ENVIRONMENTAL PERFORMANCE OF SMALLHOLDER ORGANIC AND CONVENTIONAL COTTON PRODUCTION SYSTEMS IN MEATU, TANZANIA

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EXTENDED ABSTRACT

Cotton *(Gossypium hirsutum* L.) is among the most important export crops in Tanzania, contributing directly to peoples' livelihood and economic development. Cotton is grown under both conventional and organic farming systems and both farming systems are characterised by low cotton yield. Low fertilizer input use and low fertility contributes to such low yields. A quick solution to address the low cotton yield seems to be enhanced use of fertilizer and pesticide, which is also challenging on how to simultaneously sustain natural resources conservation and the supply of cotton fibre. Inappropriate use of fertilizer is linked to increased greenhouse gases (GHG) emissions. One of these gases is nitrous oxide (N_2O), and nearly 2/3 of the anthropogenic N_2O emission originates from agricultural activities. However, there are limited studies involving in-situ measurement of N_2O in smllhoder farming systems in Sub-Saharan Africa. The use of organic and synthetic fertilizers and pesticides can also change the soil environment and hence microbial activity and soil quality. To address the problem of low cotton productivity, adequate information on the soil status and its suitability for cotton production is important. However, availability and acquisition of such information related to soil qualities in the study area is limited.

This study was undertaken for two growing seasons in semi arid cotton growing areas in Meatu, Simiyu region, Tanzania. This study aimed to generate soil information, characterise and evaluate suitability of soils in these areas in terms of their qualities for cotton cultivation; compare yield and economic performance of cotton in response to different soil fertility and pest management practices under low input small holder conventional and organic production systems; compare microbial activity as a proxy for soil quality and quantifying N_2O emission from soil under different smallholder organic and conventional cotton production practices.

To characterise the soils, four pedons were characterized namely Biore-P1 in Mwamishali village, Ng'ho-P1 in Nghoboko village, IT-P1 in Sanga Itinje village and MWAB-P1 in Mwabagalu village. Soil samples from the pedons' horizons were analyzed for physico-chemical properties and were classified according to the USDA Soil Taxonomy and the World Reference Base for Soil Resources. The soil suitability for cotton production was evaluated by using most limiting criteria approach.

A field experiment was set to test performance indicators (yield, economic benefit microbial activity and GHG emission) for fertility and pest management practice in organic and conventional farming systems. For fertility management, the recommended and current farming practices (30 kg N ha^{-1} and 3 Mg farm yard manura (FYM) ha^{-1}) were tested against high input scenario (60 kg N ha^{-1} and 5 Mg FYM ha^{-1}) and alternative practices (30 kg N ha^{-1} + 3 Mg ha^{-1} FMY and 3 Mg ha^{-1} FMY + legume intercrop) for conventional and organic cotton production, respectively. For pest management in conventional and organic treatments, respectively, the current practice (3 sprays of synthetic pesticide and pyrthrum spray as needed after scouting), higher rate (6 sprays of synthetic pesticide and pyrethrum spray as needed after scouting) and alternative practice (3 sprays neem + cow urine and spray of Neem + cow urine as needed after scouting) were tested.

Seed cotton yield, cost, revenue and gross margin for each treatment was measured to estimate yield and economic performance. For GHG emission, in-situ measurement of N_2O emission from soil was done using static chambers technique and gas analysis by gas chromatography (GC). For microbial activity, enzyme activity (arylsalfatase), potential nitrification, basal respiration and birch effect for plots under current practice, recommended practice, high input scenario and alternative practices were tested against a no fertilizer and no pesticide control treatment.

The results on soil site suitability show that soil moisture and temperature regimes in all study areas were ustic and isohyperthermic respectively. Except for Mwabagalu, which had very deep pedon (> 150 cm), all the other pedons had moderate deep and well drained soils. For Mwamishali and Ng'hoboko $CaCO_3$ concretions were observed, which is a characteristic of calcic horizon in subsoil. Soil texture was sandy clay throughout all pedons with top soil pH ranging from neutral to strongly alkaline (pH 7.05 - 9.54). In all areas pH increased with depth from topsoil to subsoil. The organic carbon content was low to medium while total N concentrations were very low; CEC and exchangeable bases ranged from low (19 and 10.1 cmol $_{(+)}$ kg^{-1}) to medium (37 and 38.4 cmol $_{(+)}$ kg^{-1}) repectively. According to the USDA Soil Taxonomy the soils at Mwamishali and Ng'hoboko were classified as Pachic Calciustolls, while that of Sanga-Itinje and Mwabagalu were Typic Rhodustalfs and Sodic Haplusterts, respectively. All the soils were rated as marginally suitable for cotton production due to soil fertility limitations and therfore, sustainable cotton production in these areas would need interventions for soil fertility and soil moisture conservation improvement.

