IMPROVEMENT OF PEARL MILLET AND GROUNDNUT PRODUCTIVITY UNDER MICRO-DOSE FERTILIZER APPLICATION AND WATER MANAGEMENT TECHNOLOGIES IN DODOMA, TANZANIA

EMMANUEL AMOS CHILAGANE

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EXTENDED ABSTRACT

Crop production in semi-arid areas is faced with different challenges that resulted into low crop productivity, low household income and food insecurity. The main production challenges in these areas are declining soil fertility and moisture stresses. The integration of different techniques, which restore soil nutrients at low costs and improve soil moisture can be used as a strategy to cope with these constraints and ensuring sustainable crop production. The purpose of this work was to investigate the effects of applying inorganic fertilizer at reduced amounts (micro-dose rates) under different in-situ rainwater harvesting and soil moisture management technologies by using tied ridges and infiltration pits in pearl millet and groundnut growth and grain yields. It also, focused on assessing profitability of integration of fertilizer rates with tied ridges and infiltration pits in smallholder farming communities. Field experiments were conducted in a semi-arid central part of Tanzania from 2015 to 2017 covering Ilolo and Idifu villages located in Chamwino district, Dodoma region. It was observed that, using tied ridges and infiltration pits increased pearl millet and groundnut yield significantly compared with flat cultivation. Application of fertilizer micro-doses from 25% to 75% of the recommended rate for pearl millet and from 50% to 75% of recommended rate for groundnut increased grain and kernel yields significantly compared with zero application. Integration of flat cultivation and tied ridges with micro-dose at 25% of recommended rate in pearl millet gave yield advantage ranging from 295 to 455 kg/ha and 537 to 959 kg/ha, respectively, compared to farmer practices. It also resulted into positive net profit. Flat cultivation with zero fertilizer application resulted in lowest groundnut yield and had a negative net profit. The integrations of tied ridges and fertilizer micro-dose at 50% of recommended rate gave significantly higher kernel yield, ranging from 906 to 1,197 kg/ha and higher net profit ranging from 424 to 558 USD/ha compared to farmer practice. Tied ridges and infiltration pits conserved soil moisture by 38% and 45%, respectively, more than flat cultivation at 30 cm depth after ten days of rainfall. Land use efficiency was 93% - 157% higher in intercropping system than in sole cropping. Intercropping of pearl millet and groundnut along with tied ridges and infiltration pits with micro-dose rates from 25% to 75% of recommended rate had financial returns of 648- 998 USD/ha higher than sole pearl millet in flat cultivation without fertilizer application. Therefore, the use of micro-dose at 25% of the recommended rate (i.e 15 kgN/ha and 10 kg P_2O_5/ha) for pearl millet, and 50% of recommended rate (22.5 kg P_2O_5/ha) for groundnuts along with tied ridges and flat cultivation is recommended to resource poor farmers of central Tanzania. The study also recommends intercropping of pearl millet and groundnut along with tied ridges and infiltration pits with micro-dose rates at 25% and advanced to higher rates up to recommended rate as their resources increases. This study is further recommending a review of fertilizer package to include lower amount such as 5 kg, 10 kg, 15 kg or 25 kg bags. This will enable smallholder farmers to purchase small amount of fertilizer as per their requirement. The study is further recommending the establishment of government agricultural center in each village to serve famers on all agricultural issues such as purchasing of improved inputs on time.

DECLARATION

I, **EMMANUEL AMOS CHILAGANE** do hereby declare to the Senate of Sokoine University of Agriculture, Morogoro, Tanzania, that this thesis is my own original work done within a period of registration and that it has neither been submitted nor being concurrently submitted for a similar degree award in any other institution.

______________________________ ____________________
Emmanuel Amos Chilagane Date

(PhD Candidate)

The above declaration is confirmed by;

______________________________ ____________________
Professor Cornel L. Rweyemamu Date

(Supervisor)

______________________________ ____________________
Professor Frederick C. Kahimba Date

(Supervisor)

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DEDICATION

This work is dedicated to Almighty God who arms me with strength and makes my way perfect. 'Take fast hold of instruction; let her not go: keep her, for she is thy life' (Proverb 4: 13).

To my beloved wife Rose Damas Mwaka and sons, Joel Emmanuel Chilagane and Jotham Emmanuel Chilagane and to all members of my family.

ORGANISATION OF THE THESIS

This thesis is organized in the "Publishable manuscript format" and consists of five chapters as follows;

i. Chapter one is the General Introduction; it covers the background of the thesis including problems statement, justification and objectives of the study.

ii. Chapter two: paper 1 Effects of fertilizer micro-dose and moisture management practices on growth and yield of pearl millet in semi- arid environment in Dodoma Tanzania.

iii. Chapter Three: paper 2 Effect of fertilizer micro-dose and moisture management practices on agronomic and economic performances of groundnut in semi- arid areas of central Tanzania

iv. Chapter Four: paper 3 Effect of fertilizer micro-dose and rainwater harvesting practices on yield and resource utilization indices in pearl mallet -groundnut intercropping system.

v. Chapter five: Contains the general Conclusion and Recommendations of the whole work.

Comment [EC1]:

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

%	Percentage
ANOVA	Analysis of variance
ARI	Agricultural Research Institute
BNF	Biological Nitrogen Fixation
CGR	Crop growth rate
CV	Coefficient of variation
DAP	Di Ammonia Phosphate
DAS	Days after sowing
FC	Flat cultivation
G	Gram
Ha	Hectare
ICRISAT	International Crop Research Institute for the Semi-arid Tropics
INM	Integrated nutrients management
IP	Infiltration pit
K	Potassium
Kg	Kilogram
LA	Leaf area

LAI	Leaf area index
LER	Land equivalent ratio
MD	Micro-dose
N	Nitrogen
NP	Net profit
NUE	Nutrient use efficient
OC	Organic carbon
P	Phosphorous
RR	Recommended rate
RWH	Rainwater harvesting
SSA	Sub Saharan Africa
TR	Tied ridges
TSW	Thousand seed weight
USD	United States Dollar
V	Monetary value
WUE	Water use efficient

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Pearl millet

Pearl millet (*Pennisetum glaucum* (L) R.Br.) is an erect, tillering cereal crop with determinate growth pattern (Boncompagni, *et al*., 2018). The crop has an extensive fibrous root system with strong lateral roots, which allow effective water and nutrients extraction from deeper soil layers that makes it to be resistant to drought and harsh environment (Dias-Martins *et al*., 2018). Pearl millet is usually grown as a rain-fed crop in the dry tropics and one of the most important cereals in the Sahel Zone- South of the Sahara in Africa (Rajaram *et al*., 2013).

The crop is mainly grown for human consumption serving as staple food in dry areas of the continent. The grain is among the most nutritious of the major cereal grains, it is used for human consumption served in forms such as porridge, cakes, breads, sweets, main meal (ugali) and alcoholic beverages (Adebiyi *et al*., 2018). Pearl millet grain is also used to feed birds, particularly poultry and game birds for recreation hunting such as bobwhite quail, turkey and dove. Pearl millets are nutritionally superior to other cereals such as rice and wheat as they contain a high amount of proteins, dietary fibers, iron, zinc, calcium, phosphorus, potassium, vitamin B, and essential amino acids (Vinoth and Ravindhran, 2017; Kimenye, 2014).

The crop does well in soils with temperatures of 23°C to 30°C and its rainfall requirement ranges from 200 to 1500 mm (DAFF, 2011)**.** Despite the importance of pearl millet in the semi-arid areas of SSA and Tanzania in particular, the yield recorded by farmers in Tanzania is still very low (770 kg/ha) (Kamhambwa, 2014) compared with the global yield (3,200 kg/ha) (Railey, 2006). In Tanzania, this crop is mainly grown in the semi-arid areas of Dodoma (50%), Singida (20%) and Shinyanga (16%). Other areas include Mara (6.4%), Mwanza (3.8%) (Rohrbach and Kiriwaggulu, 2007).

1.2 Groundnut

Groundnut (*Arachis hypogaea* L.) is one of the world's most popular oil seed crops. It is best cultivated in well drained sandy or sandy loam soils with pH ranging from 5.5 to 6.5 and rainfall requirement varying between 500 and 1200 mm (Katundu *et al*., 2012). The crop does well in areas with soil temperatures ranging from 18°C to 30°C in a well-drained fertile soil (DAFF, 2010). Groundnut is among the cultivated legumes in semi-arid part of SSA, which accounts for about 25% of household's agricultural income. Its seeds contain 40%-50% fats, 20%-50% protein and 10%-20% carbohydrates, which make it to be a very important crop for improving nutrition and health in semi-arid areas.

The crop provides a number of benefits to smallholder farmers, for instance, it improves soil fertility through BNF and saves fertilizer costs for subsequent crops; forms an important component of both rural and urban diets like a source of valuable protein, edible oil, fats, energy, minerals, and vitamins (Okello *et al*., 2010). In livestock-farming communities, groundnut residues are used as livestock feed and increases livestock productivity. Groundnut kernel yields is still low in Africa, averaging about 800 kg/ha, compared to the potential yield of 3000 kg/ha (Olayinka and Etejere, 2015). In Tanzania, the average yield is 960 kg/ha which is lower than the potential yield of 1500 kg/ha from improved varieties such as variety Pendo (Kanyeka *et al.,* 2007). Generally, the crop is grown in various regions such as Dodoma and Singida (Central Zone), Tabora and Kigoma (western zone), Shinyanga and Mwanza (Lake Zone) and Mtwara (Southern Zone).

1.3 Productions Challenges in Semi-Arid Areas of sub-Saharan Africa

Declining soil fertility is among the major production challenges in semi-arid areas of SSA including Tanzania. Crop productivity has remained low because of no or little use of fertilizers in crop production, limited or untimely availability of inorganic fertilizers and other inputs (Liverpool-Tasie *et al.*, 2017; World Bank, 2006), imperfect fertilizer markets system (Abrar *et al*., 2004), lack of agronomic knowledge for the farmers on fertilizer use (Asfaw and Admassie, 2004), riskiness and credit constraints (Liverpool-Tasie *et al*., 2017). The low use of inorganic fertilizer in Africa can be attributed to both demand side and supply-side factors. The first and most obvious demand side factor that could potentially explain the low use of fertilizer in Africa relates to profitability. Farmers' demand for commercial fertilizer is weak because fertilizer use is probably unprofitable or only marginally profitable to most farmers. Incentives to use fertilizer are often undermined by the low fertilizer response rate, high variability of crop yields, lack of credit and high fertilizer prices relative to crop output prices. The demand for fertilizer is further exacerbated by lack of information about the availability and cost of fertilizer, inability of farmers to raise resources needed to purchase fertilizer, and lack of knowledge on the part of many farmers about how to use fertilizer efficiently.

Apart from declining soil fertility, drought condition due to little and erratic rainfall is also important challenge farmers have been facing in this area. The major causes contributing to drought is increased pressure of both human and livestock population which has imposed tremendous pressure on natural resources particularly in the arid and semi-arid regions (Kgosikoma and Batisani, 2014). Lack of awareness and underutilization of rainwater harvesting practices such as tied ridges, pits and open ridges in some parts of this region limit adoption and spreading the concept and implementation of rainwater harvesting systems. Moreover, high application costs of some of the rainwater harvesting practices in terms of time, finance and labor limit its adoption by the farmer despite of their high performances.

Other factors are non-availability of seeds of improved varieties, inappropriate crop management practices, as well as pests and diseases (Aboki *et al.*, 2018). Malfunctioning and inefficient markets (largely due to a frail private sector in most countries), insufficient investment in infrastructure, high transportation costs, weak information systems and a poor regulatory framework have hampered proper remuneration of producers/farmers and deterred indeed, incapacitated them from investing and specializing in new and high-value products. Prices remain low and are highly volatile – and there are no mechanisms that can help minimize or share the risk borne by producers. Further, the political unrest and armed conflicts also constrained on agricultural development and on improved food security. This situation prevents farmers from putting more efforts on agriculture and therefore create wider gape between actual yield and potential yield (Jones, 2008; FOA,2005; Muzari 2014)

1.4 Ways Toward Improving Agricultural Productivity in Subsistence Farming Communities

1.4.1 Soil fertility management

There are two main approaches to improved soil fertility. The first is to attempt to meet plant requirements with purchased mineral fertilizers. Various studies showed that, the application of inorganic fertilizers at micro dose rates to recommended rate resulted better agronomic and economic performance compared to zero application (Liverpool-Tasie *et al.*,2017; Adedeji *et al*., 2014; Omonona *et al.*, 2012; Akighir and Shabu, 2011). According to the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), micro dosing is defined as “the application of small, affordable quantities of fertilizer with the seed at planting time or as top dressing 3 to 4 weeks after emergence. Fertilizers are often very expensive for farmers in the developing world, particularly in sub-Saharan Africa (Blessing *et al.*, 2017; Druilhe and Barreiro, 2012). Therefore, for such farmers, micro dosing can help reduce fertilizer costs and give higher returns. ICRISAT has initiated micro dosing programs in West African countries such as Mali, Burkina Faso, and Niger, reaching over 25,000 small-holder farmers and in India. The Institute reports that sorghum and millet yields have responded well to the technique – boosting yields between 44 and 120 percent and incomes has also increased by as much as 130 percent for some families. ICRISAT is working with agricultural extension services to better instruct farmers on how to effectively measure and apply fertilizer (ICRISAT. 2009).

The second relies on biological processes that resulting from the use of organic materials and other crop management options such as cereal -legume intercropping, agroforestry and use of green manures (Annicchiarico *et al*., 2011). However, the more sustainable middle path borrows the best features from both and is referred to as Integrated Nutrition Management (INM). Integrated Nutrition Management combines mineral fertilizers with organic resources, thus increasing fertilizer use efficiency, reducing the risks of acidification and providing a more balanced supply of nutrients (Hirel *et al*., 2011).

1.4.2 Soil moisture conservation

Increasing moisture availability to the agricultural crops in semi-arid areas is very important for sustainable crop production (Hong *et al*., 2018). This can be done through, harvesting water from little and erratic rainfall these areas receive, and temporary conserve harvested water in the soil for crop use. One of the methods frequently used in rainwater harvesting is the harvesting and storage of rainwater in-situ. The in-situ technology consists of making storage available in areas where the water is going to be utilized. All rainwater harvesting systems have three components: a collection area, a conveyance system, and a storage area. In this application, collection and storage is provided within the landscape. The principle behind the recommendation of different practices is to increase the water infiltration and percolation by reducing the rate of runoff, temporarily impounding the water on the surface of the soil to increase time for infiltration and modifying land configuration for inter plot water harvesting. Tied ridges and infiltration pits are some of in-situ rainwater harvesting technologies used in dry prone areas. These technologies enhance long storability of soil water and enhance sorghum and millet crop grain yield up to 65% (Kilasara *et al*., 2015; Yoseph, 2014).

1.4.3 Crop diversification and intensification

Intercropping is the practice of growing two or more crops in the same field at the same time. The goal of intercropping is to achieve increased crop yields on a piece of land through maximized crop growth and resource use efficiency (Dodiya *et al*., 2018; Aziz *et al.*, 2015). Crops grown in this system may not necessarily be sown or harvested at the same time but are grown simultaneously during their respective cropping cycle (Sandler *et al*., 2015). Having diverse crops in the same field allows the farmers to have some yield even if the primary crop is damaged or does not yield as much as expected and this insures food security.

It also maintains soil fertility as the nutrient uptake is made from both layers of soil (Ullah *et al*., 2016). Legumes, through their symbiotic relationship with nodule dwelling bacteria, fix atmospheric N through biologically changing it from the inorganic form to forms that are available for uptake by plants **(**Morris *et al*., 2017; Brooker *et al.*, 2014; Lithourgidis *et al.,* 2011). Legumes grown on soils with low N derive their N requirements entirely from the process of biological nitrogen fixation (BNF) while cereals grown may partially satisfy their N requirements from N fixed by the previous legume if residues are incorporated into the soil, which is alternative and sustainable way of introducing N into low input cropping systems. In addition, roots of legumes decompose and release N into the soil thereby increasing soil N reserves for uptake by subsequent crops (Lithourgidis *et al.,* 2011).

Intercropping also help in reduction of soil runoff by covering the soil and can control weeds by suppression (Wang *et al*., 2014). On weed suppression, intercropping of cereals and cowpea has been observed to reduce striga infestation.

This was attributed to the soil cover by the cowpea that created an unfavorable condition for striga seed germination (Hesammi, 2013). In Zimbabwe, Mashingaidze (2004) found that maize-bean intercropping reduced weed biomass through suppression by 50%-66%. when established at a density of 37,000 plants/ha for maize and 222,000 plants/ha for beans due to more surface cover. In general, intercropping systems are useful in terms of increasing productivity and profitability per unit area, water, nutrients and radiation use efficiency and pests and diseases (Wang *et al.*, 2014; Lithourgidis *et al.*, 2011).

1.5 Evaluation of the Productivity of Intercropping Systems

1.5.1 Land equivalent ratio

Land equivalent ratio (LER) is a measure of the yield advantage obtained by growing two or more crops or varieties as an intercrop compared to growing the same crops or varieties as a collection of separate sole crops (Dariush *et al.*, 2006; Berhanu *et al.*, 2016). The LER is used to evaluate the productivity of intercrops against the sole crop. The LER is calculated using the formula, LER= Σ (Ypi/Ymi), where Yp is the yield of each crop or variety in the intercrop or polyculture, and Ym is the yield of each crop or variety in the sole crop (Bantie *et al*., 2014). For each crop (i) a ratio is calculated to determine the partial LER for that crop, then the partial LERs are summed up to give the total LER for the intercropping system. An LER value of 1.0 indicates no difference in yield between the intercrop and the collection of sole crop (Dariush *et al.*, 2006). A value of less than 1.0 indicates that there is no advantage on land use when intercropping system is compared to sole crop. A value greater than 1.0 indicates the intercropping had advantage on land use compared to sole cropping system.

1.5.2 Monetary advantage

Monetary advantage (V) also is a very common index used in determination of intercropping advantages (Gebru, 2015; Choudhary, 2014). It is also done by comparing monetary values of yield proportion of intercrops and sole crops and it gives exactly monetary value of yield advantages. The formula used to estimate monetary advantage is $V=K_1Y_1+K_2Y_2$; Where: K_1 and K_2 are yields of pearl millet and groundnut respectively while Y_1 and Y_2 are prices of the respective crops; V is the financial return value.

1.6 Problem Statement and Justification

Declining soil fertility and water stress conditions are the main production challenges that resulted into low pearl millet and groundnut yield in Dodoma region. The average yield for pearl millet and groundnut in Tanzania is 770 kg/ha and 960 kg/ha, respectively (Kamhambwa, 2014). Pearl millet actual yield in Chamwino, Dodoma is much lower, averaging 360 kg/ha. The actual yields are much lower compared to the yield potential of 2400 kg/ha and 1500 kg/ha for pearl millet and groundnut, respectively (Kanyeka *et al*., 2007). In other countries, such as USA, the yield of 6100 and 3400 kg/ha for pearl millet and for groundnut, respectively were reported (Kaushik, 2013; Obeng *et al*., 2012).

Dodoma region, particularly Chamwino district is a low-rainfall district, like others in the region, which receives an average of 400 mm to 650 mm of rainfall per annum (Temu *et al*., 2011). Further there is large amount of water that is lost through surface runoff because of the topographical nature of the farmer’s fields as they are mostly located in slopes. Average yield loss due to drought is estimated to be 17%

but it may go up to 100%. Tie ridges and infiltration pits are some of the water management practices that can be used to conserve soil moisture (Kilasara *et al*., 2015; Mudatenguha *et al*., 2014).

Continuous cropping with insufficient or no fertilizer input and off season field grazing activities are major contributors to declining soil nutrients (Kamhambwa, 2014). Also, the nutrients lost through soil mining of about 15 kg N/ha and 2 kg P/ha for pearl millet and groundnut respectively, increase the rate of nutrients loss in the soil. Organic materials such as farm 'kraal' manure is recommended to be used in production system but it is needed in large quantity (10000 – 15000 kg/ha) at recommended rate, which makes it limited for use by small scale farmers (Kamhambwa, 2014). Inorganic fertilizer is mostly recommended for use in crop production but most small scale farmers are poor with low purchasing power (Odhiambo and Magandini, 2008).

