized (Gilbert, 2012). Therefore, study of cost components of micro-dose based maize production under agronomic experiments will help understand costs and can increase profitability. Thus, the objective of this paper is to evaluate the profitability of selected fertilizer types and their micro-dose rates in maize production in a sub humid farming system.

4.3 Materials and Methods

4.3.1 Study area and experimental treatments

Field experiments were carried out in Ilakala and Changarawe villages of Kilosa District, Morogoro Region in Tanzania during the 2015 and 2016 cropping seasons. Three phosphate fertilizers namely Di-ammonium Phosphate (DAP), Minjingu Mazao (MM) and triple super phosphate (TSP) were applied at planting and urea fertilizer was applied at vegetative growth of maize to supplement nitrogen (Marandu *et al.*, 2014). Different fertilizer micro-dose rates at 12.5, 25, 50 and 75% were applied and compared with no fertilizer application and recommended rates (100%) in maize, whereby, a TMV-1 variety was used as test crop (Lyimo *et al.*, 2014).

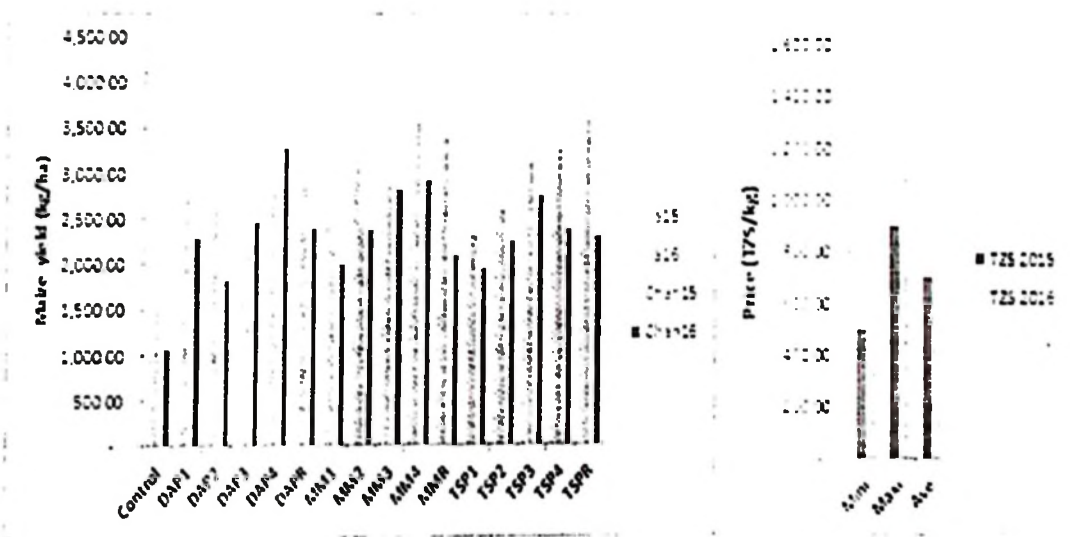
4.3.2 Data collection

Costs of inputs such as seeds and fertilizers were collected from agro-shops during procurement of these materials. Labor costs for commercial farming and number of human labor (man-days per ha) under subsistence farming for land preparation, planting, fertilizer application, weeding, harvesting, shelling, transport and storage of produce were collected during execution of the entire experimentation, respectively (Table 4.1). Commercial and subsistence farming have been distinguished by Waccke and Kimenju (2007). Subsistence farming is a form of farming in which crops or livestock are raised to sustain the farm family, farmers are not endowed with financial resources to buy inputs and very rare to hire labour as most of activities are done by family labour. Commercial farming is a type of farming which farmers maximize crop production, endowed with financial resources to buy inputs and use hired labour or implements to perform farm activities. Labor was considered in eight hours per person per days (Kirway *et al.*, 2003).

Table 4. 1: Costs of inputs and labour in field activities under commercial and subsistence farming

Item/ Activity	Unit	Cost or Labour power
Seeds	TZS per ha	62,500.00
Fertilizer- DAP	TZS per 50 kg bag	75,000.00 - 80,000.00
Fertilizer- MM	TZS per 50 kg bag	35,000.00
Fertilizer- TSP	TZS per 50 kg bag	60,000.00
Fertilizer- Urea	TZS per 50 kg bag	55,000.00- 60,000.00
Cultivation (Non- family labour)	TZS per ha	125,000.00
Cultivation (family labour)	Man-days per ha	35.00
Planting (Non- family labour)	TZS per ha	75,000.00
Planting (family labour)	Man-days per ha	7.81
Fertilizer application (Non- family labour)	TZS per ha	75,000.00
Fertilizer application (family labour)	Man-days per ha	6.25
Weeding twice (Non- family labour)	TZS per ha	200,000.00
Weeding twice (family labour)	Man-days per ha	33.75
Harvesting (Non- family labour)	TZS per ha	87,500.00
Harvesting (family labour)	Man-days per ha	6.56
Shelling (Non- family labour)	TZS per ha	60,000.00
Shelling (family labour)	Man-days per ha	7.50
Storage bags (woven/ polythene)	TZS per bag	1,200.00
Transportation of produce to home	TZS per bag	1,500.00

Yield of produce (kg/ha) was obtained from a split-block designed farm trial using the procedures described by CIMMYT (2013) and corresponding results are presented using Figure 4.1. Moreover, prices of produce in case study sites were collected during harvest and sowing from a total of 15 local key informants involving project research assistants, village agriculture extension officers and, in particularly, subsistence farmers. Minimum price was collected during harvest and the maximum at sowing period, the average price is a reflection of the overall prices combining all prices during both cropping seasons (Figure 4.1). The currency used was Tanzanian shillings (TZS), however the exchange rate was between 2150 and 2282 TZS to one US dollar from 2016 to 2018 (XE Corporation, 2018).



Key: DAP, MM and TSP are Di-ammonium phosphate, Minjingu mazao and Triple super phosphate fertilizers,
Numbers 1 to 4 are micro-dose rates 12.5, 25, 50 and 75% of recommended nitrogen and phosphorus,
R is a recommended rate 40 kg P and 80 kg N/ha in maize.
Ila is Ilakala and Chan is Changarawe site, 15 and 16 are cropping years 2015 and 2016
TZS is Tanzania Shillings, Mini is minimum, Maxi is maximum, and Ave is average

Figure 4. 1: Maize grain yield (kg/ha) and prices (TZS/kg) during 2015 and 2016 cropping seasons

Then, from these data gross return (GR), total variable cost (TVC) gross margin (GM) or net profit, return from labor and benefit- cost (C/B) ratios were calculated using the following equations (Debertin, 2012):

$$Gross\ Return = Yield\ of\ produce\ \times its\ market\ price \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Gross\ Margin = Gross\ Return - Total\ Variable\ Costs \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Return\ to\ labor = \frac{(Goss\ Return - Total\ Variable\ Costs)per\ ha}{Number\ of\ persondays\ per\ ha} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$Benefit - Cost\ ratio = \frac{Gross\ Return}{Total\ Variable\ Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

4.4 Results

4.4.1 Revenue and costs of fertilizer use in maize production

The lowest gross return was noted in control plots while the highest returns were due to fertilizer application from Ilakala and Changarawe study areas during 2015 and 2016 (Table 4.2). A gross return increased from control to micro-dose rates in DAP and thereafter decreased towards recommended rate DAP5. The trend of DAP was similar with Minjingu mazao (MM) and triple super phosphate (TSP) with few exceptions at Ilakala where gross return increased up to recommended rates in MM during 2015 and TSP during 2016 as shown in Table 4.2. The highest gross return in both sites was recorded from MM3 (2.7 million TZS/ha) and MM5 (2.3 million TZS) during 2015 while, MM4and TSP 5 (3.5 million TZS/ha) during 2016 at Ilakala and DAP4 (3.2 million TZS/ha) at Changarawe during 2016.

Total variable costs in both commercial and subsistence farming increased with fertilizer application rates and types (Table 4.2). Fertilizers TSP and DAP had more total variable cost than MM in both commercial and subsistence, however, commercial farming costs 500,000 Tanzanian shillings (TZS/ha) more compared to subsistence as far as fertilizer application is concerned. Fertilizer application had more labor demand than control but fertilizer micro-doses and recommended rate had equal labor (man-days) demand in spot application (Table 4.2).

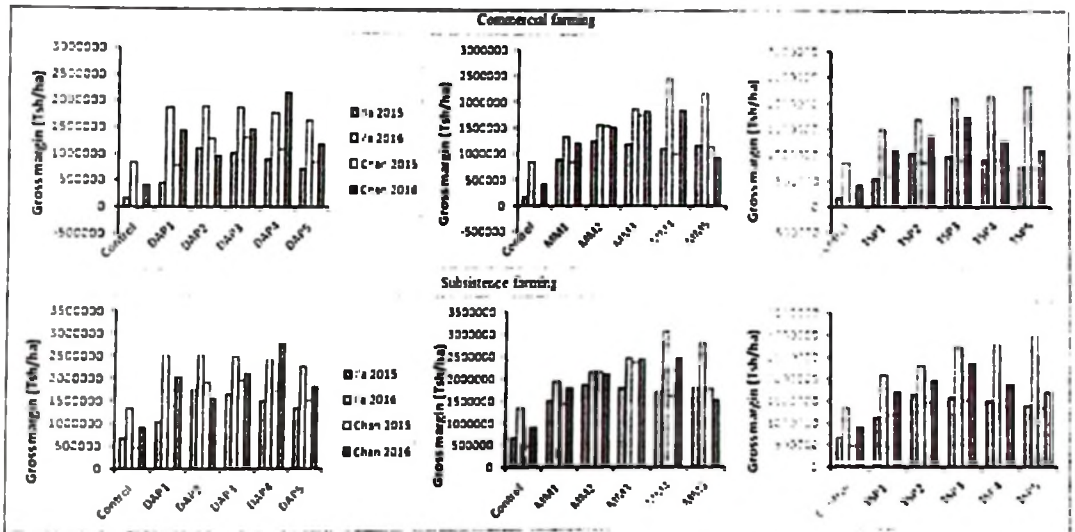
Table 4. 2 Gross return, total variable costs and labor in maize fertilizer micro-dosing technology

	Gross Return (1000'TZS/ha)				TVC (1000'TZS/ha)		Labor
Treatment	GR Ilakala 2015	GR Ilakala 2016	GR Changarawe 2015	GR Changarawe 2016	TVC-Commercial	TVC-Subsistence	Person days/ha
Control	806.4	1492.0	611.8	1059.0	639.5	149.5	91
DAP1	1263.5	2715.0	1599.5	2277.0	819.9	223.9	97
DAP2	1997.1	2776.0	2184.0	1824.0	883.5	278.3	97
DAP3	2009.0	2864.0	2323.3	2466.0	997.1	372.3	97
DAP4	1983.8	2886.0	2197.3	**3270.0**	1107.5	473.7	97
DAP5	1904.7	2846.0	2067.8	2389.0	1206.0	575.1	97
MM1	1716.4	2146.0	1646.4	2003.0	817.6	221.1	97
MM2	2136.4	2415.0	2433.9	2379.0	883.4	270.9	97
MM3	2172.8	2844.0	**2737.0**	2805.0	991.8	371.2	97
MM4	2175.6	**3543.0**	2070.6	2924.0	1092.5	471.9	97
MM5	**2363.9**	3373.0	2340.1	2089.0	1191.8	573.3	97
TSP1	1354.5	2319.0	1406.3	1940.0	815.2	223.7	97
TSP2	1932.0	2579.0	1731.1	2253.0	882.3	277.9	97
TSP3	1971.2	3106.0	1887.9	2747.0	997.7	385.2	97
TSP4	2010.4	3258.0	2015.3	2372.0	1106.7	493.6	97
TSP5	1988.7	**3573.0**	1952.3	2300.0	1214.0	600.9	97

DAP, MM and TSP are fertilizer types namely Di-ammonium phosphate, Minjingu Mazao and triple super phosphate. Numbers 1, 2, 3, 4 and 5 are fertilizer rates as 7.5 kg P and 10 kg N, 10kg P and 20, 20 kg P and 40kg N/ha. 30 kg P and 60 kg N, and 40kg P and 80 kg N/ha. GR is gross return, and TVC is a total variable costs. Number bolded are highest GR.