The results on yield and economic performance showed that, for the current farming practice, organic and conventional farming practice had no significant difference in yield. The seed cotton yield in current organic practice was 1.4 and 0.64 Mg ha^{-1} compared to the conventional practice with yield of 1.3 and 0.37 Mg ha^{-1} for season 1 and 2 respectively. The current organic farming practice had higher gross margin of USD 527 and 137 ha^{-1} compared to the conventional practice with gross margin of USD 321.2 and -74.9 ha^{-1} for

season 1 and 2 respectively. However, at higher input rate (fertilizer and pesticide) conventional cotton had significantly higher yield of 1.8 and 0.51 Mg ha^{-1}) than organic practice with seed cotton yield of 1.4 and 0.39 Mg ha^{-1} for season 1 and 2, respectively. The high input conventional cotton had relatively lower gross margin of USD 463 and -85.9 ha^{-1} compared to the organic practice with gross margin of USD 477 and -81.3 ha^{-1} for season 1 and 2, respectively. For organic cotton practice the alternative practices (intercropping cotton with green gram) had lower cotton yield of 1.3 Mg ha^{-1} in season 1 than the alternative conventional (1.7 Mg ha^{-1}) but had higher gross margin (USD 616.2 ha^{-1}) than conventional (USD 476 ha^{-1}) as a result of additional revenue from green gram. For conventional cotton the alternative practice of combining inorganic fertilizer and manure outperformed the current practice by having both better yield and gross margin. In the season with less rainfall (season 2) the control outperformed all other treatments in terms of economic return indicating the rationale for farmers reluctance in investing on inputs under such conditions.

The results on N_2O emission show that the current organic and conventional cotton farming practices had similar ($p < 0.05$) cumulative area-scaled N_2O emission. However, yield-scaled emissions were significantly higher in conventional than organic farming systems. For the high input scenario conventional cotton had higher area-scaled and yield-scaled N_2O emission than organic cotton in season 1 which received higher rainfall (759 mm) but not in season 2 which had less rainfall (522 mm). A combination of manure and inorganic fertilizer as alternative practice reduced yield-scale N_2O emission by 17% from inorganic fertilizer. In season 1, intercropping cotton with legumes reduced area-scaled emission by 27%. The emission factor for both conventional and organic systems were < 1% of applied total N. Although the cummulative N_2O emission varied between season 1 (0.24 and 0.31 kg N_2O-N ha^{-1}) and season 2 (0.52 and 0.60 kg N_2O-N ha^{-1}), results show

that the current smallholder organic and conventional cotton farming practices had similar soil N_2O emission, which is very low compared to reported emissions from cotton fields in high input farming system (0.78 - 10.6 kg N_2O-N ha^{-1}).

The results also revealed no significant ($P<0.05$) difference in microbial activity between organic and conventional cotton production practices using the current levels of fertilizer and pesticide. However, increasing N level as synthetic fertilizer or manure increased microbial activity. Manure fertilizer combination as an integrated practice increased arylsulfatase activity and potential nitrification but relatively reduced basal respiration in conventional farming in both seasons. Intercropping green gram increased microbial activity (arylsulfatase) but reduced potential nitrification and basal respiration and hence had no clear trend on improving soil microbial activity. Pest management had no effect in microbial activity in both organic and conventional farming practice and there was no significant difference between organic and conventional.

The major conclusions drawn from this study are that, all the soils were rated as marginally suitable for cotton production due to soil fertility limitations and hence sustainable cotton production in these areas would need interventions for soil fertility improvement. For the existing smallholder farming system in Meatu, Tanzania, organic and conventional cotton system have similar agronomic and economic perfromance. Increasing input level in conventional cotton would have higher yield with low economic return than organic. Combining manure and inorganic fertilizer as well as intercropping cotton with grain legumes has potential for increasing yields while reducing the risk of increased N_2O emission from cotton fields and improving microbial activity and hence soil quality. Under the prevailing semi-arid conditions, smallholder farmers are rational on limited use of fertilizer and pesticide.

Based on these conclusions it is recommended that alternative practice of cotton-legume intercrop, fertilizer-manure combination and pest control by neem and cow urine mixture are viable farming practices for smallholder cotton farmers. Further studies on the effect of cotton-legume intercrop on soil microbial activity that include other legume species are recommended. Further studies that include higher input levels and higher sampling frequencies for GHG are also recommended.

DECLARATION

I, **Thomas Nestory Bwana**, do hereby declare to the Senate of the Sokoine University of Agriculture that this thesis is my original work, done within the period of registration and that it has neither been submitted nor been concurrently submitted for a higher degree award in any other Institution.

Thomas Nestory Bwana Date
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In memory of my mother Maria Bwana and my mother in law Tabu Kimolo. Moms, "Success is no accident" all what is happening now is a result of the strong foundation you laid. You didn't work for recognition, but your work worth to be recognised.