Thus, concept of micro-dose fertilizer application which is the application of fertilizer at a third to a fourth of the recommended rate may be appropriate to the resource poor farmers in Dodoma. This method is proven to be worthy and is in use in Zimbabwe, Bukinafaso, Mali, Niger and Ethiopia to maximize return to investment on pearl millet (Sime and Aune, 2014). However, in Tanzania, few researches have been conducted to evaluate the effect of micro-dose fertilizer application in maize production in sub humid condition but non for pearl millet and groundnut production systems in semi-arid areas. Further, there is no established micro-dose rate for a particular production system. On the other hand, the synergistic effect of low to high fertilizer rates and different soil moisture conservation technologies on millet- groundnut production system is poorly understood. Therefore, the purpose of this work was to investigate the effect of integrating fertilizer at different rates (micro-dose rates) and in situ rainwater harvesting technologies on agronomic performance and household profitability among pearl millet-groundnut smallholder farming communities in semi-arid central Tanzania.

1.7 Objectives of the Study

1.7.1 Overall objective

The overall objective was to increase pearl millet and groundnut productivity at small scale farm level by optimizing fertilizer usage and soil water conservation practices in Chamwino district, Dodoma region.

1.7.2 Specific objectives

i. To evaluate the effects of fertilizer micro-dose and moisture management practices on growth and yield of pearl millet in semi-arid central part of Tanzania
ii. To determine the influence of fertilizer micro-dose and moisture management practices on groundnut yield in semi-arid central part of Tanzania
iii. To assess the response yield and resource utilization indices on pearl millet -groundnut intercropping system under fertilizer micro-dose and soil moisture management practices

1.8 Research Hypothesis

i. Application of fertilizer at micro-dose rate will not reduce pearl millet and groundnut yields significantly compared to recommended rate.

ii. Application of tied ridges and infiltration pits as rainwater harvesting practices will not increase significantly soil moisture and pearl millet and groundnut yields compared to flat cultivation.

iii. Production of pearl millet and groundnut in sole cropping and intercropping systems have no effect on yield, land use efficiency and monetary value.

iv. Integrating small fertilizer rates (micro-dose rates) and *in-situ* rainwater harvesting practice will not increase profit compared to traditional farmer's practices of flat cultivation with no fertilizer use.

1.9 References

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CHAPTER TWO

2.0 EFFECTS OF FERTILIZER MICRO-DOSE AND IN-SITU RAINWATER HARVESTING TECHNOLOGIES ON GROWTH AND YIELD OF PEARL MILLET IN A SEMI- ARID ENVIRONMENT IN DODOMA, TANZANIA

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[1]Emmanuel A. Chilagane, [2]Frederick C. Kahimba and [3]Cornel L. Rweyemamu

[1]Agricultural Research Institute Uyole, Southern Highland Zone Crop Research, Mbeya, Tanzania

[2]Sokoine University of Agriculture, Department of Engineering Sciences and Technology, Morogoro, Tanzania

[3]Sokoine University of Agriculture, Department of Crop Science and Horticulture, Morogoro, Tanzania

2.1 Abstract

Declining soil fertility and low erratic rainfall are key factors limiting crop production and threatening food security in semi-arid areas worldwide. Applying inorganic fertilizer at a reduced amount (micro-dose rates) and *in-situ* rainwater harvesting using infiltration pits (IP) or tied ridges (TR) are low-input strategies to cope with these environmental constraints. The purpose of this work was to investigate the effect of integrating fertilizer at different application rates and *in-situ* rainwater harvesting technologies on pearl millet growth and grain yield, and their household profitability among Tanzanian smallholder farming communities in semi-arid areas of central Tanzania. Split plot field experiments were conducted from 2015 to 2017 cropping seasons. Main plot factor was rainwater harvesting technologies (tied ridges and infiltration pit) and sub plot factor were fertilizer rates. Tied ridges and IP used alone and in combination with different fertilizer rates had significant positive effect on pearl millet growth and yield. The highest yield of 2,202 kg/ha was obtained with the recommended fertilizer rates under IP but it resulted into negative net profit (NP). Flat cultivation (FC) with zero fertilizer application resulted in lowest grain yield ranging from 297 to 453 kg/ha with a negative NP. Use of IP with 25% micro-dose of the recommended rate resulted into relatively higher grain yield (778 - 2,202 kg/ha) compared with TR (887-1,915 kg/ha) and FC (592-1,144 kg/ha). However, due to its higher production costs, it resulted into negative NP. The use of TR and FC with micro-dose at 25% of recommended rate had a yield advantage ranging from 537 to 959 kg/ha and 295 to 455 kg/ha, respectively, compared with farmer practices and both resulted into positive NP. The use of micro-dose at 25% of recommended rate along with TR or FC, which gave higher grain yield and NP compared with farmers' practice, is recommended to resource poor farmers for increased pearl millet productivity.

Keywords: *Pearl millet, micro dosing, tied ridges, infiltration pits, semi-arid environment*

2. 2 Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is among the primary staple food crops in semi-arid regions (Aliyu *et al*., 2015). It can withstand adverse environmental conditions, such as drought and poor soil fertility, in comparison with other cereal crops such as maize and rice (Singh *et al.,* 2017). Despite its drought resistance, it requires evenly distributed rainfall during the growing season (Mweu, 2017). Post flowering drought stress is one of the most important environmental factors reducing pearl millet grain yield (Yadav, 2010). Pearl millet is adapted to a wide range of ecological conditions but performs best in light, well-drained loamy soils (Bandyopadhyay *et al*., 2017; Ahmed *et al*., 2016; DAFF, 2011). Pearl millet is positioned sixth in area of cereal production worldwide behind wheat, maize, rice, barley, and sorghum (Mason *et al*., 2015). In semi-arid parts of sub-Saharan Africa (SSA), it is among the most widely cultivated and consumed crop (Mason *et al*., 2015; Dick, 2007). The SSA produces about 56% of the pearl millet world output (FAOSTAT, 2010*).* The top world producers are India, followed by Nigeria, Niger, and Mali (DSFN, 2017). These three African countries alone make up 70% of SSA's production (DAFF, 2011). In East African countries, the average yield is low while the yield potential of the improved varieties such as "Okoa" in Tanzania is higher with 2400 kg/ha (Kanyeka *et al.,* 2007). For instance, in semi-arid parts of Tanzania, the yields are much lower with average of 400 kg/ha (Kamhambwa, 2014).

Poor and erratic rainfall (300-600 mm) and high evapotranspiration rates are among the major production constraints in semi-arid areas (Yabe *et al.***,** 2018**;** Knipper, 2017; Kahimba *et al*., 2015; Yosef and Asmamaw, 2015). In additional to low rainfall received in these areas, large amount of water is lost in farmers' fields through surface runoff because of undulating topography, uncovered surfaces, surface crusting (Graef and Stahr, 2000), and high rainfall intensity (Graef and Haigis, 2001). Hence, more efficient use of water resources is needed to take advantage of the scarce rainfall. This can be done through *in situ* rainwater harvesting and soil moisture conservation practices such as tied ridges and infiltration pits (Kilasara *et al*., 2015; Mudatenguha *et al*., 2014; Nyamadzawo *et al*., 2013). These technologies improve storage of soil water which enhance sorghum and millet grain yields up to 65% (Kilasara *et al*., 2015; Yoseph, 2014).

Declining soil fertility (in particular nitrogen and phosphorus) is also a major production challenge that smallholder famers face in semi-arid areas. It is caused by production without or with insufficient fertilizer inputs, off-season field grazing activities (Kamhambwa, 2014; Kimenye, 2014), and soil erosion (Sharma *et al*., 2015; Serme *et al*., 2015; Pimentel and Burgess, 2013). Furthermore, nutrients are lost through crop harvest (8-88 kg/ha per annum) (Henao and Baanante, 2006). Though organic materials such as farmyard manure are sometimes used by smallholder farmers to supplement soil nutrients, they do not reach the large quantities needed (10000-15000 kg/ha) (Kanyeka *et al*., 2007). Furthermore, the availability of farmyard manure to most of the smallholders farmers is limited (Kamhambwa, 2014). The conventional approach to improve crop productivity is by applying chemical fertilizers at recommended rates (IDRC, 2014). However, it is widely realized that high fertilizer costs deter smallholder farmers from using these rates. In rural areas of SSA, fertilizer prices are about three times higher than in the developed world, Due to high prices of agriculture inputs in SSA, it lead substantially reduction of profit margin of farmers (Odhiambo and Magandini, 2008). Consequently, average fertilizer input rates in SSA for millet is low about 8 kg/ha (Chianu *et al*., 2012) compared with 100 kg/ha, 120 kg/ha, and 85 kg/ha for the entire World, Asia and India, respectively (Mala, 2013). Moreover, fertilizer recommendations fail to consider rainfall risks, capital and resource constraints, and marketing costs faced by smallholder farmers (IDRC, 2014). Furthermore, high fertilizer rates in these areas increase the risk of environmental pollution, such as N and P leaching into groundwater, ammonia volatilization into the atmosphere, and N_2O emissions via microbial denitrification (Lian *et al*., 2017).

Collaborative research among various research institutions in the Sahel, developed an effective technique to increase fertilizer use efficiency and reduce investment costs to small-scale farmers. The technique is known as fertilizer micro dosing, which is the localized application of fertilizer at reduced amount than recommended (Camara *et al*., 2013; ICRISAT, 2009). Micro-dose technology is in use in some semi-arid SSA countries and helps farmers to maximize returns on investment, in particular for pearl millet production (Sime and Aune, 2014) and reduces the yield gap between the actual and potential yield (IDRC, 2018). It has been shown that optimized soil moisture and fertilizer use have synergistic effects on crop growth, which can increase the crop yield, water use efficiency (WUE), and nutrient use efficiency (NUE) (Lian *et al*., 2017; Yang, 2015). However, synergistic effects of fertilizer rates and technologies to conserve soil moisture in pearl millet production are poorly researched to date.

The objectives of this study, therefore, were a) to investigate the effects of integrating both micro-dose fertilizer rates and in situ rainwater harvesting practices on growth and yield of pearl millet in a typical semi-arid agro-climate, with central Tanzania as a case study, and b) to assess the economic profitability of the technologies used by smallholder farmers. We hypothesize that a) combining micro-dose fertilizer rates and *in-situ* rainwater harvesting practices will increase crop yield and enhance food security compared to traditional farmer's practices, b) higher profits will be achieved when integrating small fertilizer rates (micro-dose rates) and *in-situ* rainwater harvesting practice compared to traditional farmer's practices where farmers are normally cultivation on flat land without application of fertilizer.

2.3 Materials and Methods

2.3.1 Location, soil type and climate

This study was conducted in Ilolo and Idifu villages in semi-arid Chamwino district, Dodoma, Tanzania. The sites are located at latitude 06^{θ} 20′ 45″ and longitude 35^{θ} 54′ 12″ and latitude 06^{θ} 24′ 49″, and longitude 35^{θ} 59′ 03″ for Ilolo and Idifu, respectively. The slope at Ilolo was 3.2 % with an altitude of 1,620 masl. At Idifu site,the slope was 2.2% and the altitude was 1,006 masl. The soil types for both sites were moderately acidic sandy clay loam. The area has a unimodal rainfall regime, which start in December. This gives farmers the opportunity to start planting their crops at the end of December until mid-January. The area receives highly erratic rainfall ranging from 400 to 650 mm annually, with often 2-4 weeks of dry spells in between.

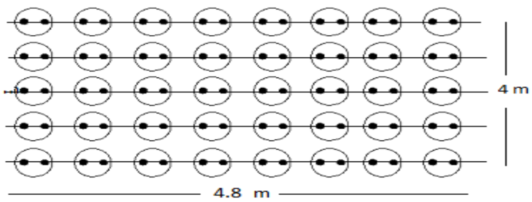
2.3.2 Experimental materials

Improved variety, 'Okoa' of pearl millet, obtained from the Agriculture Research Institute (ARI) Hombolo, was used. Okoa is an early maturing variety, resistant to drought, tolerant to fungal diseases, and reaching a height of 3-3.5 m at maturity. Under optimal management it has a yield potential of 2,400 kg/ha (Kanyeka *et al.*, 2007), which is higher compared to other pearl millet varieties released in Tanzania. Fertilizers used were Di ammoniun Phosphate (DAP) with 46% P_2O_5 and 18% N, and Urea with 46% N.

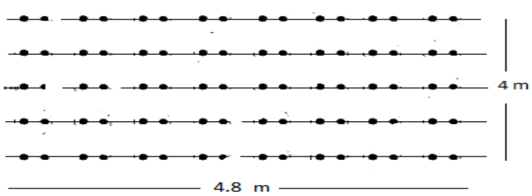
2.3.3 Experimental design

A split plot experiment in a randomized complete block design was used with three replications. The main factor was soil moisture management with three levels, tied ridges (TR) of 60 cm width and 15 cm height, infiltration pits (IP) of 40 cm diameter with 40 cm depth, and flat cultivation (FC) that represented farmer's practice. Sub factors were fertilizer rates of zero application FO (0 kg N/ha, 0 kg P_2O_5/ha), micro dose at 25% of the recommended (MD 1) (15 kg N /ha; 7.5 kg P_2O_5/ha), micro dose at 50% of recommended (MD2) (30 kg N/ha; 15 kg P_2O_5/ha), micro dose at 75% of recommended (MD3) (45 kg N/ha; 22.5 kg P_2O_5/ha) and 100% of recommended rate (RR) (60 kg N/ha; 40 kg P_2O_5/ha). Planting spacing used was 80 x 30 cm as recommended by Kanyeka *et al.* (2007) and the arrangement of planting holes flat cultivation, tied ridges and infiltration pit is shown in sketch 2.1. Sub plot size was of 19.2 m^2 with 5 rows and 16 plant hills per row. Five seeds were sown per hole and after emergence they were thinned to two plants per hill.

Inflation pits planting hole arrangement and plot dimension



Flat and tied ridges planting hole arrangement and plot dimension



Sketch 2. 1: Plot dimension and arrangement of planting holes on flat cultivation, tides ridges and infiltration pits

2.4 Data Collection

2.4.1 Soil sampling and analysis

Pre-planting soil sampling at both research sites was done in mid-November 2014 using the random soil sampling method as described by Clain (2014). An aggregate of eight soil samples was gathered from each site and the composite soil sample from each location was prepared by quartering method. Analysis of physical and chemical soil characteristics was conducted at the Department of Soil and Geological Sciences laboratory of the Sokoine University of Agriculture. 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 (K^+) by NH4-acetate filtrates by Ammonium Acetate Saturation.

2.4.2 Rainfall

Daily precipitation was recorded by standard rain gauges at both experimental sites. It consisted of a funnel emptying into a graduated cylinder, 2 cm radius, which fits inside a larger container 20 cm in diameter and 50 cm tall. If the rainwater overflows the graduated inner cylinder, the larger outer container will catch it. When measurements are taken, the height of the water in the small graduated cylinder is measured, and the excess overflow in the large container is carefully poured into another graduated cylinder and measured to give the total rainfall amount.

2.4.3 Crop growth characteristics (leaf area index and crop growth rate)

Four plants from central rows were randomly selected from each plot and number of tillers per hill and number of leaves per tiller were counted and leaf lengths and widths were measured. Leaf area (LA) and leaf area index (LAI) was calculated according to Fageria *et al.* (1997).

LA= K x Leaf length (cm) x leaf width (cm)………………………… … (EQ. 2.1)

LAI= (Total number of tillers x number of leaves per tiller x LA)/Area of land covered by total number of tillers…………………………………………. (EQ.2.2)

where; LA = leaf area, LAI= leaf area index, K=determined constant=0.75

Plant sampling was done at flag leaf and 50% flowering stages. Four plants per plot were randomly selected, cut just above ground, chopped and weighed. The samples were taken to ARI Makutupora lab for dry matter determination. Samples were oven dried at 60^{o}C for 42 hours and the total dry matter was recorded. Crop growth rate (CGR) was calculated according to Fageria *et al.* (1997).

$$CGR = \frac{(W2-W1)}{GA\,(T2-T1)}\ (g/m^2/day) \quad \text{(EQ.2.3)}$$

Where, GA is a ground area covered, W1 and W2 are weight of dry matter at flag leaf and at 50% flowering stages respectively. Further, T1 and T2 are time intervals in days at different growth stages.

2.4.4 Grain yield

Grain yield of individual plots was obtained from selected samples of 16 plants located at inner rows of each plot. The panicles of the sampled plants were cut, threshed and dried to 14% moisture content and the weight recorded.

2.4.5 Economic data

The costs of all experimental materials used in the study such as fertilizers, seeds and storage bags in Tanzanian shillings and market prices for 2015/2016 and 2016/2017 seasons in (Tsh/kg) were recorded. Furthermore, costs of crop management activities (Tsh/ha) were recorded. Then, the costs and market prices were converted to USD based on the exchange rate of 1 USD =2,100Tsh (BOT exchange rate of July 2017)

2.5 Data Analysis

Descriptive statistical analysis was used for rainfall data while inferential statistics were used for crop growth data, Analysis of variance was done by Gen-start software at $P \leq 5\%$ using the statistical model indicated in equation 2.4. Tukey's test at $P \leq 5\%$ was used for separation of means (Montgomery, 2004). $Y_{ijk} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \varepsilon_{ijk}$ ………………………………………………………………… (EQ 2.4)

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_{ik}= Interaction effect between the main plot and the subject, and ε_{ijk}= Sub-plot random error effect (Error b). Simple economic analysis using net profit were done by subtracting the total production costs from the total revenue of each technology (Sekumade, 2017; Adesoji *et al*., 2016).

2.6 Results

2.6.1 Soil characteristics on experimental units

The soil texture in experimental unit was found to be sandy clay loam for both sites with pH of 5.8 and 5.3 for Ilolo and Idifu, respectively (Table 2.1). The soil organic carbon was very low with 0.46% and 0.11% for Ilolo and Idifu respectively. Total nitrogen and extractable phosphorous of the soil was also very low at both sites. The potassium content was high at Ilolo and medium at Idifu (0.69 $cmol_c\ kg^{-1}$ and 0.43 $cmol_c\ kg^{-1}$, respectively). These physical and chemical soil characteristics are typical for Tanzanian and other SSA semi-arid regions.

Table 2. 1 Physical and chemical properties of soils at experimental sites

Particle size distribution	**Values for Ilolo site**	**Values for Idifu site**
% Clay	21.6	25.6
% Silt	2.9	4.9
% Sand	75.5	69.5
Textural class	*SCL*	*SCL*
Chemical characteristics		
Organic Carbon (OC) (%)	0.46 ^{VL}	0.11^{VL}
Soil pH (in H_2O)	5.88 ^{M}	5.30 ^{M}
Total nitrogen (N) (%)	0.06 ^{VL}	0.06 ^{VL}
Ext. Phosphorus (P) (mg/kg)	12.88 ^{L}	6.43 ^{VL}
Cation Exchange Capacity ($cmol_c\ kg^{-1}$)	15.20 ^{M}	5.40 ^{L}
Exch. Bases K+ ($cmol_c\ kg^{-1}$)	0.69 ^{H}	0.43 ^{M}
Mg ($cmol_c\ kg^{-1}$)	0.67 ^{M}	0.93 ^{M}
Ca ($cmol_c\ kg^{-1}$)	3.37^{H}	3.72 ^{H}
Na ($cmol_c\ kg^{-1}$)	0.25 ^{L}	0.48 ^{M}

SCL=sand clay loam, VL= very low, L= low, M= medium, +According to Landon 1991

2.6.2 Rainfall amount and distribution

Total rainfall received at Idifu during 2015/2016 and 2016/2017 cropping seasons were 425 mm and 153 mm, respectively (Fig 2.1). Furthermore, the total amount of rainfall at Ilolo was 298 mm and 141 mm recorded during 2015/2016 and 2016/2017 cropping seasons, respectively. Idifu site had generally higher rainfall amount in both seasons compared to Ilolo, but its distribution was more uneven as it had a lower number of rainfall events than Ilolo. During 2015/2016 cropping season, a dry spell occurred at Idifu at the end of the vegetative phase and extended up to the early stages of panicle development phase. The period of dry spell also occurred at both locations at the end of panicle development phase to early stages of grain filling phase. During the 2016/2017 cropping season, a dry spell at both locations occurred at the end of the vegetative phase and extended to the early stage of panicle development and at the second half of grain filling stage.