4.4.2 Gross margin of fertilizer rates in maize production

Gross margin that is also a net profit from fertilizer types and rates was very high under subsistence farming compared to commercial farming with the highest profit in Minjingu Mazao (MM4) as presented in Figure 4.2. Under commercial farming, control had the lowest gross margin and during 2015 Changarawe had a net loss or negative profit. Plots with DAP2 and DAP4, MM2. MM3 and MM4. TSP2, TSP3 and TSP5 had the highest gross margin (Figure 4.2).



Key DAP = Diammonium phosphate. MM = Minjingu mazao and TSP = Triple super phosphate. Numbers 1 to 5 are rate - 10 kgN and 5 kgP, 20 kg N and 10 kg P, 40 kg N and 20 kg P, 60 kg N and 30 kg P, and 80 kg N and 40 kg P ha⁻¹

Figure 4. 2: Gross margin of maize under fertilizer micro-dosing application

4.4.3 Return to labor in maize under fertilizer application

Return to labor was higher in subsistence farming than commercial with the highest amount of money saved with Minjingu mazao (MM4) as shown in Figure 4.3. Control had the lowest value, with negative return to labor at Changarawe during 2015 in commercial farming. There was increase in costs per person-day from control to micro-dose rates and it decreased towards recommended rates (Figure 4.3).

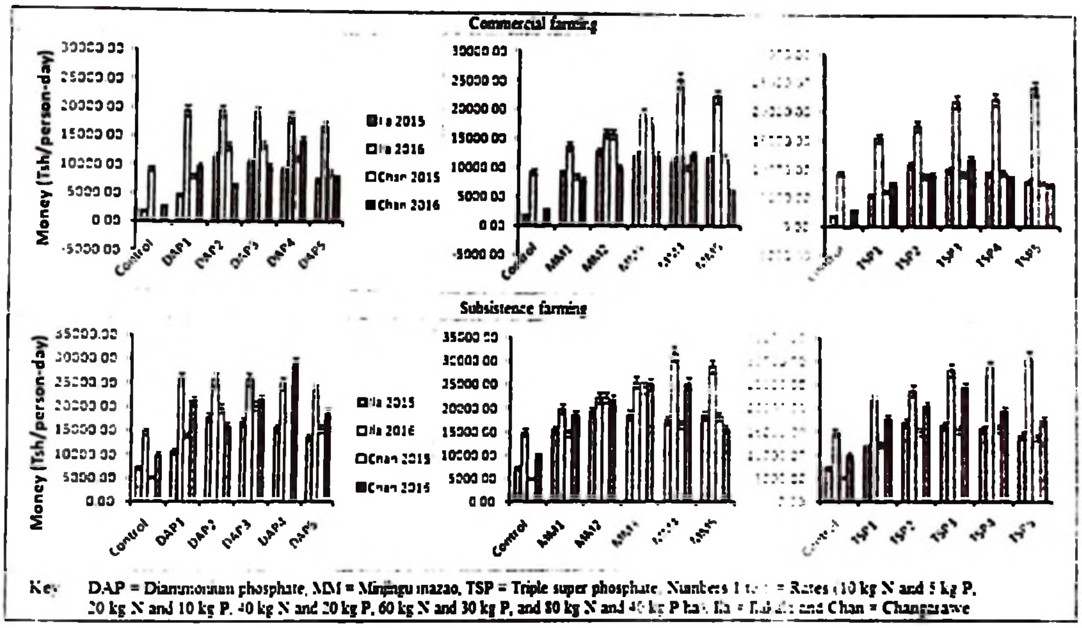


Figure 4. 3: Return to labour in maize fertilizer micro-dosing technologies for 2015 and 2016 in Ilakala and Changarawe

4.4.4 Benefit and cost ratio of fertilizer micro-dose rates in maize production

Commercial farming had lower benefit cost ratios (B/C) than subsistence. Maize commercial farming had the highest B/C in DAP2, DAP4 and MM2 with the lowest values in control plots (Table 4.3). Subsistence maize farming had the highest values in DAP1 and MM2 with different trend compared to commercial farming.

Table 4. 3:Benefit cost ratio of maize from fertilizer micro-dosing

Treatment	B/C- commercial				B/C- subsistence			
	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016
Control	1.27	2.30	0.96	1.66	5.39	9.98	4.09	7.08
DAP1	1.57	3.26	1.95	2.77	5.74	12.13	7.14	10.17
DAP2	2.26	3.12	2.43	2.12	7.37	9.97	7.85	6.55
DAP3	2.04	2.86	2.30	2.49	5.40	7.69	6.24	6.62
DAP4	1.83	2.60	1.97	2.92	4.19	6.09	4.64	6.90
DAP5	1.61	2.34	1.70	1.98	3.31	4.95	3.60	4.15
MM1	2.09	2.63	2.00	2.47	7.76	9.71	7.45	9.06
MM2	2.40	2.77	2.70	2.73	7.89	8.91	8.98	8.78
MM3	2.19	2.90	2.70	2.86	5.85	7.66	7.37	7.56
MM4	1.99	3.22	1.90	2.69	4.61	7.51	4.39	6.20
MM5	1.97	2.81	1.95	1.79	4.12	5.88	4.08	3.64
TSP1	1.67	2.82	1.73	2.39	6.05	10.37	6.29	8.67
TSP2	2.17	2.92	1.97	2.57	6.95	9.28	6.23	8.11
TSP3	1.98	3.09	1.90	2.76	5.12	8.06	4.90	7.13
TSP4	1.82	2.91	1.82	2.17	4.07	6.60	4.08	4.81
TSP5	1.64	2.90	1.61	1.92	3.31	5.95	3.25	3.83

DAP, MM and TSP are fertilizer types namely Di-ammonium phosphate, Minjingu Mazao and triple super phosphate. Numbers 1, 2, 3, 4 and 5 are fertilizer rates as 7.5 kg P and 10 kg N, 10kgP and 20, 20 kg P and 40kg N/ha. 30 kg P and 60 kg N. and 40kgP and 80 kg N/ha. GR is gross return, and TVC is a total variable costs.

4.5 Discussion

Gross return was influenced by the cost of resources invested (labour and inputs): quantity of crop produced and price fluctuation. Amount of maize crop produced per unit area varied among fertilizer types and levels applied as well as cropping year (Figure 4.1). These variations among treatments reflected the importance of fertilizer application to increase crop yield. Maize Prices fluctuated between seasons, during harvest the supply of maize was very high that resulted into low price. At sowing, maize supply was very low to most of smallholder farmers so that their value increased extremely. Fluctuation of maize prices reported in this study (Figure 4.1) followed a trend reported by Sogodo *et al.* (2016) confirming the supply and demand theory described by Debertin (2012). Total production costs increased in plots treated with fertilizers due to extra expenses incurred for purchasing fertilizers, costs of transportation and labor needed to apply fertilizers (Komarek *et al.*, 2017). Subsistence farming required some extra field activities such as cultivation, sowing, weeding, and fertilizer application and harvesting to family labor which generally is considered as routine responsibility in family farming as many other examples show (Oladele, 2008). Family labour often included self-exploitation not striving for a regular minimum salary and social benefits; but in exchange includes higher flexibility, self-determination, and more or less transparent profit-sharing (Schmitt, 1991). That resulted into lower production costs than commercial farming where everything was charged for the activity performed.

Net loss in control plots under commercial farming was caused by increased production costs in land which is not productive without fertilizer application. This indicates that whenever farmer is shifting from subsistence to commercial production especially fertilizers should be used more intensively, as experienced also by other authors (Pingali, 1997; Waceke and Kimenju, 2007). Fertilizer micro-dose rates of only 25, 50 and 75% from the recommended nitrogen and phosphorus rates produced the highest net profit (Figure 4.2). This can be considered a strategy for coping with low rainfall periods or harsh weather conditions (Murendo and Wollni, 2015), declining soil fertility (Montpellier Panel Report, 2013) and reducing fertilizer costs due to lower amount purchased (Camara *et al.*, 2013). Results of net return reported in this study are different from those reported by Bachmann *et al.* (2016) who found 16.9% lower net return in fertilizer micro-dosing rates of 55.3 % compared to the recommended rate of NPK fertilizer. This difference can be attributed to differences in better weather conditions such as 800 – 1100 mm rainfall.

The result of profitability is in similar trend with those reported by Camara *et al.* (2013) showing that micro-dosing had higher investment return compared to recommended. Profitability analysis in terms of net profit, return to labor and benefit-cost ratio indicated that MM fertilizer was more profitable followed by DAP and TSP. This is mainly due to lower market price of MM fertilizer (Table 4.1). Also, MM fertilizer had relatively more yield compared to DAP and TSP that increased revenues. Fertilizer micro-dosing at 12.5, 25 and 50% of recommended nitrogen and phosphorus were more profitable than recommended rate due to increasing yields with lower amount of fertilizer usage. Hence, these lower rates; for instance 223,900 TSH/ha for 12.5% fertilizer micro-dose rates are economically more viable for poor smallholder farmers in sub-humid tropical conditions.

4.6 Conclusions and Recommendations

Market prices of maize fluctuated over the year, with the price during harvest being low and increasing towards field operations of next cropping seasons. Minjingu Mazao fertilizer had the highest return among the phosphate fertilizer types under this study. Micro-dosing rates of 12.5% was more profitable than no fertilizer application and the profitability increased towards 25% and 50% and decreased at recommended rate (100% N and P) in subsistence and commercial farming. Subsistence farming was more profitable than commercial farming due to high labour charges.

Therefore, smallholder farmers should first adopt 12.5% as a low cost entry point to fertilizer use and later on advance to 25% and 50% micro-dosing rates which are even more profitable. These micro-fertilization techniques can easily offset fertilizer costs and bring fairly higher yields, profits and increase return on investment under the current changing of weather conditions affecting crop production in sub humid tropics.

4.7 Acknowledgement

This paper is a product of the Trans-SEC project (www.trans-sec.org). The German Federal Ministry of Education and Research (BMBF) funded the project, and the German Federal Ministry for Economic Cooperation and Development (BMZ) co-financed the Trans-SEC project. The views expressed are purely from the authors and may not in any circumstances be regarded as stating an official position of the BMBF and BMZ.