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AAS	Atomic absorption spectrophotometer
ANOVA	Analysis of variance
ASA	Arylsulfatase activity
AU	Aarhus University
BCR	Benefit cost ratio
BD	Bulk density
BR	Basal Respiration
BS	Base saturation
C/N ratio	Carbon to nitrogen ratio
CAADP	Comprehensive Africa Agriculture Development Programme
$CaCO_3$	Calcium carbonate
CBA	Cost benefit analysis
CEC	Cation exchange capacity
CH_4	Methane
CIA	Chemical index of alteration
cmol $_{(+)}$ kg^{-1}	Centimol per kg
CO_2	Carbon dioxide
CV	Coefficient of variation
DANIDA	Danish International Development Agency
DAP	Di-ammonium phosphate
DAS	Days after sowing
DFC	DANIDA felolowship centre
DMRT	Duncan’s Multiple Range Test
DTPA	Diethylyene triamine penta-acetic acid

EC	Electrical conductivity
ED-XRF	Energy dispersive x-ray fluorescence spectrometer
EF	Emission factor
ESP	Exchangeable sodium percentage
et al.	and others
FAO	Food and Agricultural Organization of the United
FC	Field capacity
FYM	Farm yard manure
GC	Gas chromatography
GHG	Greenhouse gas
GM	Gross margin
GMO	Genetically modified organisms
GPS	Global positioning system
IFDC	International Fertilizer Development Centre
IFOAM	International Federation of Organic Agriculture Movements
IGR	Insect growth regulator
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IT-P1	Itinje profile/pedon 1
kg ha^{-1}	Kilograms per hectare
kPa	Kilopascals
LUP	Land use plan
Mg ha^{-1}	Megagrams per hectare
MPa	Megapascals
MWAB-P1	Mwabagalu profile/pedon 1
N	Nitrogen

N_2O	Nitrous oxide
NBSS	National Beural of Soil Survey (India)
Ng'ho-P1	Ng'hoboko profile/pedon 1
NH_4^+	Ammonium
NH_4OAc	Ammonium acetate
NO	Nitric oxide/Nitrogen monoxide
NO_2^- g^{-1} dw h^{-1}	Nitrite per gram dry weight per hectare
NO_2^-	Nitrite
NO_3^-	Nitrate
NP g^{-1} dw h^{-1}	Nitrophenol per gram dry weight per hectare
NP	*p*-nitrophenol
NPS	*p*-nitrophenyl sulphate
OC	Organic carbon
OECD	Organisation for Economic Co-operation and Development
P.W.P	Permanent wilting point
PD	Particle density
pH	Negative logarithm of hydrogen ion activity
PhD	Doctor of philosophy
PN	Potential nitrification
SAT	Saturation
SCOPA	Sustainable Cotton Production for Africa
SCR	Silt/clay ratio
SLM	Simple limitation method
SMR	Soil moisture regime
SSA	Sub-Saharan Africa
STR	Soil temperature regime

SUA	Sokoine University of Agriculture
TCB	Tanzania Cotton Board
TEB	Total exchangeable bases
TN	Total nitrogen
TVC	Total variable cost
UNCTAP	United Nations Conference on Trade and Development
URT	United Republic of Tanzania
USD	United States Dollar
USDA	United States Department of Agriculture
VWC	Volumetric water content
WFPS	Water filled pore space
WRB	World Reference Base
XRF	X-Ray fluorescence spectrometry

CHAPTER ONE

1 INTRODUCTION

1.1 Background Information

In Tanzania, cotton *(Gossypium hirsutum L.*) is among the most important cash crops for export and provision of employment to over 500 000 rural households (TCB, 2010). The production of cotton is either under organic or conventional farming practices. The major cotton producing regions are Simiyu, Shinyanga, Mwanza, and Geita, with Simiyu region producing over 40% of the national output. The cotton production is dominated by smallholder farmers characterised by small fields with an average of 1.5 hectares, manual operation under rain-fed conditions with minimal use of inputs such as fertilisers and pesticides. The average cotton yields in Tanzania (560 to 750 kg of seed cotton per hectare) is very low compared to the Africa and World averages of 1.2 and 1.7 Mg ha^{-1}, respectively (UNCTAP, 2011). This low yield is associated, among others, with soil degradation and insufficient use of fertilizer and pesticides (TCB, 2010).

To improve the cotton yield, the government has initiatives that targeted at increasing cotton productivity from 750 kg ha^{-1} of seed cotton (260 kg ha^{-1} of lint) in 2008/09 to 1 500 kg ha^{-1} (520 kg ha^{-1} of lint) in 2014/15. Strategies for achieving this target include application of at least 2 insecticide sprays per growing season, enhanced use of fertilizer and improved cotton varieties (TCB, 2010). However, extensive use of inputs (fertilizers and pesticides) in these strategies may also be associated with negative environmental burden such as nutrient losses or eutrophication, biodiversity loss, greenhouse gas (GHG) emissions, soil acidification, energy use and land degradation (Gomiero *et al.,* 2011). With these facts at hand, farming practices that would improve yield while having better environmental and economic performance are desirable. The farming practices should ensure appropriate and efficient use of inputs by increasing productivity whilst protecting valuable resources. Such practices would include organic farming practices and integrated farming systems.

1.2 Cotton Production Systems in Tanzania

In an agro-ecosystem, soil functions are influenced by farming practices which change the soil environment and associated functions. Such practices include use of organic and synthetic/conventional fertilisers and pesticides. Both conventional and organic farming are practiced in Tanzania, where conventional farming practice dominates by contributing nearly 95% of the total production while the organic practice contribute the remaining 5% (TCB, 2010). The two farming practices are differentiated mainly by fertility and pest management practices but they are both characterised by low yield. In any case, organic and conventional farming systems can both be used with or without harmful effects to the environment, depending on the farming practices (Lori *et al.*, 2017). Understanding the management practices involved in the farming system is of great importance towards achieving sustainable farming systems.