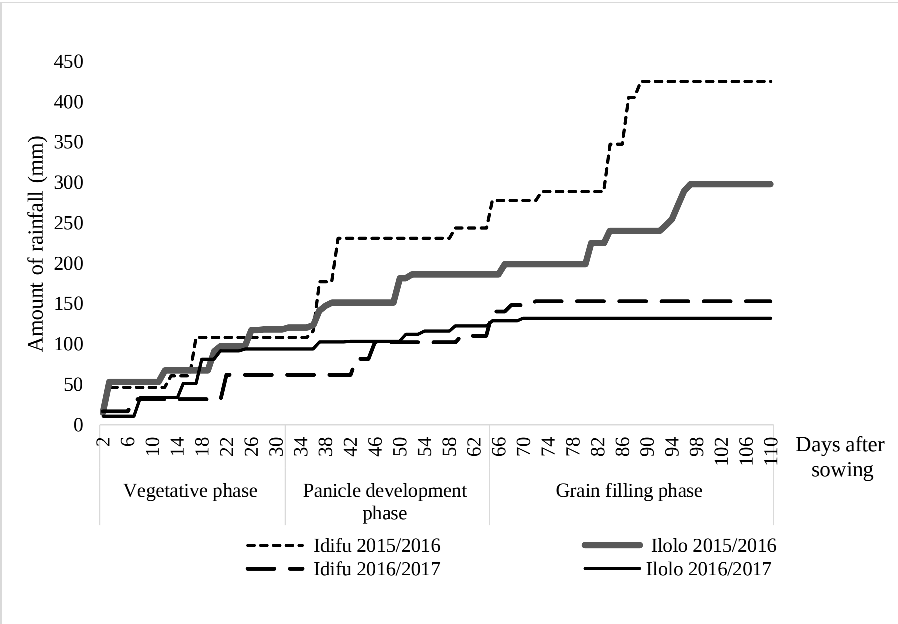


Figure 2. 1 Cumulative rainfall amount during different pearl millet growth stages at Ilolo and Idifu villages

2.6.3 Spatial and seasonal variation of leaf area index (LAI) and crop growth rate (CGR) under famers practices

The results showed no significant difference on LAI and CGR when pearl millet was planted at different locations (Table 2.2). Pearl millets at Ilolo site exhibited relatively higher LAI values (0.34) at flowering compared to Idifu (0.25). Despite relatively higher LAI of pearl millet at Ilolo site it had relatively lower CGR of 19.89 g $m^{-2}day^{-1}$ compared to pearl millets at ldifu site with 21.04 g $m^{-2}day^{-1}$. The effect of cropping seasons on LAI and CGR was significant (Table 2.2), since higher CGR of 0.38 and 24.41 g $m^{-2}day^{-1}$, were observed during 2015/2016 and 2016/2017 cropping seasons respectively.

Table 2. 2 Spatial and seasonal variation of LAI and CGR (g m^{-2}day^{-1}) under famers practices

		LAI	CGR
Locations	Ilolo	0.34	19.89
	Idifu	0.26	21.04
	Lsd	0.08^{ns}	3.59^{ns}
Seasons	2015/2016	0.39	16.52
	2016/2017	0.21	24.41
	Lsd	0.08*	3.59*

Lsd= least significant difference, *=Significant difference and ns =not significant

2.6.4 Leaf area index (LAI) and crop growth rate (CGR) of pearl millet under in-situ rainwater harvesting technologies and fertilizer rates

In situ RWH technologies (tied ridges and infiltration pits) had significant effect (P≤ 0.05) on LAI only at Idifu during 2016 (Table 2.3). The use of tied ridges and infiltration pits resulted in relatively higher LAI and CGR compared to flat cultivation.

Table 2. 3 Leaf area index and CGR (g m^{-2}day^{-1}) of pearl millet under different *in-situ* rainwater harvesting technologies

	LAI Ilolo		CGR Ilolo		LAI Idifu		CGR Idifu	
RWH	2016	2017	2016	2017	2016	2017	2016	2017
FC	0.44 a	0.24 a	17.33 a	22.45 a	0.34 a	0.18 a	15.71 a	26.37 a
TR	0.49 a	0.32 a	16.67 a	19.33 ab	0.41 ab	0.32 a	21.93 a	26.06 a
IP	0.51 a	0.31 a	18.33 a	17.82a	0.54 b	0.22 a	23.07 a	25.15 a
CV (%)	22.20	11.30	19.30	5.80	16.40	26.90	19.10	4.90
F value	0.70	0.09	0.84	0.01	0.06	0.11	0.15	0.53

Means in the same column followed by the same letters are not significantly different according to Tukey’s test at P ≤ 0.05%
RWH= Rain water harvesting, FC= flat cultivation, TR= tied ridges, IP= infiltration pits, CV =coefficient of variation

Increasing fertilizer rates from zero to the recommend rate had significant effect on CGR except during 2016/2017 cropping season in both locations. However, it resulted into significant effect on LAI and CGR during 2015/2016 cropping season (Table 2.4). Farmers practice (zero fertilizer) resulted in the lowest LAI (0.18 to 0.44) while the use of recommended rate had the highest LAI (0.73 to 1.39). Furthermore, the use of micro dose rates from MDI to MD3 resulted into higher LAI compared to famers practice. Similar trend was observed on CGR where the lowest CGR of 17.33 g $m^{-2}day^{-1}$ and the highest CGR of 32.67 g $m^{-2}day^{-1}$ were obtained from farmers practice and recommended rate, respectively during 2015/2016 at Ilolo.

Table 2. 4 Effect of water management practices and fertilizer micro dose on LAI at flowering and CGR (g $m^{-2}day^{-1}$) from 45 to 65 DAS

	LAI Ilolo		CGR Ilolo		LAI Idifu		CGR Idifu	
FR	2016	2017	2016	2017	2016	2017	2016	2017
FO	0.44 a	0.24 a	17.33 a	22.45 a	0.34 a	0.18 a	15.71 a	26.37a
MD1	0.76 ab	0.32 ab	27.00 b	20.95 a	0.49 ab	0.23 a	17.84 ab	25.73 a
MD2	0.76 ab	0.47 b	29.33 bc	21.64 a	0.71 ab	0.39 a	19.7 abc	29.07 a
MD3	1.08 bc	0.66 c	29.67 bc	22.57a	0.78 b	0.44 a	20.88 bc	28.94 a
RR	1.39 c	0.73 c	32.67 c	24.77 a	1.24 c	0.79b	22.5 c	17.58 a
CV%	15.70	11.80	6.60	12.10	20.80	29.30	7.60	30.10
Fvalue	0.001	0.001	0.001	0.535	0.001	0.002	0.004	0.412

Means in the same column followed by the same letters are not significantly different according to Tukey’s test at $p \leq 0.05\%$. *FR=fertilizer rate, FO= zero fertilizer, MD1= micro dose at 25% of recommended rate, MD2= micro dose at 50% of recommended rate, MD3= micro dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation*.

2.6.5 Leaf area index and CGR (g $m^{-2}day^{-1}$) under integrated in situ rainwater harvesting practices and fertilizer rates

Effect of integration of rainwater harvesting practices and fertilizer rates on LAI at and CGR are shown in Table 2.5. Flat cultivation with zero fertilizer (farmer practice) resulted into the lowest LAI and CGR in all locations across all seasons except in 2017 at Ilolo where infiltration pits with zero fertilizer application produced the lowest CGR of 17.82 g $m^{-2}day^{-1}$. Integration of tied ridges and infiltration pits with fertilizer micro dose at 50% to recommended rate significantly, increased LAI and CGR at both location across all seasons ($p \leq 0.001$). The smallest LAI of 0.18 and CGR of 15.71 g $m^{-2}day^{-1}$ were observed at Idifu during 2017 and 2016 cropping season, respectively, under flat cultivation with zero fertilizer. The highest values of LAI of 1.71 at Ilolo and CGR of 32.33g $m^{-2}day^{-1}$ at Idifu were observed under infiltration pits with recommended rate during 2016 and 2017 cropping season respectively. Furthermore, integration of tied ridges and infiltration pits with fertilizer micro-dose rates (MD1 to MD3) resulted into higher LAI and CGR compared to farmers practices.

Table 2. 5 Leaf area index at flowering and CGR (g $m^{-2}day^{-1}$) (from 45 to 65 DAS) under integrated in situ rainwater harvesting practices and fertilizer rates

Interaction of	LAI Ilolo		CGR Ilolo		LAI Idifu		CGR Idifu	
RWH and FR	2016	2017	2016	2017	2016	2017	2016	2017
FC x FO	0.44 a	0.24 a	17.33 a	22.45 abc	0.34 a	0.18 a	15.71 a	26.37 a
FC x MD1	0.76a bc	0.32 ab	27.00 ab	20.95abc	0.49 abc	0.23 a	17.84 ab	25.73 a
FC x MD2	0.76 abc	0.47 bc	29.33ab	21.64abc	0.71 a-d	0.39 abc	19.70 abc	28.94 a
FC x MD3	1.08 c-f	0.66 de	29.67 ab	22.57 abc	0.78 b-e	0.44 abc	20.88 abc	29.07 a
FC x RR	1.39 efg	0.73 def	32.67 b	24.77abc	1.24 fgh	0.79 de	22.50 abc	17.58 a
TR x FO	0.49 ab	0.32 ab	16.67 a	19.33 ab	0.54 abc	0.32 ab	21.93 abc	26.06 a
TR x MD1	0.82 a-d	0.41 ab	18.67 a	22.45 abc	0.59 abc	0.30 ab	24.17 abc	27.69 a
TR x MD2	0.93 b-e	0.60 cd	24.67 ab	24.42 abc	0.84 b-f	0.56 bcd	26.32abc	27.06 a
TR x MD3	1.41 fg	0.80 ef	27.00 ab	25.58 abc	1.05 d-g	0.61 b-e	28.63 bc	26.58 a
TR x RR	1.38 efg	0.84 f	34.67 b	26.97 bc	1.32 gh	0.87 e	30.25 c	23.40 a
IP x FO	0.51 ab	0.31 ab	18.33 a	17.82 a	0.41 ab	0.22 a	23.07 abc	25.15 a
IP x MD1	0.77 abc	0.46 bc	23.33 ab	20.25 abc	0.71 a-e	0.39 abc	27.68 abc	27.44 a
IP s x MD2	0.95 b-f	0.61 cd	26.67 ab	22.11 abc	0.88 c-g	0.59 b-e	28.4 bc	26.80 a
IP x MD3	1.27 d-g	0.77 def	29.33 ab	26.27 abc	1.15 e-h	0.66 cde	29.04 bc	26.12 a
IP s x RR	1.71 g	0.83 ef	32.33 b	27.89 c	1.51	0.80 de	29.47 bc	23.14 a
CV (%)	15.70	10.2	17.5	12.2	17.5	20.8	16.5	17
P value	0.001	0.001	0.001	0.001	0.001	0.001	0.007	0.760

Means in the same column followed by the same letters are not significantly different according to Tukey's test at $p \leq 0.05$

RWH= Rain water harvesting, FR=fertilizer rate, FC= flat cultivation, TR= tied ridges, IP= infiltration pits. FO= zero fertilizer, MD1= micro dose at 25% of recommended rate, MD2= micro dose at 50% of recommended rate, MD3= micro dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation.

2.6.6 Spatial and seasonal variation of thousand seed weight (g) and grain yield (kg/ha) under famers practices

The results showed that, the locations had significant effect on thousand seed weight (TSW) but had no effect on grain yield (Table 2.6). Plants at Ilolo site had significant higher TSW of 11.70 g compared to plants at Idifu with 9.03 g while the grain yield was not influenced by location. Also, it was observed that, cropping seasons had significant effect on TSW while no effect was observed on grain yield. Higher TSW of 11.15 g were observed during 2015/2016 cropping season.

Table 2. 6 Spatial and seasonal variation of thousand seed weight (TSW) (g) and grain yield (kg/ha) under farmers practices

		TSW	Grain yield
Location	Ilolo	11.77	396
	Idifu	9.03	359
	Lsd	1.00*	190 ns
Season	2015/2016	11.15	381
	2016/2017	9.65	375
	Lsd	1.00*	190 ns

Lsd= least significant difference, *=Significant difference and ns =not significant

2.6.7 Thousand seed weight (g) and grain yield (kg/ha) under *in-situ* rainwater harvesting practices and fertilizer rates

Thousand seed weight were significantly affected by in situ rainwater harvesting practices only during 2017 at Idifu. but the rest of the seasons, in situ rainwater harvesting practices had no significant effect on TWS (Table 2.7). The grain yield was also significantly affected by in situ rainwater harvesting practice in all seasons except for Idifu during 2017 cropping season. Flat cultivation resulted into lowest grain yield (297 to 453 kg/ha) while the use of tied ridges and infiltration pits resulted to higher grain yield (699 and 814 kg/ha, respectively).

Table 2. 7 Thousand seed weight (TSW)(g) and grain yield (kg/ha) under different *in-situ* rainwater harvesting practices

	TSW Ilolo		Grain yield Ilolo		TSW Idifu		Grain yield Idifu	
RWH	2016	2017	2016	2017	2016	2017	2016	2017
FC	11.54 a	12.00 a	340 a	452 a	10.76 a	7.30 a	422 a	297 a
TR	11.95 a	12.00 a	405 ab	553 a	9.98 a	10.76 b	699 ab	451 a
IP	13.60 a	11.67 a	542 b	703 b	10.43 a	10.98 b	814 b	437 a
CV (%)	7.10	6.50	14.40	6.30	7.90	5.05	19.40	17.40
P Value	0.093	0.836	0.037	0.003	0.56	0.002	0.04	0.092

Means in the same column followed by the same letters are not significantly different according to Tukey's test at $p \leq 0.05$

RWH= Rain water harvesting, FC= flat cultivation, TR= tied ridges, IP= infiltration pits, CV =coefficient of variation

The result also showed significant increase in thousand seed weight and grain yield when different fertilizer rates were applied (Table 2.8). Farmer practice (zero fertilizer) had the lowest TSW (7.3 to 12 g) and lowest grain yield (297 to 453 kg/ha) while recommended rate produced the highest TSW (11.57 to 15.34 g) and grain yield (1,115 to 1,362 kg/ha). Micro dose rates from MD1 to MD3 also resulted into significantly higher grain yield that ranged from 592 to 1,313 kg/ha compared to farmers practices.

Table 2. 8: Thousand seed weight (TSW) (g) and grain yield (kg/ha) under different fertilizer rates

	TSW Ilolo		Grain yield Ilolo		TSW Idifu		Grain yield Idifu	
FR	2016	2017	2016	2017	2016	2017	2016	2017
FO	11.54 a	12.00a	340 a	453 a	10.76 a	7.30 a	422 a	297 a
MD1	13.37ab	12.22a	756 b	844 b	10.98 a	9.91 b	848 b	592 b
MD2	14.08 b	12.56a	1,141 c	980 bc	11.32 a	10.37 b	945 bc	979 c
MD3	14.73 b	12.89a	1,313 c	1,042 c	11.65 a	11.08 b	996 bc	1,042 c
RR	15.34 b	13.00a	1,362 c	1,138 c	11.76 a	11.57 b	1,115 c	1,145 c
CV (%)	6.3	4.1	9.4	6.4	4.6	6.3	8.4	8.5
P Value	0.005	0.181	0.001	0.001	0.181	0.001	0.001	0.001

Means in the same column followed by the same letters are not significantly different according to Tukey's test at $p \leq 0.05$

FR=fertilizer rate, FO= zero fertilizer, MD1= micro dose at 25 % of recommended rate, MD2= micro dose at 50 % of recommended rate, MD3= micro dose at 75 % of recommended rate, RR= recommended rate, CV=coefficient of variation.

2.6.8 Thousand seed weigh (g) and grain yield (kg/ha) under integrated *in-situ* rainwater harvesting practices and fertilizer rates

Integration of tied ridges and infiltration pits with fertilizer micro-dose at 25% of recommended rate to recommended rate had significant increase in thousand seed weight and grain yield (P≤ 0.001) in all seasons across all locations (Table 2.9). Flat cultivation with zero fertilizer had the lowest TSW and grain yield ranging from 7.8 to 11.54 g and 297 to 453 kg/ha, respectively. Furthermore, integration of tied ridges and infiltration pits with recommended rate had significantly higher TSW, ranging from 12.32 to 15.19 g and 11.98 to 14.95 g, respectively. It further resulted into significantly higher grain yield ranging from 1696.9 to 1,915 kg/ha and 1,518.9 to 2,202 kg/ha, respectively. The integration of tied ridges and infiltration pits with micro-dose at 25% of the recommended rate resulted into yield increase ranging from 887 to 1,299 kg/ha and 778 to 1,650 kg/ha, respectively, which are significantly higher compared to that of farmers practice. However, by comparing integration of tied ridges and infiltration pits with micro-dose rates from 25% to 75% of recommended rate, the results showed no significant effect on thousand seed weight and grain yield.

Table 2. 9 Effect of integration of *in-situ* rainwater harvesting practices and fertilizer rates on thousand seed weight (TSW) (g) and grain yield (kg/ha)

Interaction of RWH and FR	TSW Ilolo		Grain yield Ilolo		TSW Idifu		Grain yield Idifu	
	2016	2017	2016	2017	2016	2017	2016	2017
FC x FO	11.54 a	12.00 ab	340 a	453 a	10.76 abc	7.30 a	422 a	296.9 a
FC x MD1	13.37 abc	12.22 abc	756 abc	844 a-d	10.98 abc	9.91 ab	848 abc	591.8 abc
FC x MD2	14.08 abc	12.56 abc	1,142 cde	980 b-e	11.32 abc	10.37 bc	945 bcd	979.3 cd
FC x MD3	14.73 c	12.89 abc	1,313 def	1,042 b-e	11.65 bc	11.08 b-e	996 bcd	1,041.9 de
FC x RR	15.34 c	13.00 abc	1,362 def	1,138 cde	11.76 bc	11.57 b-f	1,116 b-e	1,144.9 def
TR x FO	11.95 ab	12.00 ab	406 a	553 ab	9.98 a	10.76 bcd	700 ab	450.8 ab
TR x MD1	13.57 abc	12.78 abc	1,299 def	990 b-e	11.54 abc	12.81 b-g	1,240 c-f	887.1 cd
TR x MD2	14.38 bc	12.78 abc	1,665 efg	1,084 cde	11.54 abc	13.00 c-g	1,409 d-g	1,136.8 def
TR x MD3	15.13 c	13.11 bc	1,763 fg	1,327 d-g	11.87 bc	13.75 efg	1,536 e-h	1,394.9 efg
TR x RR	15.19 c	13.56 c	1,915 g	1,715 g	12.32 c	14.42 fg	1,781 ghi	1,696.9 g
IP x FO	13.6 abc	11.67 a	542 ab	703 abc	10.43 ab	10.98 b-e	814 abc	437.3 ab
IP x MD1	14.94 c	11.89 ab	1,078 bcd	1,126 cde	10.65 ab	13.56 d-g	1,650 fgh	777.6 bcd
IP x MD2	15.39c	12.22 abc	1,348 def	1,207 def	10.98 abc	14.02 fg	1,739 ghi	929.6 cd
IP x MD3	15.71 c	12.89 abc	1,473 d-g	1,418 efg	11.65 bc	14.33 fg	1,962 hi	1,079.1 de
IP x RR	14.95 c	13.22 bc	1,822 fg	1,686 fg	11.98 bc	14.95 g	2,202 i	1,518.9 fg
CV (%)	6	3.6	14.8	15.2	4.6	7.9	12.7	13.8
P value	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Means in the same column followed by the same letters are not significantly different according to Tukey's test at $p \leq 0.05$. *RWH= Rain water harvesting, FR=fertilizer rate, FC= flat cultivation, TR= tied ridges, IP= infiltration pits. FO= zero fertilizer farmers, MD1= micro dose at 25% of recommended rate, MD2= micro dose at 50% of recommended rate, MD3= micro dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation.*

2.6.9 Profitability assessment (USD/ha) of integration of fertilizer rates and water management practices

The average costs of materials, crop management activities and market prices of pearl millet for 2015/2016 and 2016/2017 were shown in Table 2.10. Preparation of flat cultivation had the lowest labour cost (66.9 USD/ha) while tied ridges and infiltration pits had higher labour cost of 330.7 USD/ha and 881.8 USD/ha, respectively.