4.8 References

Adams, A. M., Gillespie, A. W., Kar, G., Koala, S., Ouattara, B., Kimaro, A. A., et al. (2016). Long term effects of reduced fertilizer rates on millet yields and soil properties in the West-African Sahel. *Nutr Cycl Agroecosyst* 106: 17-29.

Bachmann, E., Natcher, D., Kulshreshtha, S., Baco, M. N., Akponikpe, P. B. I. and Peak, D. (2016). Profitability and institutional constraints to the adoption of fertilizer micro-dosing in Northwest Benin. *Sustainable Agriculture Research* 5 (3): 11 – 23.

Camara, B. S., Camara, F., Berthe, A. and Oswald, A. (2013). Micro-dosing of fertilizer- a technology for farmers' needs and resources. *International Journal of Agri Science* 3 (5): 387 - 399.

Cameron, A., Derlagen, C. and Pauw, K. (2017). *Options for reducing fertilizer prices for smallholder farmers in Tanzania.* Prepared for the Ministry of Agriculture, Livestock and Fisheries (MALF) United Republic of Tanzania. Policy Report. MAFAP (Monitoring and Analyzing Food and Agricultural Policies). FAO, Rome. 34pp.

CIMMYT (2013). *Yield and yield components: A practical guide for comparing crop management practices.* Mexico: International Maize and Wheat Improvement Center. 28pp.

Debertin, D. L. (2012). *Agricultural Production Economics*. Second Edition. Macmillan Publishing Company, Upper Saddle River, N.J. USA. 431pp. [http://www.uky.edu/~deberti/agprod5.pdf] Site visited 21 Sept. 2017.

Germer, J., Herrmann, L., Mahoo, H., Swai, E., Graef, F., Kahimba, F., Asch, F., Tumbo, S., Makoko, B., Kimaro, A., Schäfer, M., Saidia, P. and Chilagane, E. (2017). Fertilizer micro-dosing for increasing yields under sole and intercropping systems for rural stakeholders. Trans-SEC. [http://project2.zalf.de/trans-sec/public/media/ factsheets/ Trans-SECfactsheet1b.pdf] visited 20th October 2017.

Gilbert, N. (2012), African agriculture: dirt poor. *Nature* 483: 525 - 527. doi: 10.1038/483525a.

Hayashi, K., Abdoulaye, T. and Gerard, B. (2008). Evaluation of application timing in fertilizer micro-dosing technology on millet production in Niger, West Africa. *Nutr Cycl Agroecosyst* 80: 257 – 265.

Kirway, T. N., Lema, N. M., Lyimo, S. D., Kileo, R. O., Kapange, B. W., Schouten, C. and Schrader, T. (2003). *Farming Systems Approaches Training Manual*, Volume 2. DRD/MAFS. Tanzania. 255pp.

Komarek, A. M., Drogue, S., Chenoune, R., Hawkins, J., Msangi, S., Belhouchette, H. and Flichman, G. (2017). Agricultural household effects of fertilizer price changes for smallholder farmers in central Malawi. *Agricultural Systems* 154: 168 – 178.

Lyimo, S., Mduruma, Z. and De Groote, H. (2014). The use of improved maize varieties in Tanzania. *African Journal of Agricultural Research* 9(7): 643 - 657.

Macauley, H. and Ramadjita, T. (2015). Cereal crops: Rice, maize, millet, sorghum and wheat. 36pp. [https://www.afdb. org/fileadmin/ uploads/ afdb/Documents/Events/DakAgri2015/Cereal Crops-_Rice__Maize __Millet__Sorghum__Wheat.pdf] visited 12th October 2017.

MALF (2017). *Budget Speech of the Ministry of Agriculture Livestock and Fisheries 2017/18*. Parliament of the United Republic of Tanzania. Dodoma Tanzania. 255pp.

Marandu, A. E., Mbogoni, J. D. and Ley, G. J. (2014). *Revised Fertilizer Recommendations for Maize and Rice in the Eastern, Southern Highlands and Lake Zones of Tanzania*. Department of Research and Development. Dar es salaam: Ministry of Agriculture Food Security and Cooperatives. 40pp.

Montpellier Panel Report (2013). *Sustainable Intensification: A new paradigm for African agriculture*. London, UK. 36pp.

Murendo, C. and Wollni, M. (2015). *Ex-post impact assessment of fertilizer microdosing as a climate-smart technology in Sub-Saharan Africa*. ICRISAT. 27pp.

NAP (2013). *National Agricultural Policy*. Dar es salaam, Tanzania: Ministry of Agriculture Food Security and Cooperatives. 51pp.

Oladele, O. I. (2008). Indigenous labour sourcing: Subsistence farming and poverty status among farmers in Nigeria. *Indian Journal of Traditional Knowledge* 7 (3): 478 – 484.

Pingali, P. L. (1997). From Subsistence to Commercial Production Systems: The Transformation of Asian Agriculture. *American Journal of Agriculture Economics* 79: 628 – 634.

Schmitt, G. (1991). "Why is the Agriculture of Advanced Western Countries still Organized by Family Farms? Will this Continue to be so in the Future?" *European Review of Agricultural Economics* 18 (3): 443-458.

Shao, F. M. (2007). *Analysis of the Agricultural Technologies Development and Dissemination Situation in Tanzania*: SADC Multi-country Agricultural Productivity Programme (SADC MAPP). Food Agriculture and Natural Resources (FANR) of the SADC Secretariat. 111pp.

Sodogo, D., Coulibaly, B., Coulibaly, B. Y. and Sacko, K. (2016). Impact of mineral fertilizer microdosing on the yield of sorghum in adoption fields of women trained in farmers' field school of Niako in South Sudan area of Mali. *International Journal of Current Microbiology and Applied Sciences* 5(4): 698 – 704.

Waceke, J. W. and Kimenju, J. W. (2007). Intensive Subsistence Agriculture: Impacts, Challenges and Possible Interventions. *Dynamic Soil, Dynamic Plant* 1 (1): 43 – 53.

XE Corporation (2018). XE Currency Charts: US Dollar to Tanzanian Shilling Chart. [https://www.xe.com/currencycharts/?from=USD&to=TZS] site visited 18th August 2018.

CHAPTER FIVE

5.0 PROFITABILITY OF MAIZE-PIGEON PEA INTERCROPS UNDER SOIL MOISTURE MANAGEMENT OPTIONS AND FERTILIZER MICRO-DOSING IN SUB-HUMID TROPICS

5.1 Abstract

Low adoption of improved technologies to smallholder farmers as influenced by inadequate local supply of inputs, access to information and human capital results into low productivity. Smallholder farmers are becoming aware on financial return and other benefits before adopting a new technology due to increasing costs of production. Most recommendations of technologies are from agronomic data with emphasis on maximum yield without economic analysis resulting into poor adoption of new technologies being recommended. It is important to do profitability analysis of inter-row rainwater harvesting methods in the field and fertilizer use under sole crop and intercropping systems. Three fertilizer levels of nitrogen and phosphorus were studies under three cropping systems and three rainwater harvesting practices in the field. Profitability analysis involved net benefit and benefit cost ratios of maize and pigeon-pea crops from fertilizer use under different rainwater harvesting practices. Tie ridge and fertilizer micro-dose had higher gross margin than open ridges and flat cultivation in maize sole cropping. Pigeon-pea sole cropping had the higher gross margin in flat cultivation than tie and open ridges. Maize and pigeon pea intercropping under fertilizer micro-dosing had the highest gross margin above 4.5 million Tanzanian shillings. Intercropping maize and pigeon pea had highest B/C ratio 6.1- 15.6 in commercial farming and 12 – 32 in subsistence farming. Inter-row rainwater harvest and

fertilizer micro-dosing would optimize profit in both sole and intercropping systems.

Key words: Benefit/Cost ratio, cropping systems. gross margin, micro-dosing fertilizer, rainwater harvesting, subsistence farming.

5.2 Introduction

Maize is the most important crop grown for food and cash in sub-Saharan Africa (Smale *et al.*, 2011). This crop is widely grown in mixed cropping systems by subsistence farmers in developing countries (FAO. 1994). Maize and pigeon pea is among the multiple cropping systems common to smallholder farmers for food mainly energy and protein as well as income generation. Intercropping maize-pigeon pea maximizes land use efficient, monetary value. nutritional quality. soil fertility improvement through leaf shading and nitrogen fixation (Kimaro *et al.*, 2009; Myaka *et al.*, 2006).

Regardless of all these importance, productivity remains poor. for instance in Tanzania average yield is between 1.0 and 1.7 t/ha against the potential of 6-7.5 t/ha maize and 0.5 – 0.8 t/ha against the potential of 2.5-3.0 t/ha pigeon pea (NAP. 2013; Suleiman and Rosentrater, 2015). This is mainly due to low adoption of improved technologies to smallholder farmers which is influenced by inadequate local supply of inputs, access to information and human capital (Amare *et al.*, 2012). Due to increasing costs of production, smallholder farmers are becoming aware on financial return and other benefits before adopting a new technology (Kaliba *et al.*, 2000; Waddington *et al.*, 2007). However, more contributions to the passionate debate about how to revitalize soil fertility improvement are needed (Gilbert, 2012). Most recommendations of technologies are from agronomic analysis with emphasis on maximum yield without economic analysis (Limbu, 1999). This contributes to slow rate and poor adoption of new technologies being recommended.

It is important to supplement farm experiments which are purely agronomic with economic analysis (Kirway *et al.*, 2003). Profitability analysis have been done on rainwater harvesting using diversion canal in maize, bunded basins in rice and water storage ponds in onions for semi-arid areas (Senkondo *et al.*, 2004), net return and the marginal value-cost ratio of fertilizer micro-dosing in millet production in arid areas (Hayashi *et al.*, 2008), risk analysis of adopting fertilizer rates under erratic rainfall conditions (Monjardino *et al.*, 2013) and determining factors such as access to inputs, good agricultural practices and economic benefits for adoption of new technologies (Amare *et al.*, 2012; Kaliba *et al.*, 2000; Limbu, 1999). There is inadequate information on profitability analysis of tied ridges combined with cropping systems and fertilizer micro-dose in sub-humid tropical areas. Therefore, this study will contribute to recommendations of a type of inter-row rain water harvesting technologies in the field, cropping systems and fertilizer use which are economically viable under subsistence as well as commercial farming in sub-humid tropical conditions. Subsistence farming is the production of food primarily for consumption and done on fragmented land holdings using archaic techniques but if there is a surplus can be sold while commercial farming is primarily for sale to make a profit and is done with modern tools and inputs

(Kahan, 2013). Net profit and benefit-cost ratio are among the profitability analysis before recommending a new technology to farmers (Kirway *et al.*, 2003; Senkondo *et al.*, 2004). In this regard, this paper attempts to analyze profitability of inter-row rainwater harvesting methods in the field and fertilizer use under sole crop and intercropping systems.

5.3 Materials and Methods

Field experiments were carried out in Ilakala and Changarawe villages of Kilosa District, Morogoro Region in Tanzania. Three fertilizer levels namely control, micro-dose and recommended rates were studies under three cropping systems and three rainwater harvesting practices in the field namely tied ridges, open ridges and flat cultivation. Di-ammonium phosphate (DAP) fertilizer was applied at planting in both maize and pigeon-pea and urea fertilizer to supplement nitrogen from DAP was applied at vegetative growth of maize only.