1.3 Conventional Cotton Production

The conventional cropping system is based on the use of synthetic fertilizer and pesticides (Pimentel *et al.*, 2005). The majority of the cotton producing farmers in Tanzania practices the conventional system. However, most of the smallholder farmers who practice the conventional production system use little or no fertilizer but they appreciably use pesticides. With regard to fertilizer, recommended rates for cotton vary from soil to soil. IFDC (2014) reported a general national recommended rate of 40 kg ha^{-1} N and P, while Mowo *et al.* (1993) indicated an application rate of 20 to 30 kg N ha^{-1}, 10 - 15 kg P ha^{-1} and 5 Mg FYM ha^{-1} for the western Tanzania cotton growing areas. For the case of pesticide use, though no specific literature for national recommendation was found, the recommendations are based on the pesticide manufacturers' guide which indicated up to 6 sprays per growing season.

1.4 Organic Cotton Production

Organic agriculture refers to the farming system that enhance productivity through maximizing the efficient use of local resources, while foregoing the use of synthetic agrochemicals, genetically modified organisms (GMO), and synthetic compounds used as food additives (Gold, 2007). In recent years, organic cotton production in Tanzania has picked up. In the season 2009/10, for example, Tanzania produced 2635 tons of organic cotton lint, which placed the country at 5th position among the world's leading organic cotton producers (Textile Exchange, 2010). Organic cotton production is practised in some areas in the western cotton growing areas, like Meatu and Maswa, in Simiyu region and in Singida. The production is still project-based where farmers enter production contracts with private companies. The contracting company provides organic seeds and bio-pesticides and offers training and extension services. In return, it is entitled to purchase the entire crop. The organic cotton production practices for nutrient management includes use of FYM, crop rotation and intercropping with legumes. For pest management the practices include trap crops (intercropping with sunflower), crop rotation and use of organic pesticides (neem and pyrethrum). However, there is no information on agronomic and environmental performance of these practices.

1.5 Performance of Cotton Farming Practices

1.5.1 Yield and economic benefit

The average cotton yields in Tanzania vary between 560 to 750 kg of seed cotton per hectare. This low yield is mainly associated with factors such as rain-fed growing conditions, use of low-yield varieties and insufficient use of fertilizer and pesticides (TCB, 2010). To improve the yield, the government has initiatives that targeted at increasing cotton productivity from 750 kg ha^{-1} of seed cotton (260 kg ha^{-1} of lint) in 2008/09 to 1 500 kg ha^{-1} (520 kg ha^{-1} of lint) in 2014/15 (TCB, 2010). These initatives include enhanced use of fertilizer, pesticides and improved seeds.

Among agricultural practices, organic farming practices are perceived to be more beneficial to the environment than conventional farming because chemical fertilizers, insecticides and herbicides, are avoided (Lorenz and Lal, 2016). However, it remains unclear whether this also applies to yields and economic performance for crops grown under smallholder production systems in sub-Saharan Africa (SSA). Some authors argue that organic farming systems have lower yields than conventional farming and hence not able to meet the world's growing food demands (de Ponti *et al.*, 2012). They also argue that the system is associated with low labor productivity, high production risks and high costs due to organic certification (Borlaug, 2000; Trewavas, 2001; Nelson *et al.*, 2004; Makita, 2012). However, others argue that under good management, yield from organic can be similar to or more than that of conventional farming (Cavigelli *et al.*, 2009; Seufert *et al.*, 2012).

Most studies that compare yields between organic and conventional farming practices have been done mainly in high input farming systems in temperate countries (Rosenstock *et al.*, 2013), leaving a wide data gap for tropical and subtropical conditions. This, therefore, advocated for farming systems comparison in SSA to provide the information necessary for recommendations of sustainable cotton production in the region (Richards *et al.*, 2016). On the other hand, agronomic data like yield provides only technical information necessary for determination of technical optimum. However, farmers' choice on technologies does not depend mainly on significant differences in yield but also on economic analysis that shows which treatment is more beneficial than others. It is therefore important to compliment the agronomic data with market information necessary for the establishment of economic optimum.

1.5.2 Green house gases (N_2O) emission from agricultural soils

Globally, agricultural practices play an important role in the production and/or consumption of green house gases (GHG) that contribute substantially to the dynamics of global warming. Agriculture accounts for 10 -12% of global total anthropogenic emissions of GHGs, of which it accounts for about 5% of CO_2 , about all of CH_4 and up to two thirds of N_2O emissions (IPCC, 2007). Nitrous oxide (N_2O) is a potent GHG with global warming potential 265 times that of CO_2, and almost 2/3 of the global anthropogenic N_2O emissions come from agricultural activities (Myhre *et al.*, 2013).