Table 2. 10: Average cost of materials and crop management activities of pearl millet production

Items	Unit	Cost (Tsh*/ha)	Cost (USD*/ha
Materials			
Seeds	Tsh per ha	25,000	11.9
Fertilizers costs: DAP	Tsh per 50 kg bag	125,000	59.5
UREA	Tsh per 50 kg bag	127,000	60.5
Storage bags	Tsh per bag	1200	0.3
Activities			
Flat cultivation preparation	Tsh per ha	138,888	66.9
Tied ridges preparation	Tsh per ha	694,444	330.7
Infiltration pits preparation	Tsh per ha	1,851,85	881.8
Sowing	Tsh per ha	100,000	47.6
Fertilizer application	Tsh per ha	75,000	35.7
Weeding	Tsh per ha	85,000	40.5
Harvesting and threshing	Tsh per ha	225,000	107.1
Transportation	Tsh per bag	1500	0.7
Market price (pearl millet)	Tsh/kg	850	0.43

*Tsh =Tanzanian Shillings, USD= United state dollars

Simple economic analysis to evaluate the profitability of technologies used in the study was done by calculating the net profit (NP) (Fig 2.2). The use of flat cultivation without fertilizer input (farmer's practices) resulted in negative NP at Ilolo but positive at Idifu. The use of tied ridges and infiltration pits without application of fertilizer resulted into negative NP at both locations. Furthermore, use of micro-dose rates to recommended rate along with infiltration pits had negative NP. Integration of tied ridges and fertilizer at recommended rate resulted in the highest NP 282.0 and 277.2 USD/ha at Idifu and Ilolo, respectively, followed by flat cultivation with recommended rate of 222.9 and 224.8 USD/ha at Idifu and Ilolo, respectively. Integration of flat cultivation and fertilizer micro-dose rates from 25 % to 75 % resulted into relatively higher NP compared to the use of tied ridges with micro-dose rates. The results also showed that, integration of micro-dose with flat cultivation or tied ridges had relatively higher NP, ranging from 4.7 to 224.8 USD/ha, respectively compared to farmers practice at both locations.

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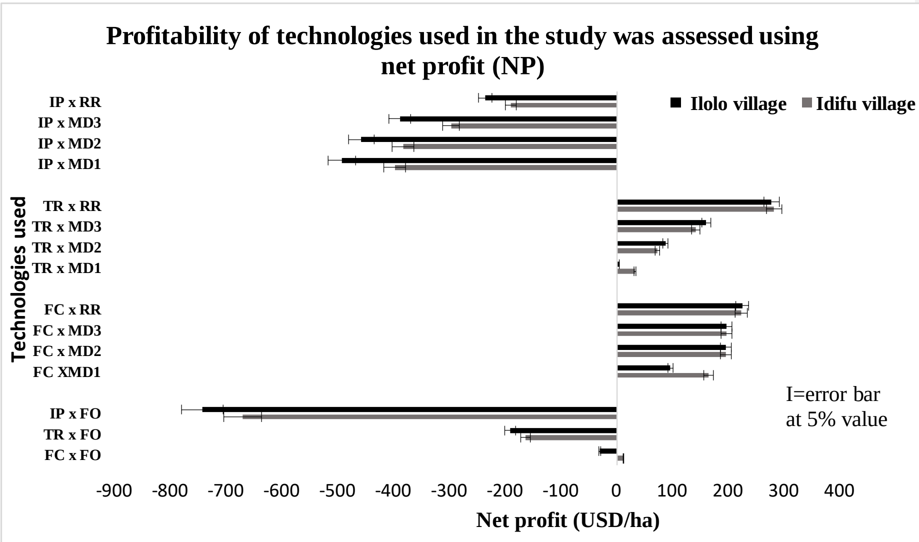

Figure 2. 2 Net profit of technologies used in the study (USD/ha)

FO= farmers practice, MD1= micro-dose at 25% of recommended rate, MD2= micro dose at 50% of recommended rate, MD3= micro dose at 75% of recommended rate, RR= recommended rate

2.7 Discussion

2.7.1 Soil fertility status

Soil fertility status of the experimental sites, was very poor in nitrogen and phosphorous contents (Table 2.1) as in most SSA arable sandy soils (Andriesse and Giller, 2017; Tully *et al.*, 2015; Vanlauwe *et al*., 2015). Low nitrogen and phosphorus status in these areas is likely to be due to the tendency of farmers to cultivate without applying fertilizers and other soil amendments that could restore soil nutrients (Zingore, 2016; Chianu *et al*., 2012). Also, off season on-field grazing of crop residues (in the fields) can reduce soil fertility (Tully, 2015). Therefore, strategies of improving soil fertility should target nitrogen and phosphorus amendments. These strategies include the use of organic sources such as manure, use of inorganic fertilizers, incorporation of green manure, plant residue management (Yusufu and Yusufu, 2008; ICRISAT, 2000) and other cultural practices such as intercropping of cereal and legumes (Ullah *et al*., 2016; Wang *et al*., 2014).

2.7.2 Rainfall amount and distribution

The amount of rainfall received in the study area was lower than that required by the crop as mentioned by Kanyeka *et al*. (2007) which is 500 to 1500 mm per growing season. Apart from amount, distribution during the growing seasons is most important for crop production (Ndamani and Watanabe, 2015; Guan *et al*., 2015). Although Ilolo received 127 mm less rainfall than Idifu in 2015/2016 season, the distribution was good, with 10 rainfall events more compared to Idifu (Fig 2.1). This favorable rainfall distribution resulted into good crop performance and relatively higher grain yield than Idifu. Well distributed annual rainfall ranging from 200 to 1200 mm promotes pearl millet growth and yield (Mweu, 2017; Reddy *et al*., 2013).

2.7.3 Effect of fertilizer micro-dose rates and in situ rainwater harvesting technologies on LAI and CGR.

Higher LAI insures more solar radiation is captured and utilized by the plant as very little amount will be penetrating to the ground (Tripathi *et al*., 2018; Schwerz *et al*., 2017). The use of ridges and pits along with micro dose at 25% of recommended rate significantly improved LAI and CGR of pearl millet at flowering stage compared to flat cultivation with no fertilizer (Table 2.5). Little nitrogen added through DAP during planting and through urea at vegetative stage together with a short term favorable soil moisture due to tied ridges and infiltration pits promoted crop growth and yield (Sibhatu *et al*., 2017; Sharma and Bali, 2017; Leghari *et al*., 2016). This resulted into healthier crops with higher LAI and CGR (Table 2.5) among fertilizer treated plots with tied ridges and infiltration pits compared to farmers practice. These results concur with those of Tajul *et al.* (2013) who assessed the influence of plant population and nitrogen fertilizer at various levels, on growth and growth efficiency of maize and found that LAI increased when fertilizer rate was increased and maximum LAI were observed at the highest rate. It has been also reported that nitrogen fertilizer significantly enhanced leaf area index, dry mass production, crop growth rate, and grain yields (Mon Ko *et al*., 2017; Bayu, 2005).

2.7.4 Agronomic and economic responses of integrating fertilizer micro-dose rates and in-situ rainwater harvesting practices

High crop yield and economic benefits are the most important attributes that farmers consider in selection of new technologies in their production systems (Goa and Kambata, 2017; Gurmu, 2013). This will ensure both food security and economic worthiness of the technologies to the famers (Mârza *et al*., 2015; Birthal *et al*., 2014).

The use of micro-dose at 25% of recommended rate along with tied ridges and infiltration pits significantly improved millet grain yield (Table 2.9). The yield advantage was 818 and 1,228 kg/ha achieved when micro dose rate of 25% were used under tied ridges and infiltration pits, respectively. The increased grain yield could be due to proper functioning of the physiological processes of the crop due to more available nitrogen and moisture in the soil (Imran *et al*., 2015; Ali *et al.*, 2011). Integration of fertilizer at micro dose rates and in-situ rainwater harvesting practices created suitable conditions for the crop to effectively utilize water and nutrients in the soil. This resulted into higher average grain yield compared to farmer practices. This observation is supported by that of Nabooji *et al*. (2018) and Aliyu *et al.* (2015) who assessed the influence of intra row spacing and nitrogen levels on pearl millet growth and found maximum millet yield at higher nitrogen rates. Although the use of micro-dose rates with infiltration pits resulted into highly agronomic value, but it is not worth for the farmers as it gave negative net profit (Fig 2.2). Constructing infiltration pits is tedious and requires high labour costs as presented in Table 2.10 and this upsets revenue generated, making farmers to operate on economic losses. Use of flat cultivation and tied ridges alongside with micro dose rates from 25% of recommended rate indicated potential to have both high economic and agronomic benefit to the farmers compared to other technologies tested. These technologies resulted into higher net profit and doubling of the grain yield compared to famer's practices. Therefore, farmers searching for both high economic and agronomic performance of the crop in semi-arid areas may favour the use of micro-dose at 25% of recommended rates alongside flat cultivation and tied ridges. However, micro-dose at 25% under flat cultivation entailed higher net profit than micro-dose of 25%

with tied ridges. In dry areas, the use of micro dose at 25% along with tied ridges can supplement nutrients at the same time harvesting rainwater and conserving soil moisture. This can help smallholder's farmers to reduce the risks of yield loss because of dry spells. Micro-dose rate of 15 kg N/ha was recommended for the sub humid drought prone areas for improved production (Mourice *et al*., 2014; Camara *et al*., 2013). Revisiting our hypotheses, we find that, integrating both micro-dose fertilizer rates at 25% of recommended rate and *in-situ* rainwater harvesting such as tied ridges and infiltration pits increases crop yield and enhances food security compared to traditional farmer's practices. Higher profits can be achieved when integrating micro-dose fertilizer rates at 25% of recommended rate and tied ridges compared to traditional farmer's practices.

2.8 Conclusions and Recommendations

This study evaluated the effects of integrating fertilizer at different application rates and in situ rainwater harvesting technologies on pearl millet growth performance and grain yield in semi-arid environment, and their household profitability among smallholder farming communities in Dodoma.

Based on the findings of this study, it is concluded that integration of inorganic fertilizer at micro dose rate of 25% of recommended rate (15 kgN/ha and 10 kg P_2O_5/ha) and in-situ rainwater harvesting using tied ridges significantly increased both grain yield and net profit compared to famers' practices. Promoting these technologies to farmers in semi-arid areas may help them to move from their traditional practices to the use of tied ridges with micro dose rates and hence increased crop productivity. Farm machinery and tools, such as ox-ridger, help famers in preparing tied ridges but need more promotion. Although infiltration pits resulted in higher yield, this technology is tedious and costly, and hence, makes it to uneconomical to famers. New equipment that make infiltration pits could increase the agronomic and economic benefits.

The study, therefore, recommends the use of inorganic fertilizer at micro-dose at 25% of the recommended rate along with TR or FC for increased grain yield and net profit instead of using flat cultivation with no fertilizer (farmers practice). The practice is recommended to resource poor farmers for increased pearl millet productivity and food security.

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CHAPTER THREE

3.0 EFFECT OF FERTILIZER MICRO-DOSE AND MOISTURE MANAGEMENT PRACTICES ON AGRONOMIC AND ECONOMIC PERFOMANCES OF GROUNDNUTS IN SEMI- ARID AREAS OF CENTRAL TANZANIA

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[1]Emmanuel A. Chilagane., [2]Frederick C. Kahimba and [3]Cornel L. Rweyemamu

[1] Agricultural Research Institute Uyole, Southern Highland Zone Crop Research, Mbeya, Tanzania

[2]Sokoine University of Agriculture, Department of Engineering, Sciences and Technology, Morogoro, Tanzania

[3]Sokoine University of Agriculture, Department of Crop Science and Horticulture, Morogoro, Tanzania

3.1 Abstract

Low soil fertility and drought are the main crop production challenges that are threatening food security in semi-arid areas globally. Use of fertilizer in small amounts (micro-dose rates) together with in-situ rain water harvesting using infiltration pits (IP) or tied ridges (TR) are low-input strategies to cope with these challenges. This research was conducted to investigate effects of integrating fertilizer micro dose rates and in-situ rain water harvesting using IP and TR on groundnuts yield and its household profitability to Tanzania smallholder farming groups. A split plot field experiment under Randomized Complete Block Design were conducted from 2015/2016 to 2016/2017 cropping seasons. Farmer practice had the lowest yield ranging from 271 to 409 kg/ha. Infiltration pits and tied ridges increased groundnut yield significantly by 20.2% to 32.6% and 34.2% to 46.6% respectively, over flat cultivation. Fertilizer micro dose at 50% of recommended rate significantly increased yield by 50.8% to 64.7% over zero application. Integration of IP and TR with MD2 increased groundnut kernel yield by 72% and 114% respectively, and also TR resulted into higher net profit (NP) compared to farmers practice. Integration of TR with fertilizer at RR resulted into highest groundnut yield ranging from 1,034 to 1,096 kg/ha and highest NP ranging from 1,027 to 1,081 USD/ha. The integrations of TR and fertilizer micro dose at 25% of recommended had significantly higher yield which ranged from 748 to 1,086 kg/ha and higher NP ranging from 405 to 662 USD/ha compared to famer practice. The integrations of micro dose rate of 25% of recommended rate with tied ridges is recommended to small holder’s famers located in semi dry areas of central Tanzania. This will enable farmers to achieve higher agronomic and economic performances than current farmer practices.

Keywords: *groundnut, micro-dosing, tied ridges, infiltration pits, semi-arid environment*

3.2 Introduction

Groundnut is one of the most important crops worldwide. It is ranked 6th most important oilseed crop in the world and 4rd major source of edible oil (Redae *et al.*, 2017; Upadhyaya *et al.*, 2006). Groundnut is also an important crop for nutrition as its kernel contains about 40-50% fats, 20-50% protein and 10-20% carbohydrates

(Redae *et al*., 2017; Janila *et al*., 2013; Bhatia *et al*., 2006). It is also a source of vitamin E and minerals, including niacin, falacin, calcium, phosphorus, magnesium, zinc, iron, riboflavin, thiamine and potassium (Katundu *et al.,* 2012; Janila *et al*., 2013; Yaw *et al* 2008). The production of groundnuts is concentrated in Asia with 64% of global production and less in Africa with 28% of global production (Redae *et al*., 2017; Janila *et al*., 2013; Nigam *et al*., 2004). In Tanzania, it is produced in only 2.9% of the global area under small-scale level with less application of improved technologies (Tamba, 2016; FAOSTAT, 2013). This had resulted into an average yield of 964 kg/ha, which is less compared to other African countries (1,264.6 kg/ha in Nigeria; 1,724 kg/ha in Guinea-Bissau) and Asia (Kamhambwa, 2014). The efforts of increasing productivity of this crop in semi-arid areas is very important as it can boost health and improve economic welfare of smallholder's farmers.

Low soil nutrients especially phosphorus is among major groundnut production constraints that face small holder's famers in semi-arid areas of sub-Sahara African (SSA). The normal practices of the farmers in these areas of producing crops with no or little fertilizer input together with off season field grazing activities and removal of crop residues in the field to feed livestock are the main courses of low soil fertility. (Kamhambwa, 2014; Serme *et al*., 2016; Pimentel and Burgess, 2013). The low soil nutrients can also be caused by crop harvest in which in Africa a loss of 8 to 88 kg N/ha per annum (due to crop harvest) is reported among the farming communities (Mwinuka, *et al.,* 2017; Henao and Baanante, 2006). Despite the presence of organic materials such as farm yard manure in farming communities, which is also recommended for use in crop production, the availability in terms of quantity needed (10,000-15,000 kg/ha) is limited to most smallholder farmers (Kamhambwa, 2014; Kanyeka *et al.*, 2007). On the other hand, it was realized that high cost of inorganic fertilizer at recommended rate limits smallholder farmers from using the inorganic fertilizer due to their financial limitations (Odhiambo and Magandini, 2008). The effective technique which reduces investment cost while increasing fertilizer use efficiency to small scale farmers was developed in the Sahel through collaborative research conducted by different institutions. This technique also reduces the risk of environmental pollution, as it decreases N and P leaching into groundwater, ammonia volatilization into the atmosphere, and N_2O emissions (Lian *et al.*, 2017). The technique is known as fertilizer micro-dosing, which is the localized application of fertilizer at reduced amount than that recommended (Camara *et al.*, 2013; ICRISAT, 2009). This technology is used in some semi-arid SSA countries and helps farmers to improve returns, in particular for cereals production (Ouattara *et al.*, 2018; Abdalla *et al.*, 2015, Sime and Aune, 2014). However, for legume crops, such as groundnuts, the information on the agronomic and economic performance of this technology is scanty.

Moisture stress condition due to low and erratic rainfall (300-600 mm annually) and high evapotranspiration rates are among major factors limiting crop production in semi-arid areas (Yabe *et al.*, 2018; Knipper, 2017; Kahimba *et al.*, 2015). Most parts of these areas have slopy topography with bare surfaces which accelerate the rate of water loss due to surface runoff (Graef and Haigis, 2001; Graef and Stahr, 2000). Therefore, efficient use of water resources is needed in these areas. Tied ridges and infiltration pits are among the *in-situ* rainwater harvesting and soil moisture conservation practices that can be used (Kilasara *et al.*, 2015; Mudatenguha *et al.*, 2014). These technologies improve soil water and increases crop productivity up to 65% compared to flat cultivation (Kilasara *et al*., 2015; Yoseph, 2014). The integration of soil moisture and fertilizer contents have synergistic effects on crop growth, which can increase crop yield, water use efficiency (WUE), and nutrients use efficiency (NUE) (Lian *et al*., 2017; Yang, 2015). However, the synergistic effect of low to high fertilizer rates and different soil moisture conservation technologies on yield is poorly understood.

The objectives of this study were to investigate the effects of integrating micro-dose fertilizer rates and *in-situ* rainwater harvesting practices on agronomic and economic performances of groundnut cultivation in semi-arid areas in Tanzania central. It was hypothesized that, integrating both micro-dose fertilizer rates and in-situ rainwater harvesting practices could increase agronomic and economic value of groundnut. Ultimately, if such technology is found appropriate for increasing agronomic and economic value compared to traditional production system, it would improve smallholder farmers livelihoods and food security.

3.3 Materials and Methods

3.3.1 Locations and climate

This study was conducted at Ilolo (latitude 06^{θ} 20′ 45″ and longitude 35^{θ} 54′ 12″) and Idifu (latitude 06^{θ} 24′ 49″and longitude 35^{θ} 59′ 03″) villages located in Chamwino District, Dodoma region of Tanzania. The slope of experimental site at Ilolo was 3.2% while the altitude of 1620 m.a.s.l. The experimental site at Idifu village had a slope of 2.2% and altitude of 1006 m.a.s.l. The area has a unimodal rainfall regime, with the rains, starting in December which gives the farmers the opportunity to start planting their crops usually up to mid-January. The area receives low and erratic rainfall ranging from 400 to 650 mm annually, and about 85% of this fall between December and March (Temu *et al.*, 2011).

3.3.2 Experimental materials

Improved groundnut seed variety 'Pendo' obtained from Agriculture Research Institute (ARI) Naliendele was used. It is a spanish type with 90- 100 days to reach maturity and under optimal management it has a yield potential of 1500 kg/ha. Also, fertilizer material used was Di Ammonia Phosphate (DAP) of 46% P_2O_5 and 18% N).

3.3.3 Experimental design

A split plot experiment in a randomized complete block design was used with three replications. The main factor was soil moisture management practices with three levels, which were tied ridges (TR) of 50 cm width and 15 cm heights; infiltration pits (IP) of 40 cm diameter and 40 cm depth; and flat cultivation (FC) that mimic farmer's practices. Sub factor was fertilizer rates of level 0% (F0) (0 kg P_2O_5/ha), micro dose at 25% of the recommended (MD1) (11.25 kg P_2O_5/ha), micro dose at 50% of recommended (MD2) (22.5 kg P_2O_5/ha), micro dose at 75% of recommended (MD3) (33.75 kg P_2O_5/ha) and 100% of recommended rate (RR) (45 kg P_2O_5/ha) were applied. Plant spacing used was 50 x 10 cm as recommended by Kanyeka *et al*, (2007).