Data collection involved costs of inputs (seeds and fertilizers) from agro-shops during procurement of these materials. Also, costs of hiring labor under commercial farming and labor power (person days) under subsistence farming for land preparation, planting, fertilizer application, weeding, harvesting, shelling, transport and storage of produce were collected during each activity (Table 5.1). Labor was considered working effectively for eight hours per person per days (Kirway *et al.*, 2003).

Table 5. 1: Costs of inputs and labour in field activities under commercial and subsistence farming

Item/ Activity	Unit	Cost or Labour power in maize	Cost or Labour power in pigeon pea
Seeds	TZS per ha	62500	75000
Fertilizer- DAP	TZS per 50 kg bag	75000 - 80000	75000 - 80000
Fertilizer- Urea	TZS per 50 kg bag	55000 - 60000	55000 – 60000
Transportation of fertilizer	TZS per 50 kg bag	3000	3000
Cultivation (non-family labour) + tie ridge	TZS per ha	155000	155000
Cultivation (family labour) + tie ridge	Man-days per ha	44	44
Cultivation (non-family labour) + open ridge	TZS per ha	145000	145000
Cultivation (family labour) + open ridge	Man-days per ha	42	42
Cultivation (non-family labour) flat	TZS per ha	125000	125000
Cultivation (family labour) flat	Man-days per ha	35	35
Planting (non-family labour)	TZS per ha	75000	50000
Planting (family labour)	Man-days per ha	8	6
Fertilizer application (Non- family labour)	TZS per ha	75000	50000
Fertilizer application (family labour)	Man-days per ha	6	4
Weeding (non-family labour) + ridge maintenance	TZS per ha	225000	175000
Weeding (family labour) + ridge maintenance	Man-days per ha	35	30
Weeding (non-family labour) flat	TZS per ha	200000	150000
Weeding (family labour) flat	Man-days per ha	34	28
Harvesting (Non- family labour)	TZS per ha	87500	62500
Harvesting (family labour)	Man-days per ha	7	4
Shelling/ threshing (Non- family labour)	TZS per ha	60000	40000
Shelling/threshing (family labour)	Man-days per ha	8	5
Storage bags (woven/ polythene)	TZS per bag	1200	1200
Transportation of produce to home	TZS per bag	1500	1500

Yields of maize and pigeon pea (kg/ha) were collected from field experiments following the procedures described by CIMMTY (2013) and ICRISAT (1992) in maize and pigeon pea, respectively and presented in Figure 5.1.

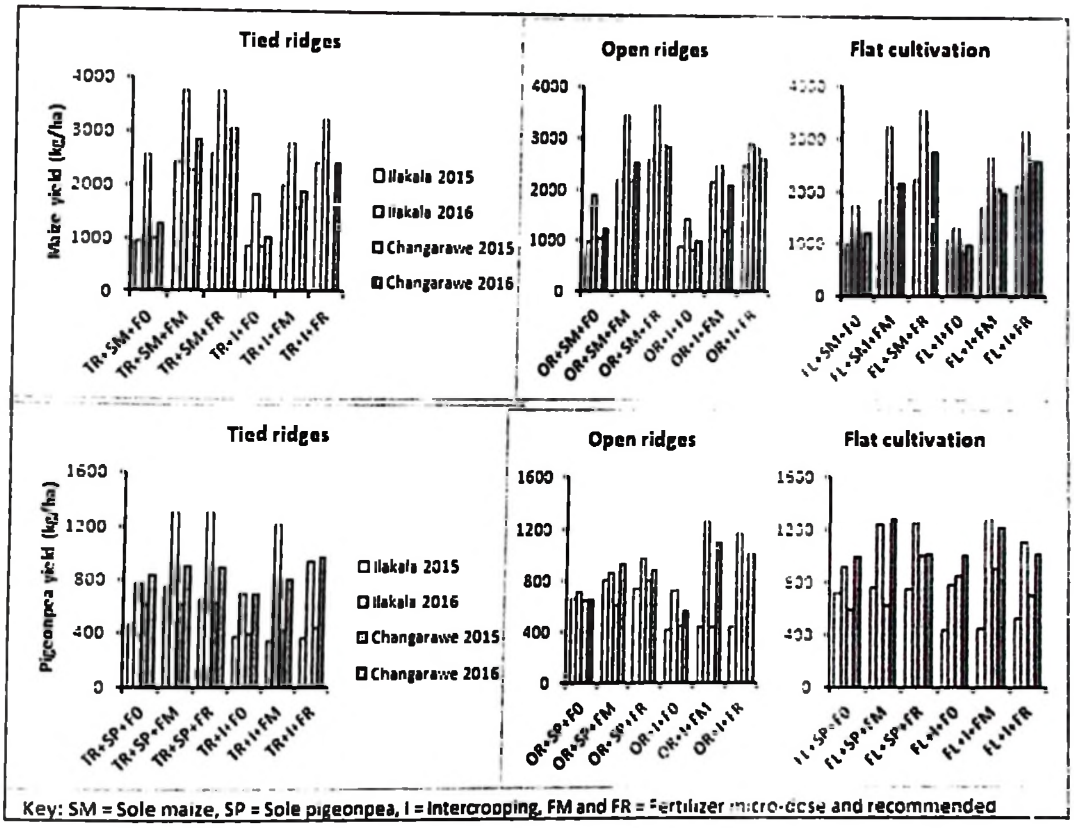


Figure 5. 1: Maize and pigeon pea yield under different moisture management, cropping systems and fertilizer use

Prices of the crops were collected at harvest and planting from 15 key informants (research assistants, Extension officers and farmers) from each case study site and presented in Figure 5.2. The currency used was Tanzanian shillings (TZS); however, exchange rate was between 2150 and 2282 TZS to one US dollar from 2016 to 2018 (XE Corporation, 2018).

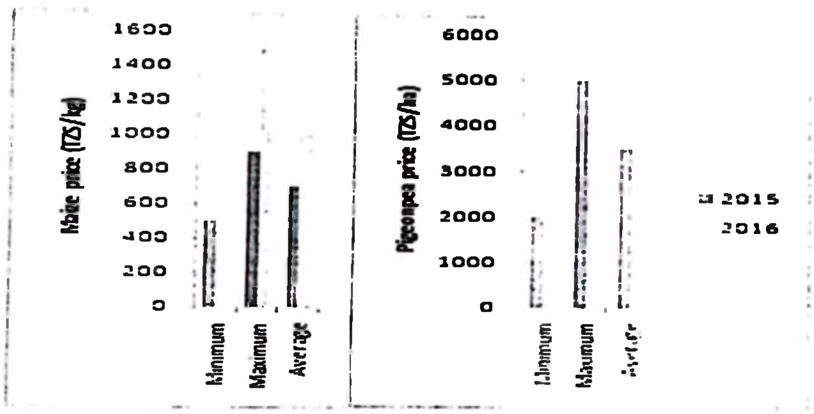


Figure 5. 2: Price of maize and pigeon pea crops

Then, data were imported in Excel sheets where variables such as gross return (GR), total variable cost (TVC) gross margin (GM) or net profit, return from labor and benefit- cost ratios were calculated using the following equations described by Debertin (2012):

$$Gross\ Return = Yield\ of\ produce \times its\ market\ price \text{ ....} (1)$$

$$Gross\ Margin = Gross\ Return - Total\ Variable\ Costs \text{ ....} (2)$$

$$Return\ to\ labor = \frac{(Goss\ Return - Total\ Variable\ Costs) per\ ha}{Number\ of\ persondays\ per\ ha} \text{ ....} (3)$$

$$Benefit/Cost\ ratio = \frac{Gross\ Return}{Total\ Variable\ Cost} \text{ ....} (4)$$

5.4 Results

5.4.1 Revenue and cost of maize and pigeon-pea production

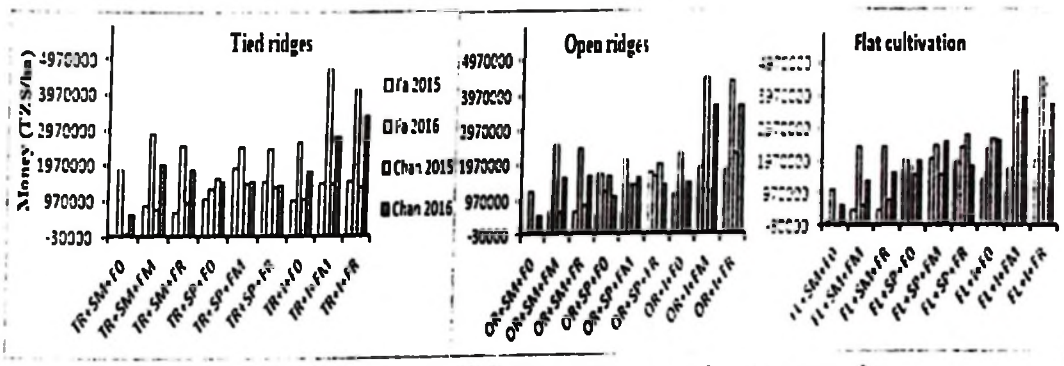
Variation in gross return, variable cost and labor was highly influenced by rainwater harvesting in the field and fertilizer application (Table 5.2). Gross return increased from 2015 to 2016 season, in some treatments with maize (TR+SM+FM. OR+SM+FM and FL+SM+FM) the increase was two-folds. Maize sole (SM) had the highest return under tied ridges (TR) and fertilizer application at recommended rate (FR). The trend of return increased rapidly from no fertilizer (F0) to micro-dose fertilizer (FM) and FR in maize sole but was different in pigeon pea. Flat cultivation (FL) and fertilizer use at recommended (FR) had the highest gross return under maize-pigeon pea intercropping (I) as shown in Table 5.2: Commercial farming had more total variable costs (TVC) and labor than subsistence farming. Intercropping between maize and pigeon pea had the highest TVC when fertilizer was used under tied ridges (Table 5.2).