Government strategies to address the problem of low cotton yield and increase cotton productivity to 1.5 Mg ha^{-1} include, among others, intensive use of fertilizers for nutrient management (TCB, 2010). But such farming practices may affect soil nutrient availability as well as soil environmental conditions, both of which directly affect the exchange of GHG between terrestrial systems and the atmosphere (Smith *et al.*, 2007). Specifically, nitrogen fertilization is a key regulating factor for soil nitrogen and carbon dynamics and the associated exchange of N_2O with the atmosphere (Adviento-Borbe *et al.*, 2007; Mutegi *et al.*, 2010). The use of excess synthetic N fertilizers is the dominating source of N_2O emissions from agricultural soils (IPCC, 2007). Nitrous oxide emission in soils occurs during both biological nitrification and denitrification (Figure 1-1), and during chemical denitrification.

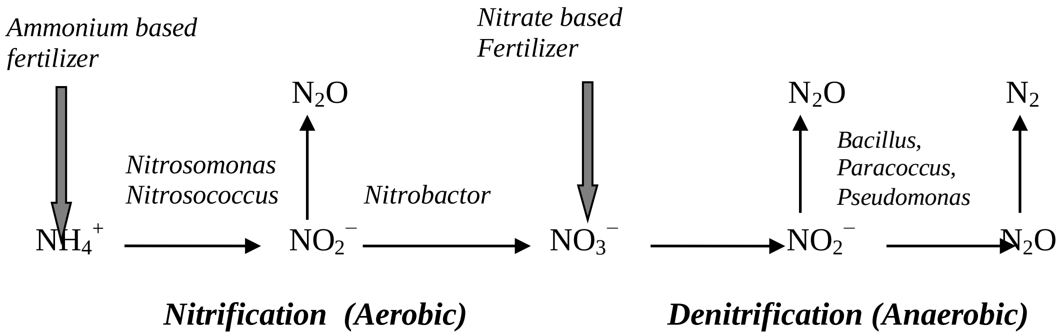

Figure 1-1: Processes for N_2O production in Agricultural soils

In agricultural soils, N_2O is primarily produced as a byproduct during nitrification, which converts ammonium (NH_4^+) to NO_3^-, and denitrification, which converts NO_3^- to N_2 and these processes can occur simultaneously in soil (Verhoeven *et al.*, 2017). Soil moisture determines which process occurs and how much N_2O is emitted from the soil as it controls oxgen supply and microbial activity. During periods of high microbial activity, soil oxygen is consumed, leading to an increase in N_2O production from nitrification (Zhu *et al.*, 2013). Denitrifiers also consume NO_3^- when soil moisture is very high (Firestone and Davidson, 1989). Fertilizer-derived nitrate is reduced to N_2O under flooded/anaerobic soil environment, producing N_2O as a byproduct as described in figure 1-1. Since agricultural GHG emissions contribute significantly to global warming, environmental and farming management strategies have to integrate best practices that reduces emission from agricultural lands.

Some studies have reported lower area-scaled N_2O emissions from organic than conventional farming (Syvasalo *et al.*, 2006; Kustermann *et al.*, 2008) and higher yield-scaled emissions from organic farming (Skinner *et al.*, 2014). Studies in France showed higher N_2O emissions from conventional than from organic crop rotations (Mathieu *et al.*, 2006; Petersen *et al.*, 2006). The lower N_2O emission level in organic is linked to the lower N input in soils under organic management compared to those under conventional management (Muller and Aubert, 2014). Other findings indicated that organic farms had higher emission than conventional farms (Wood *et al.*, 2006; Kustermann *et al.*, 2008) while others did not find any difference (Syvasalo *et al.*, 2006). The different results were associated with the geographical variations, type and scale of the farming system, level of inputs use and other management practices (Skinner *et al.*, 2014).

As already stated, most of these studies have been done only in developed countries with temperate climate and intensive organic and/or synthetic fertilizer use (Villanueva-Rey *et al.*, 2014; Meier *et al.*, 2015). Moreover, there is scanty information available from Africa, where only few studies have measured N_2O from conventional maize (Hickman *et al.*, 2015; Brümmer *et al.*, 2008; Gütlein *et al.*, 2018) and other cropping systems (Albanito *et al.*, 2017; Pelster *et al.*, 2017). Lack of N_2O flux data from developing countries has also dictated the IPCC GHG calculators to rely on models calibrated from measurements conducted under temperate, developed country conditions (Rosenstock *et al.*, 2013). This is challenging as the calculators may overestimate emissions in tropical developing countries, hence a strong need to broaden the scope of the underlying data to the tropics has been articulated (Richards *et al.*, 2016). However, some meta-analyses have indicated that current emission factors may also apply in tropical conditions (Albanito *et al.*, 2017).

In view of the need for increasing cotton yields, good farming practices that maximizes cotton productivity while keeping down GHG emissions are required. Though, organic farming practices are perceived to be more beneficial to the environment than conventional farming practices (Lorenz and Lal, 2016), it remains unclear whether this applies to GHG emissions from smallholder cotton production systems in SSA. The high level of heterogeneity of measured N_2O emissions among studies, and the lack of information addressing conventional and organic cotton production systems in smallholder farming systems, calls for further studies.