3.4 Data Collection

3.4.1 Soil information

Pre-planting soil sampling at both research sites was done in mid-November, 2014 using the random soil sampling method as described by Clain, (2014). An aggregate of eight soil samples was gathered from each site. Analysis of physical and chemical soil characteristics was conducted at the Department of Soil and Geological Sciences laboratory of the Sokoine University of Agriculture. 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 (K^+) by NH4-acetate filtrates by Ammonium Acetate Saturation.

3.4.2 Rainfall

Daily precipitation was recorded by standard rain gauges at both experimental sites. It consisted of a funnel emptying into a graduated cylinder, 2 cm in radius, which fits inside a larger container which is 20 cm in diameter and 50 cm tall. If the rainwater overflows the graduated inner cylinder, the larger outer container will catch it. When measurements are taken, the height of the water in the small graduated cylinder is measured, and the excess overflow in the large container is carefully poured into another graduated cylinder and measured to give the total rainfall.

3.4.3 Groundnut yield

One-meter square area were randomly marked on central rows of the plots, well matured groundnuts were uprooted by hand, the number of plants, number of pods, and pods weight was recorded. Harvested pods were sun dried to constant weight and the weight of kernel was recorded.

3.4.4 Economic data

The costs of materials used in the study such as fertilizer and seeds in (Tsh/kg) and average market prices for 2015/2016 and 2016/2017 season in (Tsh/kg) were recorded. Furthermore, costs of crop management activities including planting, weeding, harvesting (Tsh/ha) were recorded. The costs were then converted to USD based on the exchange rate of 1 USD =2,100.

3.5 Data analysis

Rainfall data were subjected to descriptive statistical analysis were cumulative rainfall were plotted. Inferential statistics were used for crop yield data where analysis of variance was done by Gen-start software at P ≤ 5% using the statistical model indicated in equation 1. Tukey's test at P ≤ 5% was used for separation of means (Montgomery, 2004).

$$Y_{ijk} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \varepsilon_{ijk} \qquad (1)$$

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_{ik}= Interaction effect between the main plot and the subject, and ε_{ijk}= Sub-plot random error effect (Error b). Simple economic analysis using net profit in USD of each technology was calculated by subtracting the total production costs to the total revenue of each technology (Sekumade, 2017; Adesoji *et al*., 2016).

3.6 Results

3.6.1 Soil characteristics on experimental units

The texture of the soil in experimental unit was sandy clay loam for both sites with pH of 5.8 and 5.3 for Ilolo and Idifu, respectively (Table 3.1). The organic carbon of the soil was very low with 0.46% and 0.11% for Ilolo and Idifu, respectively. Total nitrogen and extractable phosphorous of the soil was also very low at both sites. The potassium content was high at Ilolo and medium at Idifu (0.69 cmolkg^{-1} and 0.43 cmolkg^{-1}, respectively). These physical and chemical soil characteristics are typical for Tanzanian and other SSA semi-arid regions.

Table 3. 1 Soil characteristics on experimental units

Particle size distribution	**Values for Ilolo site**	**Values for Idifu site**
% Clay	21.6	25.6
% Silt	2.9	4.9
% Sand	75.5	69.5
Textural class	*SCL*	*SCL*
Chemical characteristics		
Organic Carbon (OC) (%)	0.46 ^{VL}	0.11^{VL}
Soil pH (in H_2O)	5.88 ^{M}	5.30 ^{M}
Total nitrogen (N) (%)	0.06 ^{VL}	0.06 ^{VL}
Ext. Phosphorus (P) (mg/kg)	12.88 ^{L}	6.43 ^{VL}
Cation Exchange Capacity (cmol$_c$ kg^{-1})	15.20 ^{M}	5.40 ^{L}
Exch. Bases K+ (cmol$_c$ kg^{-1})	0.69 ^{H}	0.43 ^{M}
Mg (cmol$_c$ kg^{-1})	0.67 ^{M}	0.93 ^{M}
Ca (cmol$_c$ kg^{-1})	3.37^{H}	3.72 ^{H}
Na (cmol$_c$ kg^{-1})	0.25 ^{L}	0.48 ^{M}

SCL=sand clay loam, VL= very low, L= low, M= medium, +According to Landon 1991

3.6.2 Rainfall amount and distribution

The cumulative rainfall graph which show amount of rainfall and its distribution (number of rainfall events) during 2015/2016 and 2016/2017 cropping seasons are presented in Figure 3.1. Idifu had relative higher amount of rainfall in both seasons of 425.3 mm for 2015/2016 and 153.3 mm for 2016/2017 cropping seasons compared to Ilolo which site which had a total rainfall of 298.2 mm during 2015/2016 and 141.1 mm during 2016/2017 cropping season. Although Idifu received higher amount of rainfall, the distribution was poor as it had lower number of rainfall occurrences than Ilolo.

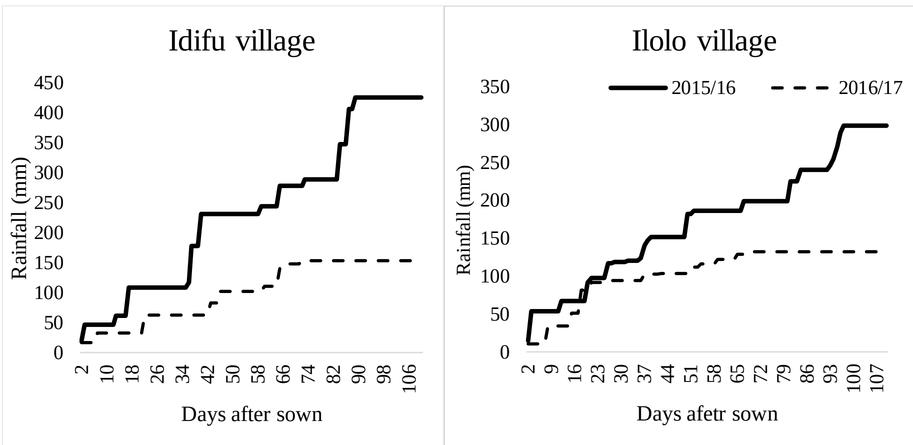

Figure 3. 1 Cumulative amount of rainfall in different days after groundnut sown

3.6.3 Spatial and seasonal variations of groundnut yield under famer's practices

The results showed that, locations and seasons had no significant effect on grain yield (Table 3.2). Ilolo had relatively higher yield compared to Idifu. Also, 2016/2017 cropping season had better crop yield than the previous one (2015/2016).

Table 3. 2 Spatial and seasonal variations of groundnut kernel yield (kg/ha) under famer's practices

		Kernel Yield
Locations	Idifu	512
	Ilolo	544
	Lsd	92.7^{ns}
Seasons	2015/2016	511
	2016/2017	546
	Lsd	92.7^{ns}

Lsd = least significant difference, ns =non-significance

3.6.4 Kernel yield under in-situ rainwater harvesting practices

Tied ridges and infiltration pits resulted into significant increase in kernel yield compared to FC except at Idifu during 2016/17 cropping season (Table 3.3). Tied ridges gave the highest kernel yield ranged from 654 to 739 kg/ha while flat cultivation gave the lowest yield ranges from 483.3 -553 kg/ha. No significant increase in yield when a tied ridge is compared to infiltration pit though tied ridges had relative greater kernel yields.

Table 3. 3 Effect of soil water management technologies on groundnut kernel yield

Factor A	Levels	Ilolo_2015/16	Ilolo_2016/17	Idifu 2015/16	_Idifu 2016/17
RWH	FC	534.8 a	553.4 a	486.3 a	537.7 a
	TR	654.6 b	699.8 b	643.2 b	739.0 a
	IP	617.7 b	638.3 b	556.1 b	685.4 a
	CV	2.7	3.0	5.7	11.4
	F value	0.002	0.002	0.01	0.07

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $P \leq 0.05$.
FC= flat cultivation, TR= tied ridges, IP= infiltration pits, CV =coefficient of variation

3.6.5 Effect of fertilizer micro-dose on groundnut kernel yield

The groundnut kernel yield increased significantly in all seasons across locations when different fertilizer rates were applied (Table 3.4). Zero fertilizer (farmers practice) resulted into lowest kernel yield in both seasons which ranged from 486.3 to 553.4 kg/ha while the recommended rate had highest yield ranging from 878.9 to 1140.4 kg/ha. Micro-dose at 50% increased yield significantly compared to farmer practice except at Ilolo during 2015/16 season when no significant yield increase was observed. Further, the results showed no significant yield increase when micro-dose at 75% of the recommended rate was compared with the recommended rate.

Table 3. 4 Effect of micro dose on groundnut kernel yield (kg/ha)

Factor B	Levels	Ilolo 2016	Ilolo 2017	Idifu 2016	Idifu 2017
Fertilizer rates	FO	534.8 a	553.4 a	486.3 a	537.7 a
	MD1	602.4 ab	637.2 ab	636.2 ab	559.9 b
	MD2	631.2 ab	757.2 b	834.0 bc	734.1 b
	MD3	780.8 bc	989.8 c	972.3 c	959.6 c
	RR	878.9 c	1,123.2 c	1,140.4 c	1,109.9 c
	CV	10.7	5.7	10.7	10.8
	F value	0.002	0.001	0.001	0.001

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $P \leq 0.05$.

FO= zero fertilizer, MD1= micro dose at 25% of recommended rate, MD2= micro dose at 50% of recommended rate, MD3= micro-dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation.

3.6.6 Kernel yield under integrated *in-situ* rainwater harvesting practices and fertilizer rates

Flat cultivation without fertilizer application which typically represents farmer practices, resulted into the lowest kernel yield at both locations. (Table 3.5). Integrating tied ridges with fertilizer at recommended rate had the highest kernel yield (1,263.5 -1,543.5 kg/ha) followed by infiltration pits with recommended rate

(1,135.8- 1,337.9 kg/ha). Integration of tied ridges and infiltration pits with fertilizer rates from 50% of recommended rate to recommended rate, increased yield significantly compared to farmer practice. The groundnut kernel yield increased by 652.3 kg/ha and 352.4 kg/ha at Ilolo during 2015/2016 and 2016/2017 cropping seasons, respectively, when tied ridges were integrated with fertilizer micro-dose at 50% of the recommended rate with similar trend for Idifu. The results also showed no significant increase in yield when micro-dose rate at 50%, 75% and recommended rate were used under both tied ridges and infiltration pits.

Table 3.5 The effect integrations of micro dose fertilizer rates and *in-situ* rainwater harvesting management practices on groundnut kernel yield (kg/ha)

Interaction (A*B)	Ilolo 2016	Ilolo 2017	Idifu 2016	Idifu 2017
FC x FO	534.8 a	553.4 a	486.3 a	537.7 a
FC x MD1	602.4 ab	637.2 ab	636.2 ab	559.9 a
FC x MD2	631.2 ab	757.2 a-d	834.0 a-d	734.1 ab
FC x MD3	780.8 ab	989.8 d-g	972.3 b-e	959.6 a-d
FC x RR	878.9 bcd	1,123.2 fgh	1,140.3 de	1,109.9 b-e
TR x FO	654.6 ab	699.8 abc	643.2 ab	739.0 ab
TR x MD1	823.7 abc	727.7 a-d	827.4 a-d	948.6 a-d
TR x MD2	1,160.1 def	906.0 c-f	981.7 b-e	1,197.7 c-f
TR x MD3	1,234.8 ef	1,134.3 fgh	1,118.7 cde	1,407.5 ef
TR x RR	1,338.5 f	1,263.5 h	1,284.0 e	1,543.7 f
IP x FO	617.7 ab	638.3 ab	556.1 a	685.4 ab
IP x MD1	819.3 abc	744.3 a-d	779.0 abc	800.7 abc
IP s x MD2	918.8 b-e	843.8 b-e	999.4 cde	1,021.5 b-e
IP x MD3	1,124.9 c-f	1,049.9 e-h	1,073.3 cde	1,174.3 c-f
IP s x RR	1,222.1 ef	1,187.8 gh	1,135.8 de	1,337.9 def
CV	12.1	10	12.9	14.4
F value	0.001	0.001	0.001	0.001

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $p \leq 0.05$. *FC= flat cultivation, TR= tied ridges, IP= infiltration pits. FO= zero fertilizer, MD1= micro dose at 25% of recommended rate, MD2= micro dose at 50% of recommended rate, MD3= micro dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation*

3.6.7 Economic assessment of all technologies used in the study

The average costs of materials, crop management activities and market prices of groundnut for 2015/2016 and 2016/2017 were shown in Table 3.6. Preparation of flat cultivation had the lowest labour cost (66.9 USD/ha) while tied ridges and infiltration pits had higher labour cost of 330.7 USD/ha and 881.8 USD/ha, respectively.

Table 3. 6: Cost of materials, management activities and average market price of groundnut kernels

Items	Unit	Cost(Tsh*/ha)	Cost(USD*/ha)
Materials			
Seeds	Tsh per ha	240,000	114
Fertilizers costs: DAP	Tsh per 50 kg bag	125,000	59.5
Storage bags	Tsh per bag	1200	0.3
Activities			
Flat cultivation preparation	Tsh per ha	138,888	66.9
Tied ridges preparation	Tsh per ha	694,444	330.7
Infiltration pits preparation	Tsh per ha	1,950,000	928.5
Sowing	Tsh per ha	120,000	57.0
Weeding and earthing up	Tsh per ha	120,000	57.0
Harvesting	Tsh per ha	180,000	85.0
Transportation	Tsh per bag	1500	0.7
Groundnut kernel market price	Tsh per kg	3500	1.4

- Tsh =Tanzanian Shillings, USD= United state dollars

The results further showed that, use of infiltration pits without application of fertilizer, with micro-dose of 25% and at 50% of recommended rate at both locations resulted into negative net profit (Figure 3.2). Integration of tied ridges and fertilizer at recommended rate resulted into the highest NP of 884.4 and 650.7 USD for Idifu and Ilolo respectively. Integration of tied ridges and micro-dose rates of 25%, 50% and 75% of recommended rate increased NP by 140.3, 347 and 522.5 USD respectively compared to farmers practices at Idifu village. Further, at Ilolo, integration of tied ridges and micro-dose rates of 25%, 50% and 75% of recommended rate increased NP by 72, 303 and 436 USD, respectively compared to farmers practices. Moreover, the use of micro-dose rates from 25% to 75% with flat cultivation gave positive NP ranging from 257.4 to 631.7 USD and 188.5 to 332 USD at Idifu and Ilolo, respectively.

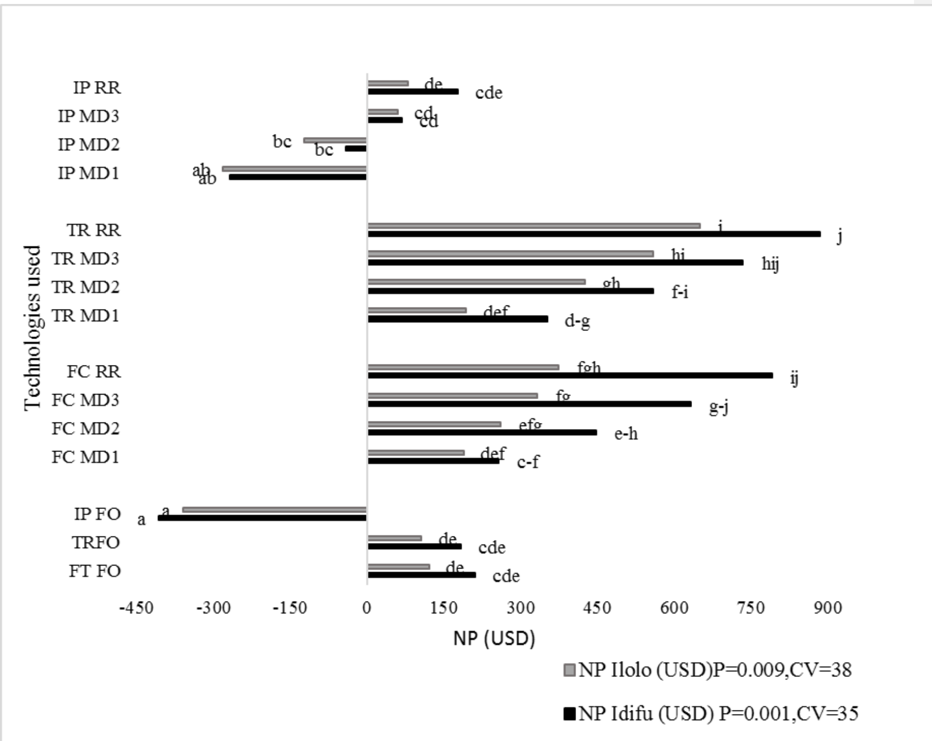

Figure 3. 2: Net profit of technologies used in the study (USD/ha)

FC= flat cultivation, TR= tied ridges, IP= infiltration pits. FO= zero fertilizer, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rate, MD3= micro-dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation

3.7 Discussion

3.7.1 Soils fertility and rainfall

Soils at the experimental sites were sand clay loam, a soil texture which is ideal for most crop growth (Birkas *et al.*, 2014) with very low nitrogen (N) and phosphorous (P) contents. Both sites had acidic soils with pH of 5.3 (Ilolo) and 5.2 (Idifu), which is slightly below that required (5.5-7) for groundnut production (Putnam *et al.*, 1991) and this affected its growth and productivity (Murata *et al*., 2011). The deficiency of P in the soils could have been due to unavailability of inherent soil P, fixation of P by aluminum, iron, or calcium as soils are acidic and poor management of on-farm organic and inorganic P resources in the soil (Cerozi and Fitzsimmons, 2016). Off season grazing activities in these areas which resulted into reduction of organic matter in the field also contributed to nutrients deficiency in the soils. In such soil, the application of lime to raise pH to appropriate range for groundnut production and to enhance availability of nutrients in the soil is very important as suggested by Goulding (2016) and Rastija *et al.* (2014).

The amount of rainfall received in both experimental sites was below that required by groundnut crop of 750-1200 mm per growing season (Temu *et al,* 2011; Kanyeka *et al.*, 2007). Low amount and poor distribution of rainfall could be due to environmental degradation, mainly deforestation. Large part of this area is covered by bare soils, grasslands and few scattered trees due to deforestation (FAO, 2001, Backéus *et al*., 1994), unlike other tropical areas which mostly are covered with forests with high amounts of rainfall. Increasing deforestation reduces the natural recycling of moisture from soils, through vegetation, and into the atmosphere, from where it returns as rainfall (Bagley *et al.*, 2014; Oliveira *et al.*, 2013). When forests are replaced by pasture or crops, water recycling process changes, leading to reduced atmospheric humidity and potentially suppressing precipitation (Devaraju, 2015; Spracklen and Garcia-Carreras, 2015; Deborah and Karen, 2014). Therefore, strategies of in situ harvesting rain water by using technologies such as tied ridges and infiltration pits are vital for increasing crop productivity these areas.

3.7.2 Effects of *in-situ* rainwater harvesting technologies and fertilizer on kernel yield

Kernel yield increased by 32% and 46% during 2015/2016 and 25% and 34% during 2016/2017 at Ilolo when infiltration pits and tied ridges were used, respectively with similar trend for the Idifu site. The increase in yield could have been due to available moisture in the soil resulting from *in-situ* catchment and temporary stored rain water by tied ridges and infiltration pits, which supported physiological processes of the crop. This explains why crops grown in tied ridges and infiltration pits performed better than those grown on flat land. According to Kilasara *et al.* (2015 and Yoseph, (2014), tied ridges can improve soil moisture and increase yield up to 67% compared with flat cultivation. Application of phosphorus at 50% of the recommended rate increased kernel yield significantly compared to zero application. The added phosphorus in the soil through inorganic fertilizer (DAP) promoted groundnut shoot and root growth. It also stimulated pods setting, decreased number of empty pods (pops) and hastened maturity of the crop (Tamba, 2016; Kamara *et al.* (2011). The groundnut yield increased by 26.7% in 2015/2016 and 34.8% in 2016/2017 seasons when micro-dose rate of 50% were applied at Ilolo. In India and West Africa, micro dosing is used as a strategy of increasing fertilizer use and income and lead into increased crop yields by up to 120% and increased family income by 50% to 130% (Abdalla, *et al*., 2015; Kamhambwa, 2014; ICRISAT, 2009). Small holder farmers in the study areas with financial constraints of purchasing inorganic P fertilizer at the recommended rate can reduce the cost of purchasing fertilizer by 50% when micro-dosing at 50% of the recommended rate is used.