Table 5. 2 Gross return, total variable costs and labour of maize and pigeon pea crops

Treatments	Gross Return (TZS/ha)				TVC (TZS/ha)		Labor
	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016	Commercial	Subsistence	Person days/ha
TR+SM+F0	669900	2581600	701400	1283200	704825	149500	100
TR+SM+FM	1701700	3760100	1606500	2870400	871050	274900	107
TR+SM+FR	1825600	3776100	2134300	3078300	1211400	579100	107
TR+SP+F0	1627500	1937500	2182600	2101250	584500	142000	89
TR+SP+FM	2629550	3240000	2177000	2255750	721000	226000	94
TR+SP+FR	2297750	3255000	2187500	2225500	798500	301000	94
TR+I+F0	1928150	3599500	2009700	2771100	946500	291500	116
TR+I+FM	2596300	5811700	2560250	3918300	1125550	416900	122
TR+I+FR	2983400	5589100	2818550	4866150	1465900	721100	122
OR+SM+F0	675500	1887400	742000	1227300	682000	149500	99
OR+SM+FM	1515500	3457200	1513400	2523400	886100	274900	105
OR+SM+FR	1801100	3613000	2009700	2848700	1186600	579100	105
OR+SP+F0	2295300	1782500	2243500	1647250	574500	142000	88
OR+SP+FM	2818200	2137500	2122050	2307500	708500	226000	92
OR+SP+FR	2563750	2427500	2802100	2206750	783500	301000	92
OR+I+F0	2056950	3243800	2159150	2423900	936500	291500	114
OR+I+FM	3052000	5591300	2349900	4831600	1136900	416900	120
OR+I+FR	3268300	5807000	3741500	5130300	1441100	721100	120
FL+SM+F0	693700	1719500	637000	1230200	637000	149500	91
FL+SM+FM	1274700	3235800	1459500	2166100	837400	274900	97
FL+SM+FR	1566600	3534700	1915900	2754800	1141600	579100	97
FL+SP+F0	2521400	2285000	2091950	2504750	529500	142000	79
FL+SP+FM	2678550	3097500	2210950	3208750	663500	226000	83
FL+SP+FR	2640400	3122500	3526600	2559500	738500	301000	83
FL+I+F0	2305800	3259500	3565100	3517000	891500	291500	106
FL+I+FM	2789150	5844900	4600050	5019250	1091900	416900	112
FL+I+FR	3356500	5926800	4263350	5119650	1396100	721100	112

5.4.2 Gross margin analysis of maize and pigeon pea cropping systems

Gross margin in Tanzanian Shillings (TZS) at commercial farming increased from sole to maize-pigeon pea intercropping with the lowest net profit in control plots under sole crops. Maize sole crop under ridges without fertilizer (TR+SM+F0 and OR+SM+F0) had negative gross margin at Ilakala while at Changarawe flat cultivation without fertilizer (FL+SM+F0) had zero gross margin during 2015 (Figure 5.3). Tie ridge and fertilizer micro-dose had higher gross margin than open ridges and flat cultivation in maize sole crop. Flat cultivation under pigeon pea sole crop resulted into more gross margin than tied and open ridges. Pigeon pea sole crop had higher gross margin than maize sole crop without fertilizer application. The highest gross margin above 4.5 million TZS was from maize and pigeon pea intercropping under fertilizer micro-dosing (Figure 5.3).



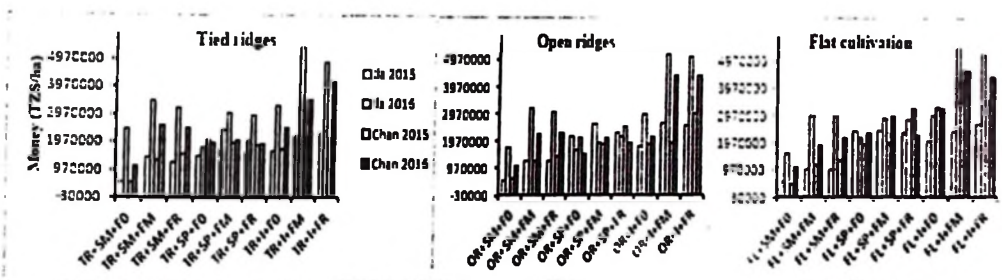
Key: TR = Tied Ridges, OR = Open Ridges, FL = Flat cultivation, SM = Sole Maize, SP = Sole Pigeonpea, I = Intercropping
F0 = No fertilizer, FM = Fertilizer Micro-dose, and FR = Fertilizer at Recommended rate. Ila = Ilakala and Chan = Changarawe villages

Figure 5. 3: Gross margin of maize and pigeon pea crops under commercial farming

Note: Ila represents Ilakala village and Chan represents Changarawe village.

Gross margin at subsistence farming increased from sole crop to intercrops with the lowest amount (500,000/= TZS) in maize sole without fertilizer (Figure 5.4).

Fertilizer micro-dose under tie ridges of maize sole crop had highest gross margin in sole cropping system. Maize and pigeon pea intercrop had higher gross margin than sole crop under fertilizer micro-dosing (Figure 5.4). The trend was similar to commercial farming however; subsistence resulted into more gross margin than commercial farming.



Key: TR = Tied Ridges, OR = Open Ridges, FL = Flat cultivation, SM = Sole Maize, SP = Sole Pigeonpea, I = Intercropping
F0 = No Fertilizer, FM = Fertilizer Micro-dose, and FR = Fertilizer at Recommended rate. Ila = Ilakala and Chan = Changarawe villages

Figure 5. 4: Gross margin under subsistence farming

Note: Ila represents Ilakala village and Chan represents Changarawe village.

5.4.3 Return to labor in maize and pigeon pea cropping systems

Return to labor in TZS per person-day was higher in subsistence than commercial farming (Table 5.3). Return to labor increased from sole crop to maize and pigeon pea intercrops. Flat cultivation had the best return to labor under intercropping with fertilizer application. Maize sole crop under tied ridges had better return to labor than flat while pigeon pea has opposite results to maize under sole cropping system (Table 5.3). Return to labor increased from no fertilizer to fertilizer micro-dosing with slight decrease towards recommended rate.

Table 5. 3: Return to labor

Treatments	Commercial (TZS/person-day)				Subsistence (TZS/person-day)			
	Ilakala 2015	Ilakala 2016	Changar 2015	Changar 2016	Ilakala 2015	Ilakala 2016	Changar 2015	Changar 2016
TR+SM+F0	-220	18406	94	5813	5188	24245	5502	11302
TR+SM+FM	7944	26836	7076	18715	13389	32706	12496	24357
TR+SM+FR	5903	23929	8800	17380	11697	30001	14591	23453
TR+SP+F0	11690	15165	17912	17000	16650	20125	22872	21960
TR+SP+FM	20419	26887	15583	16371	25681	32203	20815	21687
TR+SP+FR	16072	26193	14894	15193	21334	31562	20156	20562
TR+I+F0	68037	107808	73462	99659	80718	120188	86143	112340
TR+I+FM	65300	196943	79938	123975	78019	210085	92632	136889
TR+I+FR	71416	154218	85323	152145	84483	167563	98390	165490
OR+SM+F0	-66	12207	608	5522	5327	17599	6000	10914
OR+SM+FM	6030	24451	6010	15558	11815	30308	11795	21414
OR+SM+FR	5852	23394	7839	15830	11638	29180	13625	21615
OR+SP+F0	19631	13781	19040	12238	24565	18715	23974	17172
OR+SP+FM	22924	15527	15359	17375	28167	20770	20602	22617
OR+SP+FR	19344	17863	21934	15465	24587	23106	27177	20708
OR+I+F0	76222	108443	84775	78714	88887	121168	97441	91379
OR+I+FM	89331	201479	81294	172250	102389	214538	91352	185309
OR+I+FR	88802	187683	105502	159740	101861	200741	118561	172798
FL+SM+F0	626	11945	0	6546	6005	17324	5379	11925
FL+SM+FM	4514	24758	6422	13716	10321	30564	12228	19522
FL+SM+FR	4387	24703	7993	16652	10194	30509	13799	22459
FL+SP+F0	25344	22336	19880	25132	30275	27267	24810	30063
FL+SP+FM	24287	29336	18651	30677	29560	34609	23924	35950
FL+SP+FR	22923	28734	33604	21948	28196	34007	38877	27221
FL+I+F0	84712	117967	176029	150938	97364	130619	188681	163590
FL+I+FM	90376	208124	194326	191710	103456	221203	207405	204789
FL+I+FR	108018	183149	149303	162499	121098	196228	162382	175578

5.4.4 Benefit /cost ratios of maize and pigeon pea cropping systems

Benefit and cost ratios (B/C) increased with fertilizer application under commercial farming than subsistence. Intercropping maize and pigeon pea had higher B/C than sole crops (Table 5.4). Rations increased from pigeon pea sole to maize sole crops with the maximum B/C under intercropping. Maize sole crop without fertilizer had the lowest B/C ratios (≤1) under commercial farming. The highest B/C was noted in flat (FL) cultivation when fertilizer micro-dosing was applied under intercropping maize and pigeon pea crops under commercial farming. This trend was similar in subsistence farming however; Ilakala site 2015 revealed that FL without fertilizer (F0) had the highest ratio in pigeon pea sole crop (Table 5.4). Maize sole crop had the highest B/C under tie ridges (TR) and fertilizer micro-dosing (FM) while pigeon pea sole crop had the highest ratios in flat cultivation.

Table 5. 4. Benefit cost ratio of maize and pigeon pea under rainwater harvest practices and fertilizer application

	B/C- commercial				B/C- subsistence			
Treatments	Ilakala 2015	Ilakala 2016	Chang 2015	Chang 2016	Ilakala 2015	Ilakala 2016	Chang 2015	Chang 2016
TR+SM+F0	0.97	3.51	1.01	1.83	4.48	17.27	4.69	8.58
TR+SM+FM	1.99	4.18	1.88	3.28	6.19	13.68	5.81	10.44
TR+SM+FR	1.53	3.08	1.78	2.51	3.15	6.52	3.69	5.32
TR+SP+F0	2.78	3.31	3.73	3.59	11.46	13.64	15.37	14.80
TR+SP+FM	3.66	4.48	3.03	3.12	11.61	11.31	9.63	9.98
TR+SP+FR	2.90	4.05	2.76	2.77	7.63	10.81	7.27	7.39
TR+I+F0	6.07	9.53	6.39	8.34	13.36	21.69	13.94	19.15
TR+I+FM	6.30	14.99	7.01	10.12	13.47	31.45	14.26	21.15
TR+I+FR	6.47	11.87	7.20	11.54	11.99	22.13	13.19	21.33
OR+SM+F0	0.99	2.77	1.09	1.80	4.52	12.62	4.96	8.21
OR+SM+FM	1.72	3.89	1.72	2.84	5.51	12.58	5.51	9.18
OR+SM+FR	1.52	3.07	1.69	2.40	3.11	6.29	3.47	4.92
OR+SP+F0	4.00	3.10	3.91	2.87	16.16	12.55	15.80	11.60
OR+SP+FM	3.98	3.02	3.00	3.26	12.47	9.46	9.39	10.21
OR+SP+FR	3.27	3.10	3.58	2.82	8.52	8.06	9.31	7.33
OR+I+F0	6.57	9.23	7.06	7.06	14.27	22.34	15.00	16.72
OR+I+FM	7.78	15.12	6.91	13.14	16.36	31.03	13.72	26.91
OR+I+FR	7.54	13.86	8.62	12.09	13.88	25.47	15.87	22.23
FL+SM+F0	1.09	2.70	1.00	1.93	4.64	11.50	4.26	8.23
FL+SM+FM	1.52	3.86	1.74	2.59	1.61	11.77	5.31	7.88
FL+SM+FR	1.37	3.10	1.68	2.41	2.71	6.10	3.31	4.76
FL+SP+F0	4.76	4.32	3.95	4.73	17.76	16.09	14.73	17.64
FL+SP+FM	4.04	4.67	3.33	4.84	11.85	13.71	9.78	14.20
FL+SP+FR	3.58	4.23	4.78	3.47	8.77	10.37	11.72	8.50
FL+I+F0	7.26	9.76	12.65	11.49	15.97	22.50	24.90	24.42
FL+I+FM	7.69	15.68	14.15	14.30	15.58	32.10	27.51	28.60
FL+I+FR	8.65	13.63	11.24	12.23	15.74	21.93	20.43	22.33

5.5 Discussion

Gross margin recorded in this study (-22100 to 5428000 TZS) and benefit/cost ratios (Table 5.4) were above those reported by Matere *et al.* (2016) that ranged between -56595 to 1517000 TZS (-2625 to 70391 KES) and 1.38   1.56 in maize-pigeon pea intercropping under terraces in semi-arid Kenya. These were influenced by increased crop yields under inter-row rainwater harvesting, fertilizer application and seasonal market price of crops. Rainwater harvesting using tied ridges reduced runoff, increased water infiltration and moisture conservation in the soil during a short period of drought conditions. This enhanced a good fertilizer response to maize yield which increased gross return. Apart from crop yields, prices were different between maize and pigeon pea across the cropping seasons. Pigeon pea had higher price (2500 and 3500 TZS/ kg) than maize which had an average price of 700 and 1000 TZS/ kg during 2015 and 2016, respectively. During 2016 towards 2017, maize harvest was not as good as 2015 which raised the demand for maize and consequently higher price. Crop yields and market prices were determinants of revenue (Debertin, 2012).