1.5.3 Microbial activity

Microbial activity in soil comprises all biochemical reactions catalysed by microorganisms. Microorganisms drive many fundamental processes and services in the soil, and respond quickly to natural and environmental stress (Barrios, 2007). This allows the use of microbial population and activity as an indicator of changes in soil quality (Kennedy and Smith, 1995; Pankhurst *et al.,* 1995) and determinant of productivity of soil and agricultural land (van der Heijden *et al.,* 2008). Measurements of microbial activity in soils are based on the presence of intact and active microbial cells that reflect the physiological state of microbial cells (Alef and Nannipieri, 1995). In this light, determination of soil microbial activity provides a better way of determining sustainable agricultural production practice. Currently, there is a range of methods available to measure microbial biomass and microbial activity in soils including basal respiration, enzyme activity and potential nitrification/ammonia oxidation.

1.5.3.1 Enzyme activity

Enzymes are catalysts in different reactions during carbon and nutrient cycling in soil (Balota *et al.,* 2004; Sicardi *et al.,* 2004), and also represent the metabolic level of the soil microbial community. Enzymes may be free in soil as exo-enzymes excreted by plants, animals, and mainly microorganisms (Weaver *et al.*, 1994), linked to cell structures or internally in cells, but later released to the soil after cell lysis and death (Badiane *et al.,* 2001). When the soil microbal community is affected by land use and management, changes in soil enzyme activities are also expected (Nayak *et al.,* 2007). Soil enzyme activity is a sensitive indicator of alteration of soil quality by management (Balota *et al.*, 2004), and arylsulfatase activity is among the good indicators of microbial activity (Li and Sarah, 2003). Comparing organic and conventional farming practices, some studies found that soil microbial activity and biomass was significantly greater in organic compared with conventional practices (Araújo *et al.*, 2009). Manured soils were found to have significantly greater concentrations of enzymes than un-manured soils (Czurak-Dainard, 2005).

1.5.3.2 Potential nitrification

Nitrogen undergoes a variety of microbial transformations in the soil, including the nitrification process, in which microbial conversion of ammonia to nitrite and nitrate occurs. Nitrification plays a key role in the regulation of soil N dynamics in relation to leaching and gaseous losses (Subbarao *et al.*, 2006). Furthermore, ammonia oxidizing bacteria (mediating the transformation of ammonia to nitrite) are known as sensitive indicator organisms that may respond rapidly to environmental and chemical disturbances (Sims *et al.*, 2013). In that respect, potential net nitrification is often used as an indicator of nitrogen availability in ecosystems (Bai *et al.*, 2010).

1.5.3.3 Basal respiration

Soil respiration results from several sources, including microbial respiration, plant root and faunal respiration; dissolution of carbonates in soil solution with microbial respiration being the major source. The metabolic activities of soil microorganisms can be quantified by measuring the CO_2 production (Nannipieri *et al.*, 1990). Soil respiration describes the level of microbial activity and reflects the capacity of soil to support soil life. Microbial processes are important for the management of farming system and improvement of soil quality. Microbial respiration of soil can therefore be used as a soil quality indicator

(Brendecke *et al.,* 1993) and it is one important variable to quantify soil microbial activity (Alef, 1995).

Higher soil respiration has been reported in soil under organic farming practice than conventional (Araujo *et al.,* 2009; Zhen *et al.,* 2014; Ren *et al.,* 2017) due to significant increase in amount of exogenous source of labile organic matter to the soil and the consequent stimulation of heterotrophic microorganisms (Saffigna *et al.,* 1989; Zhen *et al.,* 2014). However, some studies have reported decreased soil respiration in organic manure application compared to inorganic fertilizer, when soil total nitrogen was less than $1.0\,\mathrm{g\,kg^{-1}}$ (Ren *et al.,* 2017). Other studies also found no difference in soil respiration between organic and conventional treatments (Edesi *et al.,* 2013). This implies that conclusion from these results depends on variations in local parameters such as type of amendments, rates of application, soil and climatic characteristics, which indicates the need for case by case consideration.

1.5.3.4 Birch effect

In an arid and seasonally dry ecosystem like in Meatu and other cotton growing areas of Tanzania, seasonal rainfalls which fall after a long dry period causes rewetting pulses that causes high CO_2 flux (Wang *et al.*, 2015). This phenomenon, referred to as "Birch effect" (Birch, 1958; Fraser, 2016), is linked to the immediate release of microbial osmolytes upon rewetting and/or rapid metabolism of organic substrates released after disruption of soil structure (Unger *et al.*, 2010; Moyano *et al.,* 2013). Soil fertility management practices influences soil edaphic and biotic factors which upon rewetting have effects on the CO_2 flux. Since the rate of the CO_2 flux upon rewetting relates to the active organic pool in the soil (Franzluebbers *et al.*, 2000) and hence fertility management practice, the

"Birch effect" can be used as an indicator of the performance of a given farming practice and a useful indicator of soil quality (Marumoto *et al.,* 1982; Sparling *et al.,* 1995).