3.7.3 Agronomic and economic responses of integrating fertilizer micro dose and in situ rain water harvesting technologies

The potential of using either fertilizer at micro dose rates alone or soil moisture management practices on yield performance was vivid. However, integration of these technologies is very important for smallholder famers in semi-arid areas as it simultaneously tackle the problem of low soil fertility and drought. Integration of tied ridges with micro dose rate at 50% of recommended rate increased groundnut kernel yield by 63.7% to 117% at Ilolo and 101 to 122.7% at Idifu while infiltration pits with micro-dose rate at 50% increased yield by 52 to 71% and 90% to 105% at Ilolo and Idifu, respectively. Kamhambwa (2014)reported that, integration of *in-situ* rainwater harvesting technologies along with fertilizer micro dosing increased crop yield up to 80 % compared to famers practices. Significant increase of kernel yield when integrating in-situ rainwater harvesting and fertilizer could be due to the presence of enough moisture in the soil which facilitate the dissolution and absorption of soil nutrients. This enhances the availability of the nutrients in particular P for proper growth and development of the crop. Considering the economic worthiness of the technologies, all technologies that resulted to negative net profit are not economical to invest as they lead to economic losses (Adinya *et al*., 2010; DFA, 2006). The use of infiltration pits without fertilizer inputs and with fertilizer application up to 50% of recommended rate resulted into economic losses to the famers. This is because of highly production costs especially during infiltration pits preparation (tedious and time consuming) and little harvests received from these treatments. Integrating fertilizer micro-dose at 50% of recommended rate with tied ridges or flat cultivation are options that could benefit stallholder farmers in semi-arid area. These technologies resulted into higher economic and agronomic performances compared to farmer's practices.

3.8 Conclusions and Recommendations

This study evaluated the effect of integrating fertilizer at different application rates and in-situ rainwater harvesting technologies on groundnut kernel yield in semi-arid environment, and their household profitability among smallholder farming communities in central Tanzania. The amount of rainfall in these areas are below average to support crop production. Tied ridges and infiltration pits significantly increased kernel yield compared to flat cultivation. Micro-dose fertilizer application at 50% of recommended rate had higher yield than farmer's practice. Also, the integration of tied ridges or flat cultivation and fertilizer micro-dosing at 50% of recommended rate to recommended rate had high agronomic and economic performance compared to farmer practices. The study, therefore, recommends the use of tied ridges and application of inorganic fertilizer at micro-dose rate at 50% of recommended rate (22.5 kg P_2O_5/ha) for small holder groundnut farmers in semi-arid areas of central Tanzania. This will enable farmers to achieve high economic and agronomic performances compared to farmer practices. This recommendation will transmute negative thinking of most farmers on the use of inorganic fertilizers and inspire them towards use of tied ridges with micro-dose rates and could make them moves to recommend rate as resources increased.

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CHAPTER FOUR

4.0 EFFECT OF FERTILIZER MICRO-DOSE AND RAINWATER HARVESTING PRACTICES ON YIELD AND RESOURCE UTILIZATION INDICES IN PEARL MALLET-GROUNDNUT INTERCROPPING SYSTEM

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[1]Emmanuel A. Chilagane., [2]Frederick C. Kahimba and [3]Cornel L. Rweyemamu

[1] Agricultural Research Institute Uyole, Southern Highland Zone Crop Research, Mbeya, Tanzania

[2]Sokoine University of Agriculture, Department of Engineering, Sciences and Technology, Morogoro, Tanzania

[3]Sokoine University of Agriculture, Department of Crop Science and Horticulture, Morogoro, Tanzania

4.1 Abstract

Poor soil fertility and moisture stress are among the main challenges facing small scale farmers in semi-arid areas worldwide, resulting into food and income insecurity. Application of small rates of fertilizer (micro-dose rates) along with in-situ rain water harvesting practices under intercropping system may improve crop productivity, land use efficiency and financial return to small scale farmers. This study aimed at evaluating effect of integrating micro-dose rates and moisture management practices using tied ridges (TR) and infiltration pits (IP) on soil moisture, yield and resource utilization indices under pearl millet and groundnut intercropping system in a semi-arid environment. Split split plot field experiments under Randomized Complete Block Design were conducted on sandy loam soils at two sites from 2015/2016 to 2016/2017 cropping seasons. Tied ridges and infiltration pits conserved soil moisture by 38% and 45%, respectively more than flat cultivation at 30 cm depth ten days after rainfall. Use of micro-dose rate at 25% of recommended rate along with tied ridge and infiltration pit had a yield advantage of 969 kg/ha and 766 kg/ha, respectively than flat cultivation without fertilizer. Land use efficiency was 93% – 157% higher in intercropping than sole crop. The financial return was 1117-1120 USD/ha higher from pearl millet and groundnut intercropping under tied ridges and infiltration pits, respectively, applied with fertilizer at the recommended rate. Intercropping of millet and groundnut along with tied ridges and infiltration pits with micro dose rates from 25% to75 % of recommended rate had financial return of 760- 1076 USD/ha higher than sole millet in flat land with no fertilizer application. The use of tied ridges and infiltration pits conserved more soil moisture than flat cultivation, this enhanced fertilizer use efficiency that improved crop yield and land equivalent ratio under intercropping system. This strategy could increase food availability and income generation among smallholder farmers in semi-arid areas.

Key words: cropping systems, fertilizer micro-dosing, rainwater harvesting, resource utilization indices

4.2 Introduction

Trends in agricultural production systems is towards achieving high productivity and promoting sustainability over time to meet the needs of the rapid by increasing population (Metwally *et al*., 2015). Pearl millet and groundnuts are among important crops not only in semi-arid areas of sub-Saharan Africa but also in semi-arid parts worldwide (Tarawali, 2014; Melese and Dechassa, 2017; Redae *et al*., 2017). Diversifications of crops in production is among very important strategies for stallholder's farmers to avoid total crop failure as it enables farmers to have more food crops alternatives in their production systems. The arable land is a scarce resource, crop diversification by intercropping and efficient utilization of soil nutrients and moisture (intensification) seem feasible over increasing area under cultivation without efficient utilization of nutrients and soil moisture (Bassi and Dugje, 2016; Nkamleu, 2011). Intercropping provides better opportunity to accommodate legumes which are otherwise neglected crops in the space provided for cereal crop (Kiroriwal and Yadav, 2013). This can even help farmers to cope with planting period because most of these parts have shorter planting period and also can reduce the impact of land degradation by expansion of production land (Nkamleu and Manyong, 2005). Apart from crop diversification, intercropping of cereal and legumes has more advantages including improvement of soil fertility, reduction of weed population and hence improving crop productivity (Bassi and Dugje, 2016; Dereje *et al*., 2016; Feng *et al*., 2016).

Despite the importance of crop diversification in the semi-arid areas, major problems associated with crop production were declining soil fertility and drought conditions which resulted into food insecurity to most of semi-arid areas (Melese and Dechassa, 2017). The declined soil fertility is caused by inherent low fertility of the soil, little or no fertilizer application in production system (Kamhambwa, 2014; Kimenye, 2014). Other causes include soil erosion, off season grazing activities (reduces organic matters in the soil), soil mining and nutrients leaching (Mwinuka, *et al.*, 2017; Sharma *et al.*, 2015; Serme *et al.*, 2016; Pimentel and Burgess, 2013). Fertilizer use in most of the SSA countries is low averaging 16 kg/ha (Cameron *et al.*, 2017) and 19 kg/ha in Tanzania (MALF, 2017). These rates are below that committed by African Union's through the Abuja Declaration of increasing fertilizer use to 50 kg/ha (Cameron *et al.*, 2017). This is because, most farmers in semi-arid areas are small holders , with low knowledge on fertilizer use (Mohapatra and Kameswari, 2014) and low ability of using fertilizers and other improved agricultural inputs due to high costs at current recommendations (Emmanuel *et al.*, 2016; MALF, 2017). Despite the awareness of rain water harvesting practices such as tied ridges and infiltration pits in some parts of semi-arid areas, its application level is low. Application of these technologies in dry prone areas can improve soil moisture and increase crop productions (Kathuli and Itabari, 2014; Kathuli *et al.*, 2010; Gichangi *et al*., 2007). Fertilizer application at reduced amount (micro-dose rates) is one of the ways of increasing its use and crop productivity in regions where farmers do not apply fertilizer due to financial limitations. The integrations of fertilizer use (micro-dose rate) and in-situ rainwater harvesting practices can improve crop productivity through the synergistic effect of providing nutrients and water to the crop simultaneously (Lian *et al.,* 2017; Yang, 2015). Micro-dose fertilizer application and in-situ rain water harvesting practices were proved to be potential on increasing soil fertility, soil moisture and crop yield (Kilasara *et al*., 2015; Yoseph, 2014; Sime and Aune, 2014).

Therefore, efficient utilization of moisture and nutrients in the soil, the sustainable way of intercropping systems under in-situ rain water harvesting (tied ridges and infiltration pits) and reduced fertilizer doses is becoming very vital. Although several researches on intercropping have been conducted globally, knowledge on influence of in situ rainwater harvesting methods as well as fertilizer micro-dosing on yield, land use efficiency and financial returns of pearl millet and groundnut intercropping in the semi-arid areas is scarce. The objectives of this study were to examine the influence of *in-situ* rainwater harvesting methods as well as fertilizer micro-dosing on land use efficiency and financial returns of pearl millet and groundnut intercropping systems in the semi-arid areas of Tanzania.

4.3 Materials and Methods

4.3.1 Locations and climate

This study was conducted at Ilolo and Idifu villages located at latitude $06^{\theta}\ 20'\ 45''$; longitude $35^{\theta}\ 54'\ 12''$ and latitude $06^{\theta}\ 24'\ 49''$; longitude $35^{\theta}\ 59'\ 03''$, respectively. These villages are in Chamwino District, Dodoma region of Tanzania. The experimental site at Ilolo had a slope of 3.2% and an altitude of 1620 masl while at Idifu, the slope was 2.2% and an altitude of 1006 masl. The areas have low and erratic unimodal rainfall regime ranging from 400 to 650 mm annually. About 85% of its amount of rain falls between December and March (Temu *et al.*, 2011), which gives farmers the opportunity to start planting their crops up to mid-January.

4.3.2 Experimental materials and design

Improved groundnut seed variety 'Pendo' and millet variety Okoa obtained from Agriculture Research Institute (ARI) Naliendele and ARI -Hombolo, respectively were used. Under optimal management variety Pendo has a yield potential of 1500 kg/ha whereas Okoa yields 2400 kg/ha. Also, fertilizer materials Di Ammonium Phosphate (DAP) with 46% P_2O_5 and 18% N and Urea with 46% N were used. A split-split plot experiment in a Randomized Complete Block Design was used with three replications. The main factor was soil moisture management practices with three levels; (1) tied ridges (TR), (2) infiltration pits (IP), and (3) flat cultivation (FC) that mimic farmer's practices. Sub-factor was cropping systems; (1) peal millet sole crop, (2) groundnut sole crop and (3) pearl millet-groundnut intercropping and the sub sub factor was fertilizer rates; (1) 0% of the recommended rate (2) micro-dose at 25% of the recommended (MD1), (3) micro-dose at 50% of recommended (MD2), (4) micro-dose at 75% of recommended (MD3) and (5) 100% of recommended rate (RR). The recommended rate for pearl millet is 60 kg N/ha and 40 kg P_2O_5/ha and for groundnut 45 kg P_2O_5/ha (Kanyeka *et al*, (2007). The spacing for millet sole crop was 80 x 30 and for groundnut sole was 50 x 10 cm as recommended by Kanyeka *et al*, (2007). For intercropping option, the spacing of main crop (pearl millet was used and in between groundnut was intercropped. The size of tied ridges was 75 cm width, 20 cm height for pearl millet and 50 cm width, 15 cm height for groundnuts, while the size of infiltration pits were 40 cm diameter and 40 cm depth for both crops.

4.4 Data Collection

4.4.1 Soil moisture

Soil moisture content expressed in percentage by volume (% vol) was determined by using a Delta T device Moisture Meter type HH2 with SM 300 moisture sensor. A hole dug by hand-hoe at a soil depth of 35 cm. Volumetric soil moisture content as the ratio between the volume of water present and the total volume of the sample was expressed in percentage (%vol) as described by Delta T Devices Ltd (2013). Measurements were taken from a device screen after inserting a pair of metal rings (sensor) on the soil at 5 cm, 15 cm and 30 cm soil depths.

4.4.2 Rainfall

Daily precipitation was recorded by standard rain gauges at both experimental sites. It consisted of a funnel emptying into a graduated cylinder, 2 cm in radius, which fits inside a larger container 20 cm in diameter and 50 cm tall. If the rainwater overflows the graduated inner cylinder, the larger outer container will catch it. When measurements are taken, the height of the water in the small graduated cylinder is measured, and the excess overflow in the large container is carefully poured into another graduated cylinder and measured to give the total rainfall.

4.4.3 Crop yield for pearl millet and groundnuts

Grain yield of pearl millet was obtained from randomly selected samples of 16 well matured plants located at inner rows of each plot. The panicles of the sampled plants were cut, threshed and grains dried to 14% moisture content and the weight recorded. For sole crop groundnuts, one-meter squared area was randomly marked on the central rows, well matured groundnuts were uprooted by hand, the number of plants, number of pods, pods weight was recorded. Harvested pods were sun dried to constant weight and the weight of kernel was recorded. For intercropped groundnuts, all groundnut plant in the plot were harvested.

4.4.4 Economic data

The costs of materials used in this study (fertilizer and seeds) and maximum and minimum market prices for 2015/2016 and 2016/2017 seasons in (Tsh/kg) were recorded. Furthermore, costs of crop management activities (Tsh/ha) were recorded. Then, the costs and market prices were converted to USD based on the exchange rate of 1 USD =2,100Tsh (BOT exchange rate of July 2017)

4.4.4 Computation of land equivalent ratio, benefit cost ratio and momentary values of the crops

Land equivalent ratio (LER), the relative land area under sole crops that is required to produce the yields achieved by intercropping was calculated using Equation 4.1 as suggested by Metwally *et al.* (2015) as follows.

$LER= (Y_{ab}/Y_{aa}) + (Y_{ba}/Y_{bb})$ ………………………………………………… (4.1)

where Y_{aa}= pure stand yield of crop 1(pearl millet), Y_{bb}= pure stand yield of crop 2 (groundnut), Y_{ab}=intercrop yield of crop 1, Y_{ba}= intercrop yield of crop 2. Benefit cost ratio of all technologies tested were calculated using the equation 4.2 (Debertin, 2012).

Benefit cost ratio = Gross return/Total production cost……………….…… (4.2)

The monetary values of crops were calculated from yield and price data as described by Federer (1993) and shown in equation 4.3 below:

$V=K_1Y_1+K_2Y_2$……………………………………………………………...…. (4.3)

Where: K_1 and K_2 are yields of pearl millet and groundnut, respectively while Y_1 and Y_2 are prices of the respective crops; V is the financial return value.

4.5 Data Analysis

Rainfall data were subjected into descriptive statistical analysis were cumulative rainfall were plotted. Crop yield**,** LER and momentary values of the crops were subjected to analysis of variance (ANOVA) using Gen-start software at $P \leq 5\%$ basing on the statistical model for the split-split-plot design. The mean separation test was done using Tukey's test.

4.6 Results

4.6.1 Soil characteristics and rainfall

The texture of the soil in experimental unit was sandy clay loam for both sites with pH of 5.8 and 5.3 for Ilolo and Idifu, respectively (Table 4.1). The organic carbon of the soil was very low with 0.46% and 0.11% for Ilolo and Idifu, respectively. Total nitrogen and extractable phosphorous of the soil was also very low at both sites. The potassium content was high at Ilolo and medium at Idifu (0.69 $cmol_c$ kg^{-1} and 0.43 $cmol_c$ kg^{-1}, respectively). These physical and chemical soil characteristics are typical for Tanzanian and other SSA semi-arid regions.

Table 4. 1 Soil characteristics on the experimental areas

Particle size distribution	**Values for Ilolo site**	**Values for Idifu site**
% Clay	21.6	25.6
% Silt	2.9	4.9
% Sand	75.5	69.5
Textural class	*SCL*	*SCL*
Chemical characteristics		
Organic Carbon (OC) (%)	0.46 ^{VL}	0.11^{VL}
Soil pH (in H_2O)	5.88 ^{M}	5.30 ^{M}
Total nitrogen (N) (%)	0.06 ^{VL}	0.06 ^{VL}
Ext. Phosphorus (P) (mg/kg)	12.88 ^{L}	6.43 ^{VL}
Cation Exchange Capacity ($cmol_c$ kg^{-1})	15.20 ^{M}	5.40 ^{L}
Exch. Bases K+ ($cmol_c$ kg^{-1})	0.69 ^{H}	0.43 ^{M}
Mg ($cmol_c$ kg^{-1})	0.67 ^{M}	0.93 ^{M}
Ca ($cmol_c$ kg^{-1})	3.37^{H}	3.72 ^{H}
Na ($cmol_c$ kg^{-1})	0.25 ^{L}	0.48 ^{M}

SCL=sand clay loam, VL= very low, L= low, M= medium, +According to Landon1991

The amount and number of rainfall events during 2015/2016 and 2016/2017 cropping seasons are indicated in Fig 4.1. Idifu had relatively higher amount of rainfall in both seasons of 425.3 mm for 2015/2016 and 153.3 mm for 2016/2017 cropping seasons compared to Ilolo site which had a total rainfall of 298.2 mm during 2015/2016 and 141.1 mm on 2016/2017 cropping season. Although Idifu received higher amount of rainfall, the distribution was poor as it had lower number of rainfall occurrence than Ilolo.

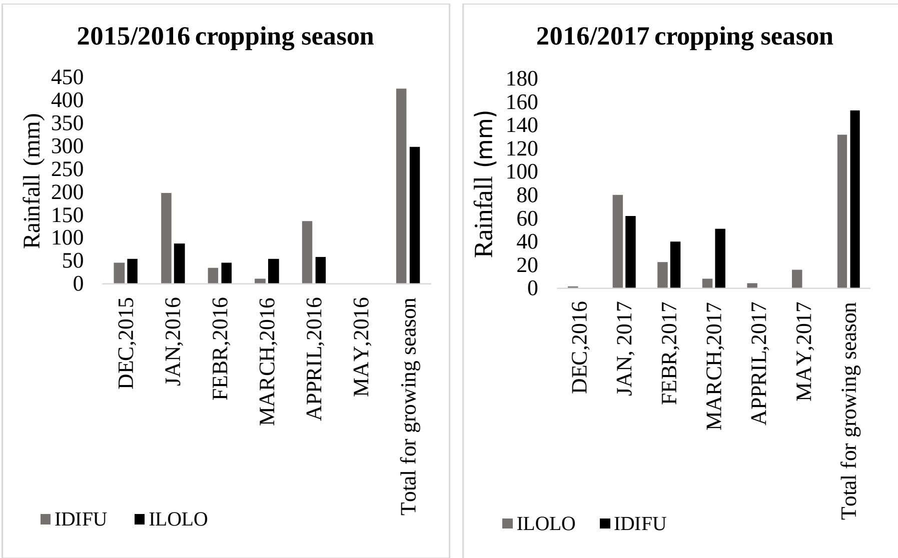

Figure 4. 1: Total amount of rainfall (mm) per month and per growing season

4.6.2 Soil moisture management practices

Soil moisture at different soil depths in percentage by volume (%vol) varied with different rainwater harvesting (RWH) practices as shown in Fig 4.2. Tied ridges and infiltration pits improved soil moisture retention, two days after rain by 24.4% at 5-15 cm soil depth to 27.8% at 15-30 cm soil depth while infiltration pits improved soil moisture retention by 15.9% at 5-15 cm soil depth to 18.5% at 15-30 cm soil depth. It was further observed that, ten days after rainfall the soil moisture retention was improved by 34.1% at 5-15 cm soil depth to 38.3% at 15-30 cm soil depth and 45.6 at 5-15 cm soil depth to 50.2% at 15-30 cm soil depth when tied ridges and infiltration pits respectively were used compared to flat cultivation.