Total variable costs were highly influenced by technologies involved in crop production. Construction of ridges and their subsequent maintenance increased costs of production than flat plots. Fertilizer micro-dosing was a cheaper way of fertilizer adoption under subsistence farming due to its lower costs of production from reduced amount of fertilizer than recommended fertilizer usage. However, if this is to be commercialized a farmer would need more money because family labor and assistance from neighbors and friends is not applicable under commercial farming. Tie ridges were labor intensive than flat plots because of difficulties associated with ridging and fertilizer application.

Maize and pigeon pea intercropping under fertilizer micro-dosing were more profitable because intercropping reduced or saved labor costs for management like land preparation, weeding and pest control. Under commercial farming, negative gross margin in sole maize crop and ridges without fertilizer was due to increased labor costs of constructing and maintaining ridges with low yield which failed to compensate variable cost of production as reflected in return to labor (Table 5.3) and benefit/cost ratios (Table 5.4). Maize sole crop would be considered for commercialization under tied ridges with fertilizer micro-dose due to increased yield which compensated total variable costs of production. Intercropping maize and pigeon pea could be commercialized under flat cultivation with fertilizer micro-dosing (10 kg P and 20 kg N/ha) because of the highest net profit (Figure 5.3) due to lower costs of production and better yield of pigeon pea which fetched a good market price (2500 to 3500 TZS/kg). However, higher gross margin under subsistence farming of maize and pigeon pea cropping systems and fertilizer micro-dosing were attributed by the use of family labor which reduced money expenditure compared to commercial which hired labor for all operations (Schmitt 1991).

5.6 Conclusions and Recommendations

Tie ridge is more labor intensive than flat cultivation, also maize crop need more resource allocation such as labor and capital than pigeon pea. Maize sole crop and fertilizer micro-dosing had higher net profit and benefit/cost ratio than recommended fertilizer application in tied ridges. Intercropping maize and pigeon pea was more profitable than sole crops, however fertilizer micro-dosing optimized gross return, gross margins and benefit/cost under smallholder farming conditions. Adoption of inter-row rainwater harvest and fertilizer micro-dosing would optimize profit in both sole and intercropping systems.

5.7 Acknowledgement

This paper is a product of the Trans-SEC project (www.trans-sec.org). The German Federal Ministry of Education and Research (BMBF) funded the project, and the German Federal Ministry for Economic Cooperation and Development (BMZ) co-financed the Trans-SEC project. The views expressed are purely from the authors and may not in any circumstances be regarded as stating an official position of the BMBF and BMZ.

5.8 References

Amare, M., Asfaw, S. and Shiferaw, B. (2012). Welfare impacts of maize-pigeon pea intensification in Tanzania. *Agricultural Economics* 00: 1-17.

CIMMYT (2013). *Yield and yield components: A practical guide for comparing crop management practices.* Mexico: International Maize and Wheat Improvement Center. 28pp.

Debertin, D. L. (2012). Agricultural Production Economics. Second Edition. Macmillan Publishing Company, Upper Saddle River, N.J. USA. 431pp. [http://www.uky.edu/~deberti/agprod5.pdf] Site visited 21 Sept. 2017.

FAO (1994). Review of CGIAR Priorities and strategies. Food and Agriculture Organization of the United Nations, Rome Italy. 295pp.

Gilbert, N. (2012). Dirt Poor: The key to tackling hunger in Africa is enriching its soil. The big debate is about how to do it. *Nature* 483: 525 – 527. [https://www.nature.com/polopoly_fs/1.10311!/menu/main/topColumns/topLeftColumn/pdf/483525a.pdf] site visited 21 Sept. 2017.

Hayashi, K., Abdoulaye, T., Gerard, B. and Bationo, A. (2008). Evaluation of application timing in fertilizer micro-dosing technology on millet production in Niger, West Africa. *Nutrient Cycl Agroecosyst* 80: 257 – 265.

ICRISAT (1992). *Pigeon pea Botany and Production Practices*: Skill Development Series no.9. Human Resource Development Program of the International Crops Research Institute for the Semi-Arid Tropics. Patancheru, Andhra Pradesh 502 324. India. 41pp.

Kahan, D. (2013). *Market-oriented farming: An overview*. Farm management extension guide. Food and Agriculture Organization of the United Nations, Rome. 104pp.

Kaliba, A. R. M., Verkuijl, H. and Mwangi, W. (2000). Factors Affecting Adoption of Improved Maize Seeds and Use of Inorganic Fertilizer for Maize Production in the Intermediate and Lowland Zones of Tanzania. *Journal of Agricultural and Applied Economics* 32 (1): 35 – 47.

Kimaro, A. A., Timmer, V. R., Chamshama, S. A. O., Ngaga, Y. N. and Kimaro, D. A. (2009). Competition between maize and pigeonpea in semi-arid Tanzania: Effect on yields and nutrition of crops. *Agriculture, Ecosystems and Environment* 134: 115 – 125.

Kirway, T. N., Lema, N. M., Lyimo, S. D., Kileo, R. O., Kapange, B. W., Schouten, C. and Schrader, T. (2003). *Farming Systems Approaches Training Manual*, Volume 2. DRD/MAFS, Tanzania. 255pp.

Limbu, F. (1999). Agricultural Technology Economic Viability and Poverty Alleviation in Tanzania. *Paper Presented at the Structural Transformation Policy Workshop* held on 27- 30 June at Sarena Hotel, Nairobi, Kenya. Organized by the ECAPAPA. TEGEMEO Institute. and Michigan State University. 55p.

Matere, S. J., Mbatia, O. L. E., Nzuma, J. M. and Nyamwaro. S. O. (2016). Financial benefit-cost analysis in maize-pigeon pea intercrop in semi-arid areas of Kenya. *Journal of Agriculture and Environmenntal Sciences* 5 (1): 140 – 148.

Monjardino, M., McBeath, T. M., Brennan, I. and Llewellyn. R. S. (2013). Are farmers in low-rainfall cropping regions under-fertilising with nitrogen? A risk analysis. *Agricultural Systems* 116: 37 – 51.

Myaka, F. M., Sakala. W. D., Adu-Gyamfi, J. J.. Kamalongo. D.. Ngwira. A.. Odgaard, R., Nielsen, N. E. and Hogh-Jensen. H. (2006). Yields and accumulations of N and P in farmer-managed intercrops of maize-pigeonpea in semi-arid Africa. *Plant Soil* 285: 207-220.

NAP (2013). *National Agriculture Policy.* Ministry of Agriculture Food Security and Cooperatives, Dar es salaam, Tanzania. 51pp.

Schmitt, G. (1991). "Why is the Agriculture of Advanced Western Countries still Organized by Family Farms? Will this Continue to be so in the Future?" *European Review of Agricultural Economics* 18 (3): 443-458.

Senkondo, E. M. M., Msangi, A. S. K., Xavery, P., Lazaro, E. A. and Hatibu, N. (2004). Profitability of Rainwater Harvesting for Agricultural Production in Selected Semi-Arid areas of Tanzania. *Journal of Applied Irrigation Science* 39 (1): 65 81.

Smale, M., Byerlee, D. and Jayne, T. (2011). *Maize Revolution in Sub-Saharan Africa*: The Policy Research Working Paper 5659. the World Bank Development Research Group of Agriculture and Rural Development Team. 34pp.

Suleiman, R. A. and Rosentrater, K. A. (2015). Current maize production. postharvest losses and the risk of mycotoxins contamination in Tanzania. *Agricultural and Biosystems Engineering Conference Proceedings and Presentations.7-2015*. St. Joseph. Michigan: Iowa State University.

Waddington, S. R., Mekuria, M., Siziba, S. and Karigwindi. J. (2007). Long-term Yield Sustainability and Financial Returns from Grain Legume Maize Intercrop on a Sandy Soil in sub-humid North Central Zimbabwe. *Expl Agric.* 43: 489 – 503.

XE Corporation (2018). XE Currency Charts: US Dollar to Tanzanian Shilling Chart. [https://www.xe.com/currencycharts/?from=USD&to=TZS] site visited 18th August 2018.

CHAPTER SIX

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 General Conclusions

Soils under the study sites had low nitrogen, phosphorus and zinc. There was inter and intra-seasonal variation of amount and distribution of rainfall causing moisture stress at the study sites.

Minjingu mazao fertilizer had higher maize yield averaging 2317 kg/ha than DAP by 6.63% and TSP by 9.55%.

A combination of fertilizer rates of 10 kg N and 5 kg P ha^{-1} (12.5%) as well as 20 kg N and 10 kg P ha^{-1} (25%) micro-doses increased yield from 1012 kg/ha in control to 1928 kg/ha and 2394 kg/ha, respectively. Grain yield increased from control to micro-dosing rates and intermediate rates (50 and 75% of recommended) and decreased towards recommended rate. The profitability increased towards 12.5%, 25% and 50% and decreased at recommended rate (100% N and P).

Tied ridges conserved more soil moisture than flat cultivation and increased fertilizer use efficiency. Intercropping maize and pigeon pea had higher land use efficiency than sole cropping. Maize growth and yield was better under tied ridges than pigeon pea crop. Fertilizer micro-dosing at 25% doubled yield compared to no fertilizer application. Intercropping resulted into more diversified crop production, better land use efficiency and high financial returns indices when micro-dose fertilizer at 10kg P/ha was applied. Intercropping maize and pigeon pea was more profitable than sole crops; fertilizer micro-dosing optimized gross return, gross margins and benefit/cost.

6.2 General Recommendations

Fertilizer rates of 12.5% (10 kg N and 5 kg P ha^{-1}) and 25% (20 kg N and 10 kg P ha^{-1}) are the appropriate micro-dose fertilizer rates for maize production in the study site and other areas with similar conditions. Adoption of these micro-dosing fertilizer rates could be used as an entry point to promote fertilizer usage with lower investment risk relative to current recommended rates under the current change of rainfall amount, pattern and distribution.

Also, combination of 40 kg N and 20 kg P $ha^{-1}$and 60 kg N and 30 kg P ha^{-1} are recommended as optimum rates in the study sites and others with similar conditions to replace 80 kg N and 40 kg P ha^{-1} that was recommended by Marandu *et al.* (2014) due to agronomic and economic benefits.