1.6 Characterization of Soils in Cotton Growing areas in Meatu, Tanzania

The productivity and sustainability of cotton production in the cotton growing areas depend on inherent ability of soils to supply nutrients and maintain soil physical conditions necessary for optimal cotton yields. Improvement of cotton yield and sustainability of cotton production in the areas would therefore involve, among others, proper soil fertility management practices. Adequate information and good knowledge of the soil resource and its suitability for cotton is important for proper soil fertility management and sustainable cotton production. Soil characterization is therefore important as it provides information on soil properties which is key to sustainable use of soil resources (Msanya *et al.,* 2003). For crop production soil characterization can further provide insight on the suitability of soil for production of specific crop such as cotton because climatic and soil-site parameters play significant role on crop yield (Sehgal, 1991). Soil-site suitability classification is useful because some land attributes (soil, climate and topography) can be suitable for specific crops but unsuitable for others (Amara Denis *et al.,* 2016).

Like in the other part of the country, soil and other land resources information in cotton growing areas of Meatu are still unknown in terms of their properties (Msanya *et al.,* 2016), and suitability and/or limitations for sustainable cotton production. There is a wide gap between needed pedological soil characterization and actual soil information available. This situation is challenging the management and sustainable cotton production because proper choice of appropriate soil and water management systems depends on the understanding of the type and fertility status of soil. Through pedological characterisation, a clear understanding on soil genesis, morphology, classification and spatial distribution of soils in an area is generated so as to sustainably manage soil resource and/or plan for land uses. With these facts at hand, characterisation and evaluation of the soils in the area is crucial to provide necessary information and knowledge for proper decision making on best management options for economic and sustainable crop production (Msanya *et al.*, 2016).

1.7 Problem Statement and Justification

Sustainable cotton production would need proper management strategies which should be supported by adequate soil/land resources information and information on the performance of the farming practices in use. Like in other areas in SSA, such information in the cotton growing areas of Meatu are still unknown in terms of their properties and suitability for cotton production. This makes proper management plan for sustainable cotton production difficult. On the other hand, little is known on the performance of the existing farming systems. Though organic farming is perceived to be more beneficial to the environment than conventional farming, it remains unclear whether this applies to smallholder cotton production systems. There are limited studies on performance of cotton farming system in low input farming systems in SSA. There is also no specific information in the cotton growing areas of Tanzania.

Existing studies were done in high input farming system and are inconsistent, and hence application of such information may be misleading. For the case of GHG, the IPCC greenhouse gas calculators rely on data from high input farming systems in temperate climate which may overestimates emission from low input farming systems in developing countries as the data generated are from high input farming systems. Studies on specific environmental indicators have shown different and inconsistent results where benefits have also been observed in conventional farming. In Europe, Gosling and Shepherd (2005), found lower soil organic matter (SOM) content in organic than conventional systems. Potential for conventional farming to achieve similar or higher SOM levels was reported by Tuomisto *et al.* (2012).

For GHG emission, in Australia, Wood *et al.* (2006) concluded higher GHG emissions from organic than conventional farms while in Switzerland other workers (Leifeld and Fuhrer, 2005; Flessa *et al.,* 2002) observed less GHG emissions in organic farming. In Finland, Syvasalo *et al.* (2006) could not find any difference in emissions of N_2O and CH_4 between the systems. For the case of microbial activity, although there are a lot of information that show the relation between soil management and microbial activities, very little is known about these effects under tropical/subtropical smallholder farming conditions. The variation of microbial response to organic and conventional management depend on local parameters like type of amendments, rates of application, soil and climatic characteristics, and hence dictates the need for site-specific studies.

Apart from the inconclusive findings, most studies have only been done in developed countries with temperate climate and intensive input use (Villanueva-Rey *et al.,* 2014; Meier *et al.,* 2015), leaving a knowledge gap for low input smallholder farms in tropical climate like in Tanzania. There is also scanty information regionally where only few studies have been done (Hickman *et al.,* 2015). The high level of heterogeneity among studies and lack of information that addresses specific type and scale of the farming system advocates for further studies. The study reported herein, quantified GHG emission, microbial activities, and yield and economic performance of the smallholder farming system to provide scientific information necessary for recommendation of best management options.

1.8 Objectives

1.8.1 Overall objective

To establish best cotton farming practices for smallholder farmers in cotton growing areas of Meatu, Tanzania, that maximize yield and economic benefit at minimum environmental cost.

1.8.2 Specific objectives

i. To determine the Soil-site suitability for cotton production.
ii. To determine yield and economic benefit of cotton grown under different scenarios of soil fertility and pest management in conventional and organic production systems.
iii. To quantify the GHG emissions from soils under organic and conventional cotton farming systems.
iv. To determine the effect of pesticide and nutrient management practices on microbial activities in soils under organic and conventional cotton production systems.

1.9 Outline of the Dissertation

Chapter 1: This chapter covers the general introduction providing theoretical background information of the study, justification and objective of the study.

Chapter 2: This chapter covers pedological characterization and evaluation of the suitability of the study site for cotton production. The chapter covers soil morphology, physical and chemical characteristics, soil classification and rating the factors with respect to its quality for cotton production. A draft paper for this chapter, Bwana, T. N., Msanya, B. M., Amuri, N. A. and Semu, E. Pedological Characterization and Soil-site suitability assessment for cotton production in the cotton Growing areas of Meatu District, Tanzania has been prepared.