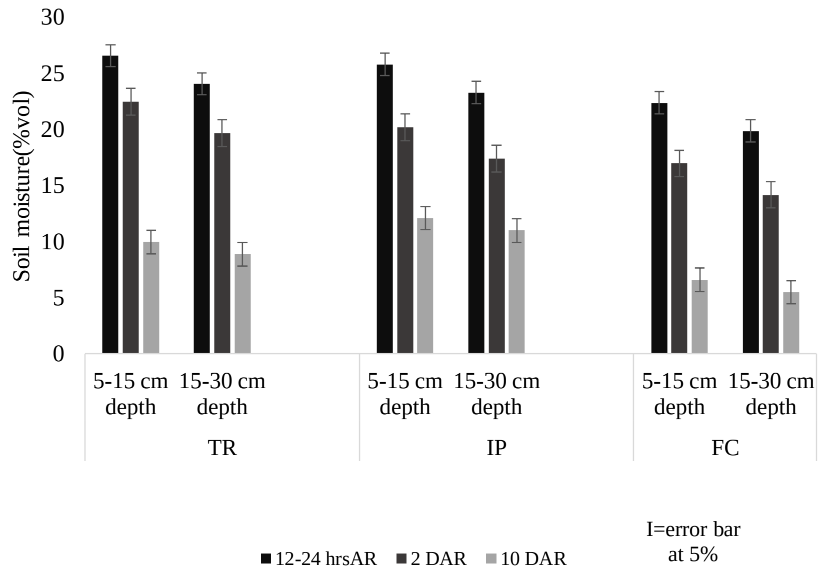

Figure 4. 2 Soil moisture as influenced by rainwater harvesting practices at different soil depths and duration after rainfall

AR= after rainfall, DAR = days after rainfall, FC= flat cultivation, TR= tied ridges, IP= infiltration pit

4.6.3 Effect of in-situ rain water harvesting, cropping systems and micro dose fertilizer on pearl millet yield

Rain water harvesting practice under zero fertilizer input significantly ($p \leq 0.05$) affected grain yield only at Ilolo (Table 4.2). Infiltration pits resulted into highest grain yield followed by tied ridges whereas flat cultivation had the lowest yield. At Idifu site, rainwater harvesting practices under zero fertilizer input had no significant effect on grain yield but it resulted into relatively better yield than flat cultivation. Fertilizer application rates increased grain yield significantly ($P \leq 0.001$) at both sites. Application of fertilizer at recommended rate resulted into highest grain yield followed by micro-dose rate at 75 %, 50 % and 25 % of recommended rate while zero application scored the lowest yield. Cropping systems had no significant effect on grain yield, however, pearl millet produced in sole cropping system had relative higher yield than the one produced in intercropping system.

Table 4. 2 Effect of in-situ rain water harvesting, cropping systems and micro dose fertilizer on pearl millet yield

Factors	Levels	Ilolo 2017	Ilolo 2016	Idifu2016	Idifu 2017
RWH	FC	306.3 a	250.9 a	296.8 a	258.2 a
	TR	460.6 b	357.8 ab	552.3 a	341.5 a
	IP	576.4 b	472.3 b	635.6 a	375.4 a
	CV (%)	8.9	15.6	27.2	14.6
	P-value	0.003	0.021	0.078	0.086
Fertilizer rates	FO	306.3 a	250.9 a	296.8 a	258.2 a
	MD1	773.4 b	605.5 b	686.7 b	554.4 b
	MD2	874.3 bc	1001.2 c	827.7 b c	855.5 c
	MD3	966.1 cd	1191.1 cd	913.7 c	978.9 c
	RR	1037.2 d	1263.4 d	935.9 c	1094.5 c
	CV (%)	7.2	10.5	9.7	11.6
	P-value	0.001	0.001	0.001	0.001
Cropping systems	Intr	306	250.9	297	258
	SC	505	340.2	422	297
	CV (%)	33.9	5.3	19.3	12.7
	P-value	0.218	0.02	0.158	0.312
	Lsd	482.9	54.87	243.4	124.2

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $p \leq 0.05$ *FC= flat cultivation, TR= tied ridges, IP= infiltration pits. CV=coefficient of variation SC = sole peal millet, Int= intercropping of pearl millet and groundnut, cv= coefficient of variation. FO= zero fertilizer farmers, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rat e, MD3= micro-dose at 75% of recommended rate, RR= recommended rate*

Interaction effects of rainwater harvesting, cropping systems and fertilizer use on grain yield were highly significant at Ilolo in both seasons and Idifu during 2017 (Table 4.3). Intercropping of millet in a flat cultivation with zero fertilizer application (FC+Intr+ZERO) had the lowest grain yield in both locations. The application of tied ridges and infiltration pits whether in a sole or in an intercropping system along with micro dose rate at 25% resulted into significant higher grain yield than (FC+Intr+ZERO)

Table 4. 3 Interaction effects of rainwater harvesting, cropping systems and fertilizer use on pearl millet grain yield

Interaction	Ilolo 2017	Ilolo 2016	Idifu 2016	Idifu_2017
FC SC FO	505 abc	340ab	422ab	296.9 ab
FC SC MD1	844 b-h	756 b-e	848 b-e	591.8 a-g
FC SC MD2	980 b-i	1142 efg	945 c-f	979.3 f-l
FC SC MD3	1042 d-j	1313 f-k	996 c-g	1041.9 g-m
FC SC RR	1138 f-j	1362 f-l	1116 d-h	1144.9 i-n
FC Intr FO	306 a	251a	297 a	258.2 a
FC Intr MD1	773 a-g	605 a-d	687 a-d	554.4 a-f
FC Intr MD2	874 b-h	1001 c-f	828 b-e	855.5 e-j
FC Intr MD35	966 b-i	1191 e-h	914 b-e	978.9 f-l
FC Intr RR	1037 d-j	1263 f-j	936 c-f	1094.5 h-n
TR SC FO	553 a-d	1299 f-k	1240 e-i	887.1 e-j
TR SC MD1	990 b-i	1665 h-m	1409 f-k	1136.8 i-n
TR SC MD2	1084 e-j	1763 j-m	1536 h-l	1394.9 k-o
TR SC MD3	1327 h-k	1915 m	1781 j-m	1696.9 o
TR SC RR	1715 k	358 ab	552 abc	341.5 abc
TR Intr FO	461 ab	406 ab	700 a-d	450.8 a-e
TR Intr MD1	798 a-h	1192 e-h	1025 c-g	739.4 b-i
TR Intr MD2	1031 c-j	1551 g-m	1295 e-j	1022.6 g-l
TR Intr MD3	1271 g-k	1656 h-m	1456 g-k	1231.8 j-n
TR Intr RR	1553 jk	1773 klm	1613 i-m	1496.5 mno
IP SC FO	703 a-f	542 abc	814 b-e	437.3 a-e
IP SC MD1	1126 f-j	1078 d-g	1650 i-m	777.6 c-j
IP SC MD2	1207 f-k	1348 f-l	1739 j-n	929.6 f-j
IP SC MD3	1418 ijk	1473 f-m	1962 lmn	1079.1h-n
IP SC RR	1686 k	1822 lm	2202 n	1518.9 no
IP Intr FO	576 a-e	472ab	636 a-d	375.4 a-d
IP Intr MD1	986 b-i	1069 d-g	1448 g-k	654.4 a-h
IP Intr MD2	1036 d-j	1239 e-i	1592 h-m	833.9 d-j
IP Intr MD3	1250 g-k	1329 f-l	1811 k-n	941.2 f-k
IP Intr RR	1475 ijk	1703 i-m	2039 mn	1411.5 l-o
CV%	16.1	13.5	12.6	15.8
F value	0.001	0.001	0.032	0.001

Means in the same column followed by the same letter are not significantly different according to Tukey’s test at $p \leq 0.05$ *FC= flat cultivation, TR= tied ridges, IP= infiltration pits. CV=coefficient of variation SC = sole crop, Int= intercropping of pearl millet and groundnut, cv= coefficient of variation*. *FO= zero fertilizer farmers, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rate, MD3= micro-dose at 75% of recommended rate, RR= recommended rate*

Groundnut kernel yield was significantly affected by rain water harvesting only at Ilolo during 2017 and Idifu during 2016 cropping season (Table 4.4). Flat cultivation resulted into the lowest kernal yield while infiltration pit and tied ridges had relatively better yield compared to flat cultivation. However, no significance differences were observed at Ilolo in 2016 and Idifu in 2017. However, the infiltration pits and tied ridges resulted into relatively greater kernel yield than flat cultivation. The use of different fertilizer rates also increased kernel yield significantly except at Idifu in 2017 where differences were not significant (Table 4.4). The results showed positive response of fertilizer on kernel yield. Zero application resulted to lowest kernel yield while the recommended rate had the maximum yield. The use of micro-dose rates from 25% to 75% of recommended amount had greater yield than zero application. Cropping systems had significant effect on kernel yield (Table 4.4). Production of groundnut as a sole cropping system gave higher kernel yield compared with intercropping system.

Table 4. 4 Effect of *in-situ* rainwater harvesting, cropping systems and micro-dose fertilizer on groundnut kernel yield

Factors	Levels	Ilolo 2017	Ilolo_2016	Idifu 2017	Idifu 2016
RWH	FC	154.1a	192.7 a	156.9 a	233.4 a
	TR	221.7 a	216.8 a	257.2 a	402.2 b
	IP	336.3 b	332.1 a	358.4 a	424.1 b
	CV (%)	13.7	21.5	27.9	24.9
	P-value	0.006	0.065	0.064	0.104
Fertilizer rates	FO	154.1 a	192.7 a	156.9 a	233.4a
	MD1	228.5 ab	307.9 b	212.9 a	336.3 ab
	MD2	292.5 ab	343 b	344.1 a	418.6 bc
	MD3	324.2 b	421.7 c	396.6 a	449.3 bc
	RR	370.9 b	453.8c	372.4 a	549.1 c
	CV (%)	20.2	7.2	38.6	15
	P-value	0.01	0.001	0.121	0.002
Cropping systems	Intr	154a	193a	157a	233a
	SC	553b	535b	538b	486b
	Cv (%)	9.8	10.6	20.2	16.1
	P-value	0.005	0.008	0.022	0.033
	Lsd	121.3	135.2	246.2	203.4

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $p \leq 0.05$ *FC= flat cultivation, TR= tied ridges, IP= infiltration pits. CV=coefficient of variation SC = sole crop, Intr= intercropping of pearl millet and groundnut, cv= coefficient of variation*. *FO= zero fertilizer farmers, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rate, MD3= micro-dose at 75% of recommended rate, RR= recommended rate*

Interaction effects of rainwater harvesting, cropping systems and fertilizer rates on kernel yield were highly significant (Figure 4.5). Intercropped of groundnut in a flat cultivation with zero fertilizer application (FC+Intr+ZERO) resulted into the lowest grain yield in both locations. The use of tied ridges and infiltration pits in a sole cropping system along with recommended rate resulted into the highest kernel yield in both locations. The application of tied ridges and infiltration pits in a sole cropping system along with micro-dose rate at 25% resulted into significantly higher grain yield than (FC+Intr+ZERO).

Table 4. 5 Interaction effects of rainwater harvesting, cropping systems and fertilizer rates on groundnut kernel yield

Interaction	Ilolo 2017	Ilolo 2016	Idifu 2017	Idifu 2016
FC SC FO	553.4 c-h	534.8 c-g	537.7 a-f	486.3 a-e
FC SC MD1	637.2 d-i	602.4 c-h	559.9 a-g	636.2 b-f
FC SC MD2	757.2 g-k	631.2 d-i	734.1 b-h	834 f-k
FC SC MD3	989.8 j-n	780.8 f-i	959.6 e-j	972.3 g-l
FC SC RR	1123.2 lmn	878.9 h-k	1109.9 g-k	1140.3 kl
FC Intr FO	154.1 a	192.7 a	156.9 a	233.4 a
FC Intr MD1	228.5 ab	307.9a bc	212.9 ab	336.3 ab
FC Intr MD2	292.5 abc	343 a-d	344.1 abc	418.6 abc
FC Intr MD3	324.2 abc	421.7 a-e	372.4 abc	449.3 a-d
FC Intr RR	370.9 a-e	453.8 a-e	396.6 a-e	549.1 a-f
TR SC FO	699.8 f-j	654.6 e-i	739 b-h	643.2 b-f
TR SC MD1	727.7g-j	823.7 g-j	948.6 d-j	827.4 f-k
TR SC MD2	906.0 i-m	1160.1 kl	1197.7 h-k	981.7 h-l
TR SC MD3	1134.3 lmn	1234.8 l	1407.5 jk	1118.7 kl
TR SC RR	1263.5 n	1338.5 l	1543.7 k	1284 l
TR Intr FO	221.6 ab	216.8 ab	257.2 abc	402.3 abc
TR Intr MD1	403.1 a-f	342.1 a-d	349.3 abc	599.3 b-f
TR Intr MD2	530.6 b-g	565.4 c-g	453.4 a-e	663.6 c-h
TR Intr MD3	583.7 c-h	575.5 c-g	454.2 a-e	693.8 c-i
TR Intr RR	641.2 d-i	688.7 e-i	649.5 a-h	776.3 d-i
IP SC FO	638.3 d-i	617.7 d-i	685.4 a-h	556.1 a-f
IP SC MD1	744.3 g-k	819.3 ghi	800.7 c-i	779 e-j
IP SC MD2	843.8 h-l	918.8 ijk	1021.5 f-k	999.4 i-l
IP SC MD3	1049.9 k-n	1124.9 jkl	1174.3 h-k	1073.3 jkl
IP SC RR	1187.8 mn	1222.1 l	1337.9 i-k	1135.8 kl
IP Intr FO	336.3 a-d	332.1a-d	358.4 abc	424.1 abc
IP Intr MD1	397.4 a-f	396.8 a-e	389.1 a-d	472.6 a-e
IP Intr MD2	526.2 b-g	505.3 b-f	443.5 a-e	554.9 a-f
IP Intr MD3	563.4 c-h	679.2 e-i	481.6 a-f	653 b-g
IP Intr RR	647.6 e-i	766.7 f-i	599.2 a-g	655 b-h
CV (%)	14.8	14	25.5	14.3
F value	0.016	0.001	0.001	0.043

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $p \leq 0.05$ *FC= flat cultivation, TR= tied ridges, IP= infiltration pits. CV=coefficient of variation SC = sole crop, Int= intercropping of pearl millet and groundnut, CV= coefficient of variation. FO= zero fertilizer farmers, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rat e, MD3= micro-dose at 75% of recommended rate, RR= recommended rate*

4.6.5 Effect of rain water harvesting practices and fertilizer rates on LER under pearl millet – groundnut intercropping system

The application of rainwater harvesting had no effect on LER except at Ilolo during 2015/2016 where infiltration pits had significantly higher LER values (Table 4.6). However, using of rainwater harvesting practices resulted into relatively higher LER. Application fertilizer at different rates also had no significant effect on LER, however, significant differences were observed only at Ilolo in 2016 season.

Table 4. 6 Effect of rain water harvesting practices on LER under pearl millet – groundnut intercropping system

Factors	Levels	Idifu 2016	Idifu 2017	Ilolo 2016	Ilolo 2017
RWH	FC	1.21 a	1.16 a	1.10 a	0.93 a
	TR	1.43 a	1.11 a	1.21 a	1.15 ab
	IP	1.56 a	1.39 a	1.40 a	1.35 b
	CV (%)	16.10	19.20	9.30	6.80
	P-value	0.28	0.37	0.08	0.01
Fertilizer rates	FO	1.21 a	1.16 a	1.10 a	0.93 a
	MD1	1.35 a	1.31 a	1.31 b	1.26 a
	MD2	1.39 a	1.38 a	1.43 b	1.28 a
	MD3	1.39 a	1.39 a	1.45 b	1.29 a
	RR	1.33 a	1.30 a	1.45 b	1.24 a
	CV (%)	6.8	9.7	5.6	11.7
	P-value	0.212	0.262	0.002	0.06

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $P \leq 0.05$. *FC= flat cultivation, TR= tied ridges, IP= infiltration pits, CV =coefficient of variation FO= zero fertilizer, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rate, MD3= micro-dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation*

The integration of rainwater harvesting and fertilizer rates had significant effects on LER only at Ilolo (Table 4.7). Flat cultivation with zero fertilizer gave the lowest LER (0.9-1.2) while the use of rainwater and fertilizer rate from 25% up to recommended rate increases the values of LER. At Ilolo, application of tied ridges and infiltration pits along with the application of fertilizer micro-dosing from 50% to

75 % had significant effects on LER compared with farmer practice, but the differences were not significant when compared with recommended rate.

Table 4. 7 Effect of integrating rainwater harvesting and fertilizers rates on LER under pearl millet – groundnut intercropping system

Interaction	Idifu 2016	Idifu 2017	Ilolo 2016	Ilolo 2017
FC FO	1.21 a	1.16 a	1.10a	0.93 a
FC MD1	1.35 ab	1.31 a	1.31abc	1.29 ab
FC MD2	1.39 ab	1.38 a	1.43 bc	1.28 ab
FC MD3	1.39 ab	1.39 a	1.45 bc	1.26 ab
FC RR	1.33 ab	1.30 a	1.45 bc	1.24 ab
TR FO	1.43 ab	1.11 a	1.21 ab	1.15 ab
TR MD1	1.58 ab	1.20 a	1.34 abc	1.36 b
TR MD2	1.65 ab	1.20 a	1.40 bc	1.53 b
TR MD3	1.54 ab	1.28 a	1.42 bc	1.46 b
TR RR	1.51 ab	1.28 a	1.44 bc	1.41 b
IP FO	1.56 ab	1.39 a	1.40 bc	1.35 b
IP MD1	1.49 ab	1.33 a	1.48 bc	1.41 b
IP MD2	1.48 ab	1.35 a	1.49 bc	1.49 b
IP MD3	1.54 ab	1.29 a	1.51 c	1.42 b
IP RR	1.50 ab	1.38 a	1.57 c	1.43 b
CV (%)	8.3	13.9	7.0	9.7
F -value	0.571	0.59	0.001	0.001

Means in the same column followed by the same letter are not significantly different according to Tukey’s test at $P \leq 0.05$. *FC= flat cultivation, TR= tied ridges, IP= infiltration pits. FO= zero fertilizer, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rate, D3= micro-dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation*

4.6.6 Cost benefit ratio analysis

The effect of in-situ rain water and soil moisture conservation, cropping systems and fertilizer rates are shown in Table 4.8. Application of tied ridges and infiltration pits had higher values of CBR compared to flat cultivation. In cropping systems, production of pearl millet as a sole crop resulted into higher values of CBR compared to intercropping. Production of groundnut as sole crop and intercropping of pearl millet with groundnut resulted into significantly lower values of CBR, which ranged from 0.47 to 0.84. Furthermore, the use of fertilizers from micro-dose at 25 %

to the recommended rate had significantly lower values of CBR ranging from 0.60 to 0.9 compared to the zero fertilizer treatment with values of 1.1 and 1.3 for Idifu and Ilolo, respectively. It was also observed that, the values of cost benefit ratio decreased with increasing of fertilizer rates.

Table 4. 8 Effect of RWH, cropping system and fertilizer rates on cost benefit ratio

Factors	Levels	CBR DIFU	CBR ILOLO
RWH	FC	0.59 a	0.69 a
	TR	0.67 b	0.72 a
	IP	1.04 c	1.20 b
	CV (%)	2.5	3.3
	F value	0.001	0.001
Cropping systems	Sole PM	1.11 c	1.22 c
	Sole GN	0.75 b	0.84 b
	Intr	0.47 a	0.57 a
	CV (%)	2.5	15.2
	F value	0.001	0.001
Fertilizer rates	ZERO	1.10 e	1.31 d
	MD 25	0.79 d	0.90 c
	MD 50	0.72 c	0.78 b
	MD 75	0.66 b	0.72 ab
	RR	0.60 a	0.66 a
	CV (%)	8.6	10.6
	F value	0.001	0.001

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $P \leq 0.05$. *FC= flat cultivation, TR= tied ridges, IP= infiltration pits. FO= zero fertilizer, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rate, D3= micro-dose at 75% of recommended rate, RR= recommended rate, CV=coefficient of variation*

Integration of RWH, cropping systems and different fertilizer rates had significant effect on benefit cost ratio (BCR) (Figure 4.3). Intercropping of pearl millet and groundnut, and production of pearl millet as sole crop in a flat land with zero fertilizer application, had BCR values less than 1. Also, the use of infiltration pits in sole crop and intercropping system under all levels of fertilizer resulted into significantly lower values of BCR, which ranged from 0.3 to 1.1. The results also showed that, production of pearl millet as a sole crop on flat land with no fertilizer application resulted into higher value of BCR. Intercropping of pearl millet and groundnut both flat cultivation, tied ridges and infiltration pits along with fertilizer at micro-dose rate at 25% of recommended rate to recommended rate had higher values of BCR which ranges from 1.5-2.9.