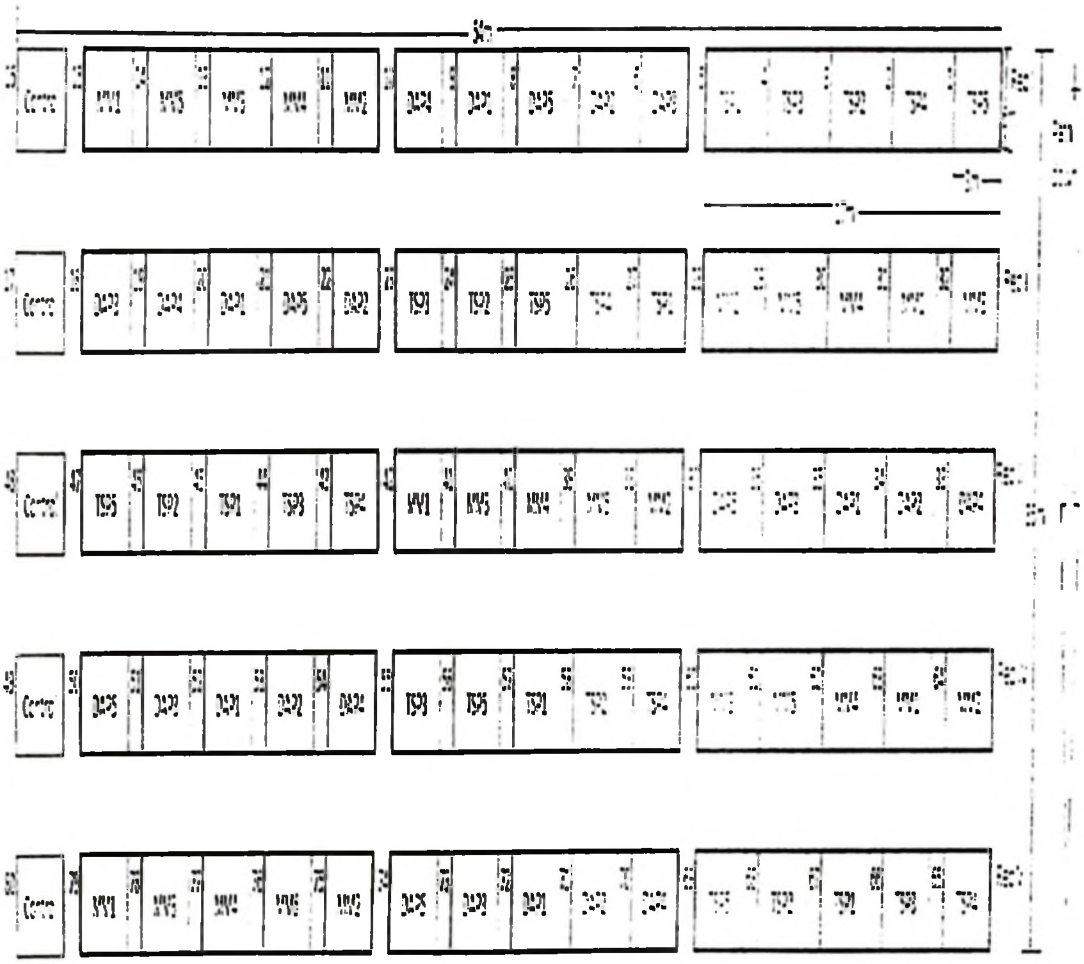
Fertilizer package has to include lower amount such as 5, 10, 20 and 25 kg bag to accommodate micro-dose strategy and affordability to resource poor farmers who can rarely afford to buy a 50 kg bag package.

It is important to avail locally produced cheap fertilizers such as Minjingu mazao due to their lower market price, more profitability and good agronomic effectiveness.

The strategy of intercropping under inter-row rainwater harvesting and fertilizer micro-dose is encouraged to increase food, nutritional and income security in smallholder farming systems.

APPENDICES

Appendix 1: Experimental layout in fertilizer micro-dose rates of N and P for maize in Kilosa study sites



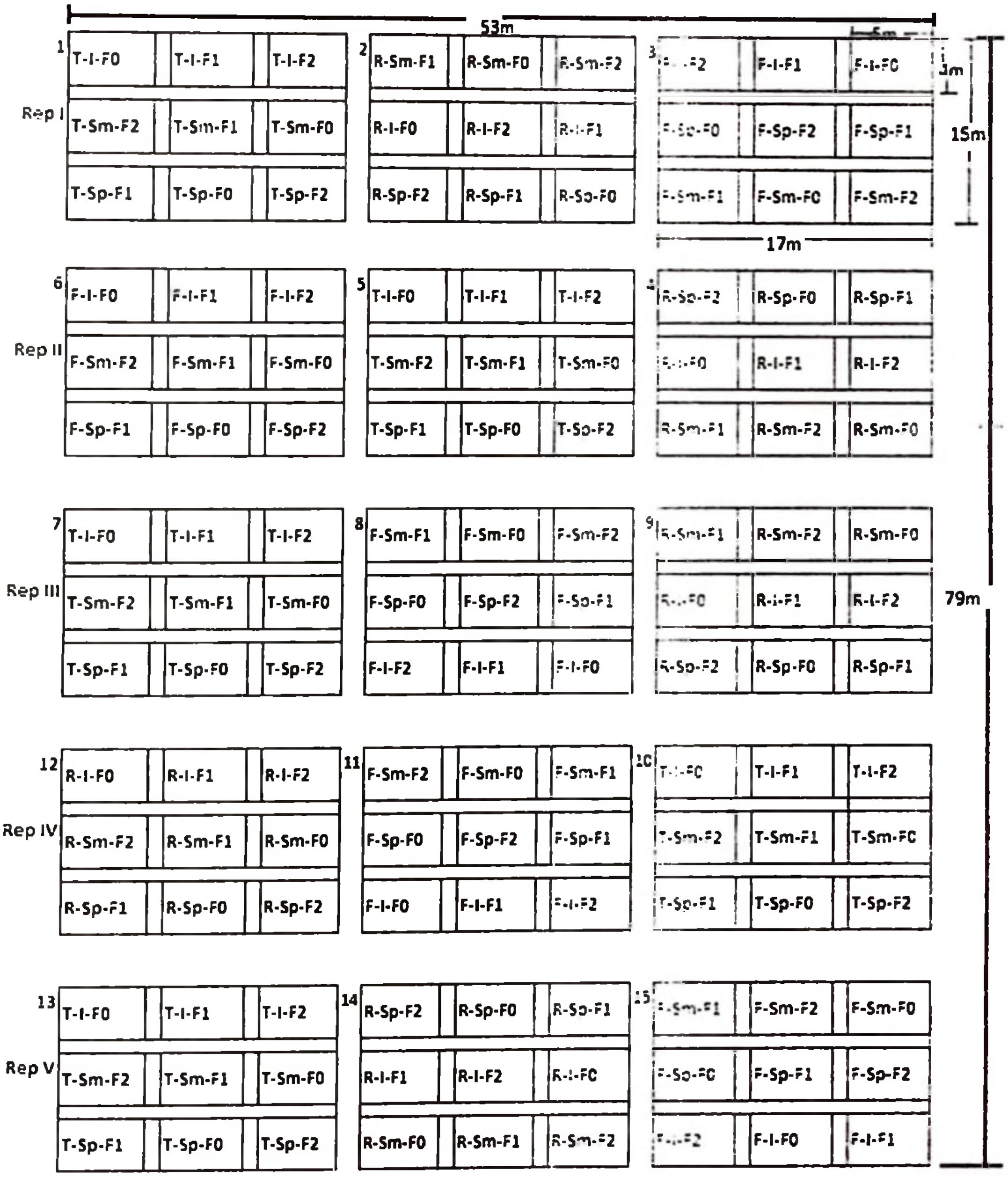
[illegible]

[illegible]

[illegible]

[illegible]

Appendix 2: Experimental Layout for Maize –Pigeon pea cropping systems under moisture conservation practices and fertilizer use in Kilosa study sites



Key: 1- 15 are main plots, Rep I- V are replications

Moisture management options T= Tie ridge, R= Ridges (open/ normal), F Flat cultivation

Cropping systems: Sm is sole maize, Sp is sole pigeon pea, and I is intercrop (maize-pigeon pea)

F= fertilizer placement at three levels F0 = farmer practice, F1 micro-dose and F2 recommended rate.

Maize spacing = 75cm x 30cm, pigeon pea spacing = 75 cm x 50 cm.

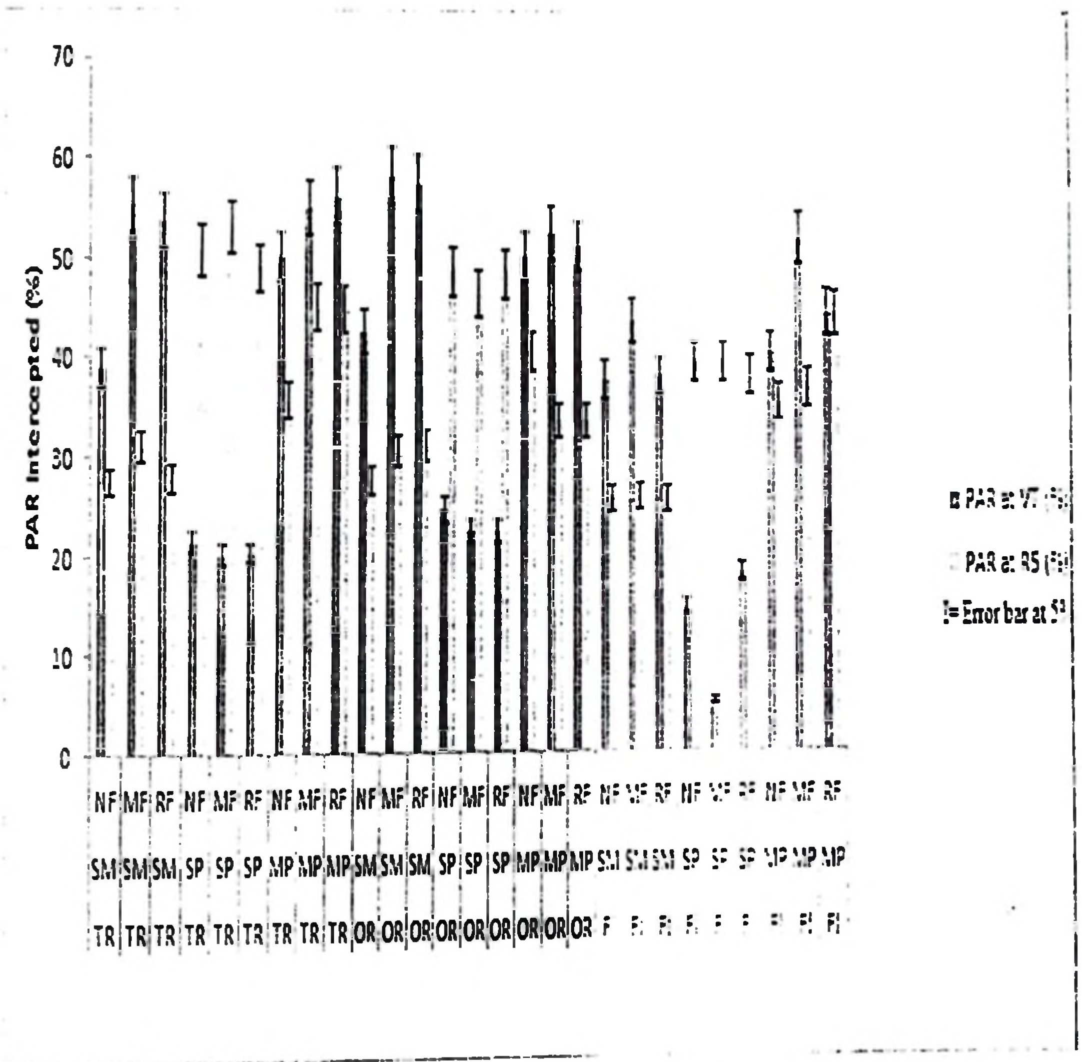
Appendix 3: Effects of rainwater harvesting (RWH) practices, cropping systems and fertilizer use on photo-synthetically active radiation (PAR) at different growth stages

Photosynthetically active radiation (PAR) interception was measured using AccuPAR PAR/LAI Ceptometer model LP 80 (Decagon device, 2015).This device measured above and below canopy PAR, then average intercepted PAR was calculated as follows:

$f \cong 1 - t$..