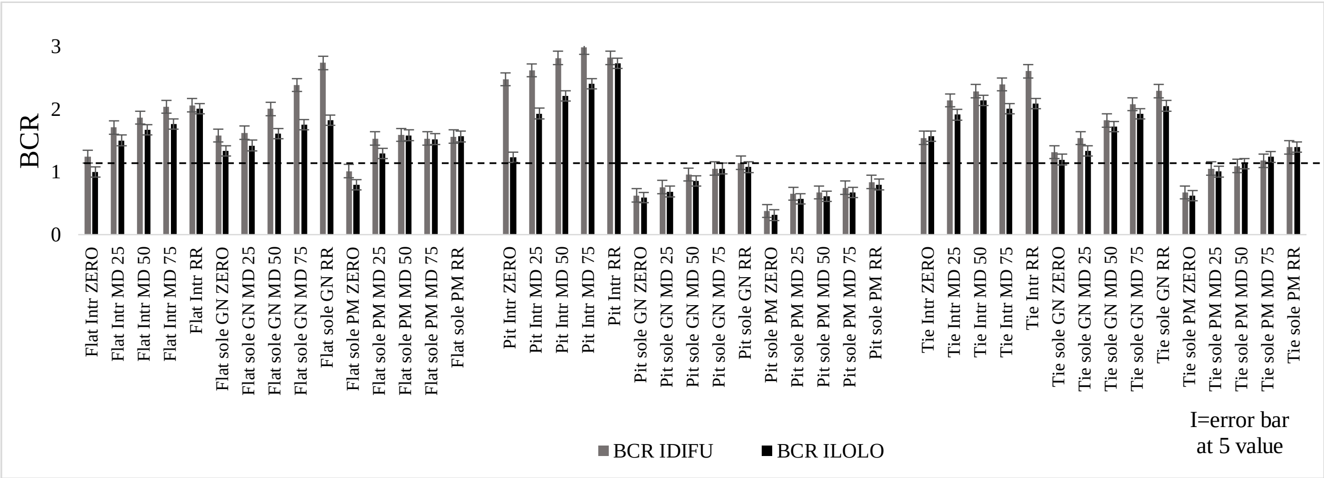

Figure 4. 3: Benefit cost-ratio for integration of the technologies tested

4.6.7 Effect of rainwater harvesting practices, cropping system and fertilizer rates on monetary value of pearl millet and groundnut under intercropping system

Effects of soil moisture conservation practices on monetary value of pearl millet - groundnut intercropping are shown in Table 4.9. Soil moisture conservation practices had significant effects on monetary values of the crops at Ilolo and Idifu only in 2015/2016 cropping season. Application of infiltration pits had higher monetary value (198- 370 USD/ha) compared to flat cultivation and tied ridges at Ilolo in both seasons and at Idifu only in 2015/2016 cropping seasons. It was followed by tied ridges with value ranges from 184 to 318 USD/ha and flat cultivation had the lowest monetary value (154 -229 USD/ha).

There were significant effects in monetary value when pearl millet and groundnut were produced in different cropping systems at both sites in 2015/2016 cropping season (Table 4.9). Production of groundnut as sole crop resulted in the highest monetary value which ranged from 332 to 502 USD/ha. On the other hand, pearl millet in sole crop system had the lowest monetary value ranging from 154 m to 309 USD/ha. Intercropping of pearl millet and groundnut had higher monetary value (328- 433 USD/ha) compared to when pearl millet was produced in a sole crop. Application of fertilizer at micro-dose to recommended rate resulted into significant effects on monetary value ($P \leq 0.001$) (Table 4.9). The highest monetary values ranged from 507 to 619 USD/ha were recorded when fertilizer was used at the recommended rate followed by 452-596 USD/ha at micro-dose at 75% and the lowest values (135-229 USD/ha) form farmer practice. Micro-dose fertilizer application from 25% to 75% of recommended rate had significant effects on monetary value compared to zero application.

Table 4. 9 Effect of rainwater harvesting practices, cropping system and fertilizer rates on monetary value of pearl millet and groundnut under intercropping system

Factors	Levels	Ilolo 2016	Ilolo 2017	Idifu 2016	Idifu 2017
RWH	FC	279.2 a	263.4 a	335.4 a	247.8 a
	TR	342.7 ab	386.6 b	593.5 b	375.0 ab
	IP	496.2 b	539.9 c	646.0 b	484.3 b
	CV (%)	18.9	4.6	16.5	21.4
	F value	0.044	0.001	0.024	0.052
Cropping systems	SCM	129.6 a	192.5 a	160.6 a	113.1 a
	Int	279.2 b	263.4 a	335.4 b	247.8 a
	SGN	509.3 c	527.1 b	463.1 b	512.1 b
	CV (%)	14.7	8.6	18.5	25
	F value	0.001	0.001	0.009	0.006
Fertilizer rates	FO	279.2 a	263.4 a	335.4 a	247.8 a
	MD1	523.9 b	512.3 b	581.9 b	414.0 ab
	MD2	708.1 c	611.6 bc	714.0 bc	653.6 bc
	MD3	855.4 d	676.8 bc	775.9 cd	750.6 c
	RR	913.5 d	748.4 c	879.5 d	771.6 c
	CV (%)	7.0	10.7	8.4	18.3
	F value	0.001	0.001	0.001	0.001

Means in the same column followed by the same letter are not significantly different according to Tukey's test at $p \leq 0.05$ *FC= flat cultivation, TR= tied ridges, IP= infiltration pits. CV=coefficient of variation SM = sole peal millet, SGN=sole groundnut Int= intercropping of pearl millet and groundnut, cv= coefficient of variation. FO= zero fertilizer farmers, MD1= micro-dose at 25% of recommended rate, MD2= micro-dose at 50% of recommended rat e, MD3= micro-dose at 75% of recommended rate, RR= recommended rate*

Interaction effects of soil moisture conservation practices, cropping systems and fertilizer rates on monetary value of pearl millet and groundnut were significant (Figure 4.4). Production of pearl millet as a sole crop under flat cultivation with zero fertilizer application resulted into the lowest monetary value 129.6-192.5 USD/ha and 113.1-160.6 USD/ha for Ilolo and Idifu respectively. The highest monetary values were obtained when pearl millet and groundnut intercropped in an infiltration pit and tied ridges along with application of fertilizer at recommended amount. Pearl millet and groundnut intercropping system under infiltration pits and tied ridges along with application of fertilizer at micro-dose rate from 25% to 75% of recommended rate had significantly higher monetary values in both locations compared to farmers practices (FC SCM FO).

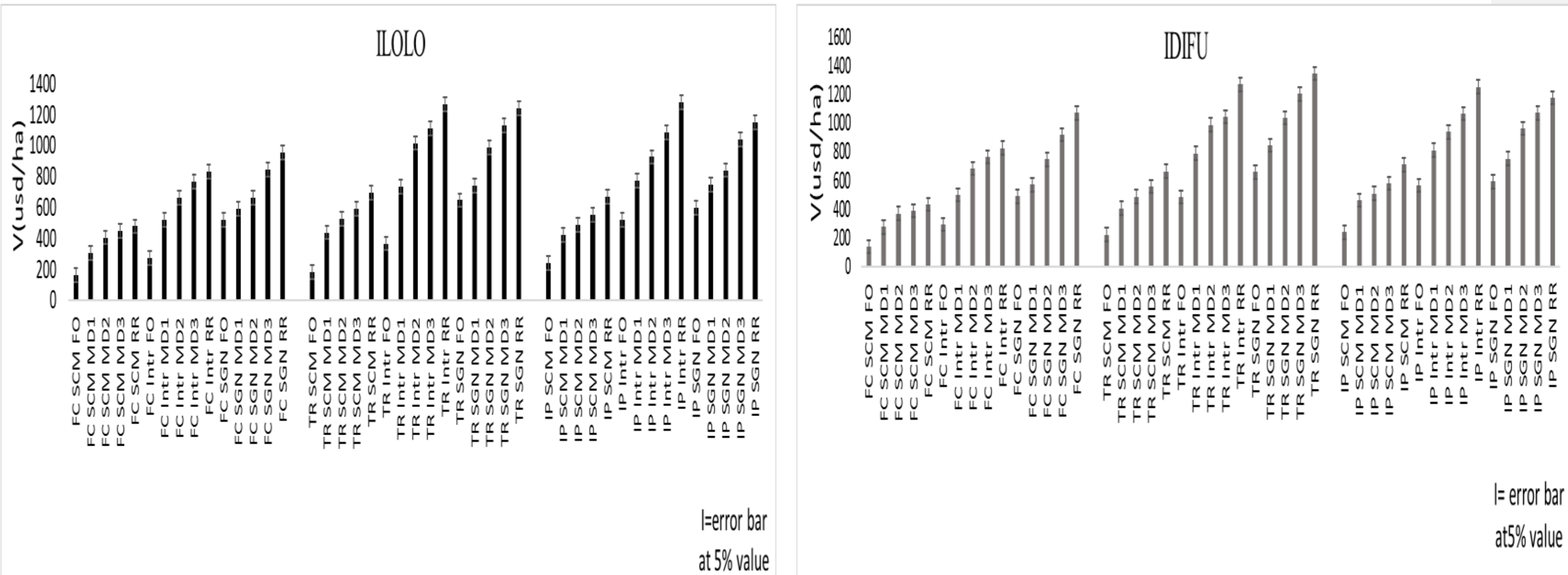

Figure 4. 4: Interaction effects of soil moisture conservation practices, cropping systems and fertilizer rates on monetary value of pearl millet and groundnut

4.7 Discussion

4.7.1 Soils and weather condition

The soils at both sites were sand clay loam with very low total nitrogen and exchangeable phosphorous (P) Low nitrogen content could be due to little or no fertilizer use in their production systems and off season grazing activities in these areas, which resulted into reduction of organic matter in the field. The deficiency of P in the soils could have been due to unavailability of inherent soil P, fixation of P by aluminum, iron, or calcium as the soil is acidic (Table 4.1) and poor management of on-farm organic and inorganic P resources in the soil (Cerozi and Fitzsimmons, 2016). Both sites had an acidic soil which is slightly below the range of 6.5-7 required for groundnut production (Thilakarathna *et al.*, 2014). In such soil, the application of lime will favor crop productivity as it will allow fixed amount of nutrient mainly phosphorus to be available in the soil solution. (Goulding, 2016 and Rastija *et al.*, 2014).

The amount of rainfall was also low and its distribution was very poor in both experimental sites (Figure 4.1). This could be due to environmental degradation mainly by deforestation. Larger part of the area has bare soils in dry season with very few grasslands vegetation and few scattered trees due to deforestation (Chu *et al.*, 2015), unlike other tropical areas which mostly covered with forests with high amount of rainfall. Increasing deforestation reduces the natural recycling of moisture from soils, through vegetation, and into the atmosphere, from where it returns as rainfall (Spracklen and Garcia-Carreras, 2015; Bagley *et al.*, 2014; Oliveira *et al.*, 2013). When forests are interfered with human activities like crop production and livestock keeping as in these areas, water recycling process changes, leading to reduced atmospheric humidity and potentially suppressing precipitation.

4.4.2 Effect of *in-situ* rainwater harvesting and fertilizer rates on soil moisture conservation and yield

In situ rain water harvesting and soil moisture conservation practices by using tied ridges and infiltration pits showed potential on the short-term conservation of moisture in the soil. Infiltration pits and tied ridges improved soil moisture by 23% and 39%vol respectively, within 15 -30 cm soil depth in 2 days period after rain compared to flat cultivation. In 10 days after rain, tied ridges and infiltration pits improved soil moisture by 62% to 101% vol compared to flat cultivation. Therefore, the strategies of in situ rainwater harvesting using technologies such as tied ridges and infiltration pits are vital for soil moisture conservation in semi-arid areas. It was also observed by Kilasara *et al*. (2015) and Yoseph (2014) that, in-situ rainwater harvesting improved moisture in the soil and increase crop productivity. Tied ridges and infiltration pits have structures, that enable harvesting of rainwater and temporary storage. This increases the duration of water/moisture to be available in the soil compared to flat cultivation where much water is lost by runoff. These structures also increased infiltration and percolation of rain water, which both improved moisture status of the soil resulting into higher grain yields than flat cultivation (Table 4.2). These results are similar with findings by Demoz (2016) and Gebreyesus *et al*. (2006), which showed potential of using of tied ridges as it can improve soil moisture and yield by 40% and 25%, respectively compared to traditional tillage practice.

The significant increase in pearl millet yield from fertilizer micro-dose and recommended rates indicated the importance of applying fertilizer under the low soil nitrogen and phosphorus. Production of pearl millet and groundnut in sole crop had better yield compared to when intercropped by groundnut. This is due to interactions and resources competition effects created by intercrop. For intercropped groundnuts, the yield is much smaller compared to sole groundnut and this is due to spacing as the intercropped groundnut spacing is dictated by main crop (pearl millet). Although production of these crops as a sole crop had better yield. Intercropping of these crops is important in crop diversification for soil improvement, avoidance of risk of total crop failure, food and income security especially in semi-arid areas. Integration of tied ridges and infiltration pit with fertilizer application at small rates in millet-groundnut intercropping system are very good strategy of overcoming the problems of declining soil fertility and drought stresses in dry prone areas.

4.7.3 Monetary value of pearl millet and groundnut crops

The monetary value of crops highly depends on quantity of yield harvested and the market price of each crop. The monetary value of pearl millet and groundnut were significantly influenced by soil moisture management practices, cropping systems and fertilizer application rates. Production of pearl millet in sole crop under a flat land with zero application of fertilizer which is typically farmer practice had the lowest monetary value (Fig 4.3). The application of in-situ rain water harvesting practices (tied ridges and infiltration pits) and use of fertilizer in peal millet and groundnut intercropping system showed potential in increasing monetary value compared to farmers practices. The highest monetary value was obtained when pearl millet and groundnut were intercropped on tied ridges and infiltration pit along with application of fertilizer at recommended amount. The higher monetary values observed is a result of higher yield of both crops compared to farmers practice which is caused by availability of growth resources (nutrients and soil moisture) attributed to applied technologies. The market price of pearl millet is low (600-1000 Tsh/kg) compared to market price of groundnut (2000-3500 Tsh/kg). Therefore, the production of pearl millet alone will have resulted into famers selling their produce at low price. By intercropping, farmers can earn more financial benefits due to high groundnut price. Thus, production of groundnut which is primarily cultivated for sale (cash crop) and pearl millet basically grown for food in an intercropping system has a potential to increase monetary value compared to production of pearl millet in sole crop.

4.7.4 Land use efficiency in pearl millet and groundnut intercropping system

The efficiency land use in an intercropping system is measured by the land equivalent ratio (LER). It is the sum of the ratio of yields in sole crop and intercrop of the component crops. Higher values of LER above 1.0 indicate that intercropping system was more efficient on land utilization than sole crop system ((Dariush *et al.*, 2006; Berhanu *et al.*, 2016). In this study, the LER ranged from 1.23 to 1.78 which imply that intercropping of pearl millet and groundnut had higher land productivity than when it was produced as a sole crop. The use of tied ridges and infiltration pits along with application of fertilizer from micro dose rate at 25% of the recommended rate to recommended rate had higher LER than famers practices. Maximization of land use efficiency to 1.6 -1.78 under intercropping system was a result of nutrient availability and soil moisture conservation through rainwater harvesting practices and fertilizer use. The addition of 10 and 20 kg P/ha in the form of DAP at planting increased LER, indicating the importance of applying N as starter dose and P for root development and enhanced nitrogen fixation in low soil N and P. Therefore, pearl millet-groundnut intercropping under inter-row rainwater harvesting and fertilizer use increases land use efficiency and would reduce land use conflict between farmers and pastoralists (Zhang *et al*., 2015).

4.8 Conclusions and Recommendations

The fertility status of the soil in the experimental sites was generally very low and this necessitated use of fertilizer in crop production. The sites had low and erratic rainfall, which pose a big challenge of moisture stress and drought condition. The use of rainwater harvesting practices such as tied ridges and infiltration pits should be encouraged in this area as they are capable of harvesting rain water and conserve soil moisture, increase water infiltration while reducing run-off and soil erosion compared to flat cultivation. Intercropping of millet and groundnut had better land utilization efficiency compared to when produced as sole crops. Intercropping of millet and groundnut under tied ridges and infiltration pits along with micro dose rate from 25% to recommended rate had significantly higher monetary value than when pearl millet produced as sole crop in flat cultivation with zero fertilizer application. The use of intercropping system along with tied ridge and infiltration pits with micro dose at 25% is therefore the best strategy for improving crop and land productivity in the semi-arid areas. This strategy is recommended to semi-arid areas to increase farmer's food and income security.

4.9 References

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CHAPTER FIVE

5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 General Conclusions

The fertility status of the soils in the experimental sites was generally very poor and this makes increasing of fertilizer use to be very important in crop production. The sites had low and erratic rainfall, this posed a big challenge of moisture stress and drought condition. Based on the findings of this study, it is concluded that, application of tied ridges and infiltration pits increased pearl millet and groundnut yields significantly compared to flat cultivation. Application of micro dose fertilizer from 25% to 75% of the recommended rate for pearl millet and from 50% to 75% of the recommended rate for groundnut, increased grain and kernel yields significantly compared to zero application. Integration of tied ridges and flat cultivation with micro dose at 25% of recommended rate had a pearl millet yield advantage ranging from 537 to 959 kg/ha and 295 to 455 kg/ha respectively, compared to farmer practice and both resulted into positive net profit. Flat cultivation with zero fertilizer application resulted in the lowest groundnut yield and had a negative net profit. The integration of tied ridges and fertilizer micro dose at 50% of the recommended rate had significantly higher kernel yield ranging from 906 to 1,197 kg/ha and higher net profit ranging from 424 to 558 USD/ha compared to farmer practice. Tied ridges and infiltration pits conserved soil moisture by 38% and 45%, respectively, more than flat cultivation at 30 cm depth after ten days of rainfall. Land use efficiency was 93% - 157% higher in intercropping system than in sole crop. Intercropping of pearl millet and groundnut along with tied ridges and infiltration pits with micro dose rates from 25% to 75% of recommended rate had financial return of 648-998 USD/ha higher than sole pearl millet in flat cultivation with no fertilizer application.

5.2 Recommendations

1. The study therefore recommends the use of inorganic fertilizer at micro-dose rate at 25% of recommended rate (15 kg N/ha and 10 kg P_2O_5/ha) along with TR or FC for increased grain yield and net profit, instead of using flat cultivation with no fertilizer use (farmers practice). The practice is recommended to resource poor farmers for increased pearl millet productivity at affordable fertilizer input, and hence improved livelihood and food security.

2. The study also recommends the use of tied ridges and application of inorganic fertilizer at micro-dose rate of 50% of recommended rate (22.5 kg P_2O_5/ha) for small holder groundnut farmers located in semi-arid areas of central Tanzania. This will enable farmers to achieve high economic and agronomic performances using affordable input compared to farmer practices. This recommendation will transmute negative thinking of most farmers on the use of inorganic fertilizers and encourage them to adopt tied ridges with micro-dose technologies, and finally recommend rate for improved groundnut productivity.

3. Intercropping of pearl millet and groundnut is also recommended as it increase land use efficiency, soil fertility and crop productivity, food and

income security to small holder farmers located in the semi-arid areas of Dodoma.

4. Further innovative research should be done on coming up with tool/ implements for infiltration pits preparation. This will reduce the cost in terms of time and capital that farmer can spend during infiltration pit preparation.

5. The government should formulate policy on fertilizer packaging materials and fertilizer distribution channels to local areas. The policy should specify the packaging materials to include lower amount such as of 5 kg, 10 kg and 15 kg and 20 kg fertilizer packages. This will help produces to purchase as per their demands compared to current situation where farmers are forced to buy fertilizer at only 25 kg and 50 kg packages.