Where f is the fractional absorption PAR and t is the fraction of incident radiation transmitted by the canopy which was calculated as the ratio between below and above canopy readings.

Results are presented in the Figure below.

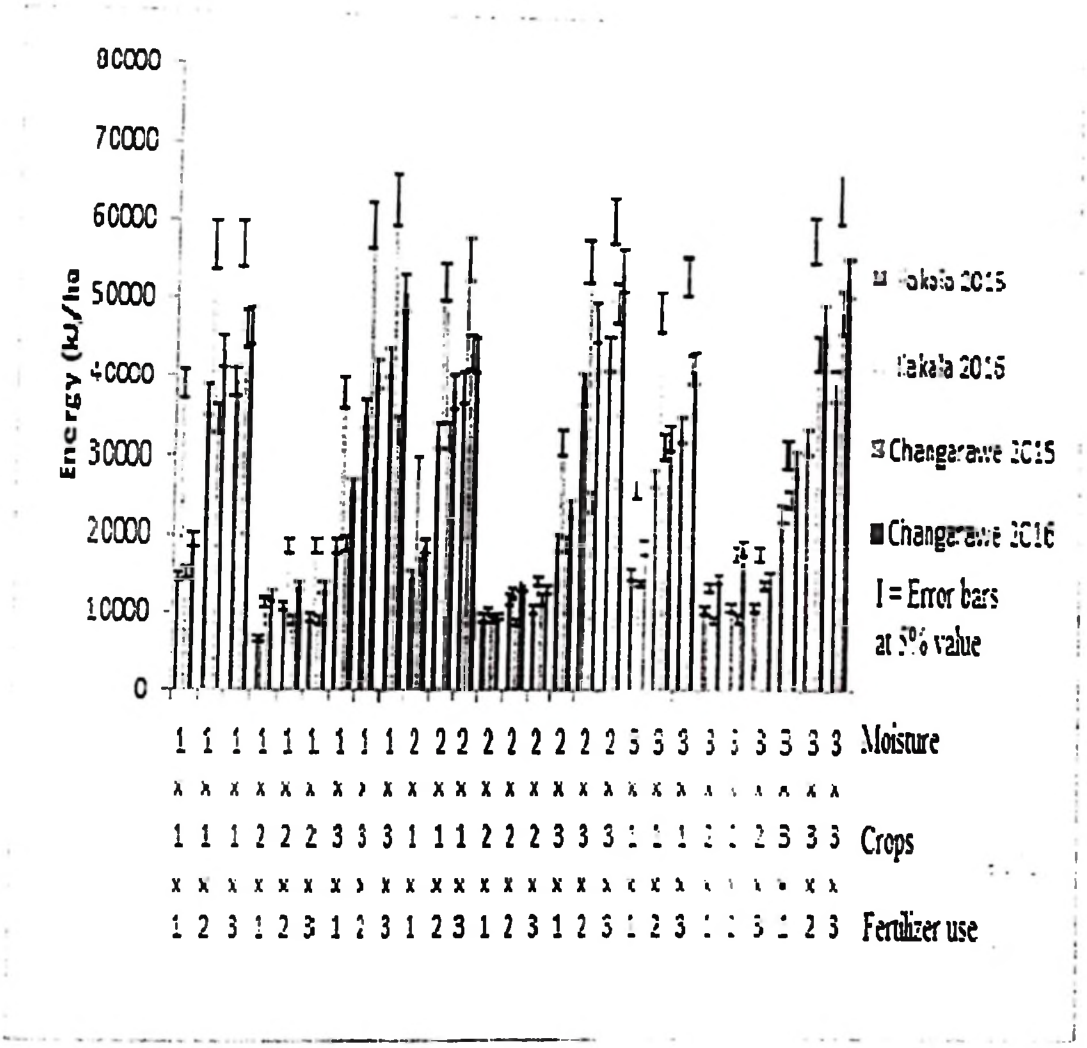


Fertiliser use (NF= No fertiliser, MD= Micro-dosing fertiliser and RF= Recommended fertiliser
Cropping systems (SM= sole maize, SP= sole pigeonpea and MP= maize and pigeonpea intercrop
Inter-row rainwater harvesting practices (TR= tie ridge, OR= open ridge and FI= flat cultivation

Appendix 4: Effect of soil moisture conservation, cropping systems and fertilizer use on energy content (kJ/ha) from maize and pigeon pea crops

Nutritional values in form of energy (joules) and protein (g) were calculated using food composition tables and equations below. Energy from maize was calculated using the food composition tables in which 100g of dried maize grains in Tanzania contains 362.0kilo calories or 1514.6J (1kcal = 4.184joules) (Lukmanji *etal.*, 2008). For pigeon pea grains 100 g contain 343 kcal or 1437.17J (Lukmanji *etal.*. 2008; Janila *et al.*, 2016) as shown in the equation below.

$$Energy = Grain\ yield\ X\ Energy\ content\ per\ 100\ g\ of\ edible\ portion\ of\ crop.$$



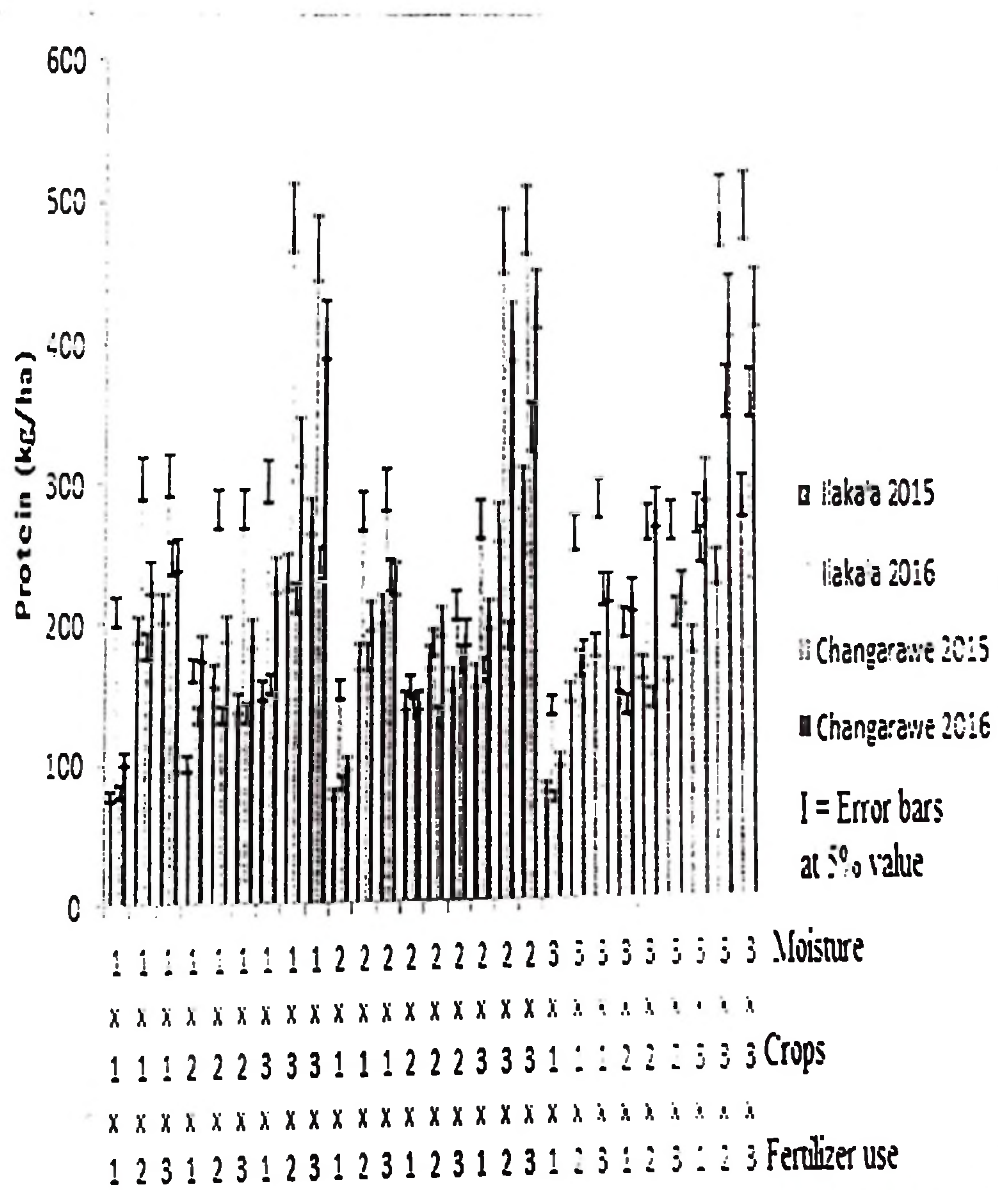
Key: 1 = Tied ridges, 2 = Open ridges, and 3 = Flat cultivation in moisture conservation practices
1 = Maize sole crop, 2 = Pigeonpea sole crop, and 3 = Maize and pigeonpea intercrop in cropping systems
1= Control (No fertilizer), 2 = Micro-dose fertilizer (20 kg N and 10 kg P ha), and 3 = Recommended

Appendix 5: Effect of soil moisture conservation, cropping systems and fertilizer use on protein (kg/ha) from maize and pigeon pea crops

Protein from maize was calculated using food composition table where 100g dried grain contains 8.1g protein. For pigeon pea, 100 g of grains contain 21.7g of protein (Lukmanji *et al.*, 2008) as shown in the equation below.

$$Protein = Grain\ yield\ X\ Protein\ content\ per\ 100\ g\ of\ edible\ portion\ of\ crop$$

The highest energy (60,000 – 70,000 kJ/ha) and protein (400-500 kg/ha) was produced in maize- pigeon pea intercropping. The energy required by people in most of Eastern and Southern African countries is 1873 2479 kcal/capita/day while protein is 46.6 – 69.9 g/capita/day (Nuss and Tanumihardjo. 2011). Maize-pigeon pea cropping system applied with fertilizer at micro-dose and recommended in one hectare could meet energy required by 6591 to 7689 capita/day and protein by 6867 to 8584 capita/day.



Key: 1 = Tied ridges, 2= Open ridges, and 3 = Flat cultivation in moisture conservation
1 = Maize sole crop, 2 = Pigeonpea sole crop, and 3 = Maize and pigeonpea intercrop
1 = Control, 2 = Micro-dose fertilizer (20 kg N and 10 kg P ha), and 3 = Recommended fertilizer (80 kg N and 40 kg P/ha)

SNAL SPECIAL COLLECTION