Chapter 3: This chapter covers assessment of the yield and economic performance of cotton under smallholder organic and conventional farming practices. A draft paper for this chapter, Bwana, T. N., Amuri, N., Semu, E., Olesen, J. E., Baha, M., Henningsen, A. and Hella, J. Yield and profitability of cotton grown under smallholder organic and conventional cotton farming systems in Tanzania has been submitted as a chapter in a book on -Climate Impacts on Agricultural and Natural Resource Sustainability in Africa-Springer Publisher.

Chapter 4 covers assessment of greenhouse gas emission from soils under organic and conventional farming systems. A draft paper, for this chapter, Bwana, T. N., Amuri, N., Semu, E., Elsgaard, L., Butterbach-Bahl, K., Pelster, D. and Olesen, J. E. Nitrous oxide emission from soils under smallholder organic and conventional cotton farming systems in Tanzania. to be submitted to the *Journal of Plant Nutrition and Soil Science* has been prepared.

Chapter 5 presents assessment of microbial activity in soils under organic and conventional farming systems. A draft paper Bwana, T. N., Amuri, N., Semu, E., Elsagard, L. and Olesen, J. E. Effect farming practices on microbial activities in soils under smallholder organic and conventional cotton farming systems in Tanzania, to be submitted to the *Applied Soil Ecology* journal has been prepared.

Chapter 6 is the general conclusions and recommendations. In this chapter key issues are concluded in relation to soil suitability for cotton production, yield response, economic benefit and environmental benefit on the farming systems.

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CHAPTER TWO

2 SOIL-SITE SUITABILITY FOR COTTON PRODUCTION IN MEATU, TANZANIA

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2.1 Abstract

Low cotton yield in semi-arid cotton growing areas of Tanzania is associated among others with low soil fertility. The current study was undertaken in the semi-arid cotton growing areas of Meatu, Simiyu Region, Tanzania. The study aimed to generate soil information by characterising and evaluating suitability of soils in terms of their qualities for cotton production. Four pedons representing major cotton growing soils namely BioRe-P1, Ng'ho-P1, IT-P1 and MWAB-P1 were characterized. Soil samples from generic soil horizons were analyzed for physico-chemical properties and soils were classified according to the USDA Soil Taxonomy and the World Reference Base (WRB) for Soil Resources. Soil suitability for cotton production was evaluated using *"the most limiting criteria approach"*. Results show that soil moisture and temperature regimes in the study areas were ustic and isohyperthermic, respectively. Except for MWAB-P1 which had very deep soil (> 150 cm), all the other pedons had moderate deep soils. $CaCO_3$ concretions characteristic of calcic horizon were observed in the subsoils of Pedons Biore-P1 and Ng'ho-P1. Soil texture was dominantly clayey throughout all studied pedons whereas soil reaction ranged from neutral to strongly alkaline (pH 7.05 - 9.54). Organic carbon content was generally low to medium (0.66-1.56 %) while the total N levels were very low to low (0.09 - 0.2%). CEC ranged from 26.6 to 37 cmol$_{(+)}$kg^{-1} which is rated as high to very high. For exchangeable bases, magnesium was medium to high (1.57 - 3.62 cmol$_{(+)}$kg $^{-1}$), potassium high to very high (1.27 - 2.26 cmol$_{(+)}$kg $^{-1}$) and sodium low to high (0.1 - 0.96 cmol$_{(+)}$kg $^{-1}$). According to USDA Soil Taxonomy, pedons BioRe-P1 and Ng'ho-P1 were classified as Pachic Calciustolls, while pedons IT-P1 and MWAB-P1 were respectively, Typic Rhodustalfs and Sodic Haplusterts. All studied soils were rated as marginally suitable for cotton production due to soil physical properties and fertility limitations. Sustainable cotton production in these areas would therefore need interventions for soil fertility improvement.

Keywords: Pedological characterization, land suitability, cotton production, physico-chemical properties, soil classification, Tanzania

2.2 Introduction

In Tanzania, cotton (*Gossypium hirsutum L.*) is among the most important cash crops for national export and provision of employment to over 500 000 rural households (Tanzania Cotton Board - TCB, 2010). Cotton production is dominated by smallholder farmers characterized by small fields with an average of 1.5 hectares, manual operation, rain-fed conditions with minimal use of inputs, such as fertilizers and pesticides. The average cotton yields in Tanzania is very low (0.56 to 0.75 Mg of seed cotton per hectare) compared to Africa and World averages of 1.2 and 1.7 Mg ha^{-1}, respectively (UNCTAP, 2011). This low yield is associated among others to soil degradation and insufficient use of fertilizer and pesticides (Tanzania Cotton Board - TCB, 2010).

The productivity and sustainability of cotton production in the cotton growing area depends on inherent ability of soils to supply nutrients and maintenance of soil physical conditions to optimize cotton yields. Improvement of cotton yield and sustainability of cotton production in the area would therefore involve among others, proper soil fertility management practices. Adequate information and good knowledge of the soil resource and its suitability for cotton is important for proper soil fertility management and sustainable cotton production. Soil characterization is therefore important as it provides information on soil properties for sustainable use and management of soil resources (Msanya *et al.*, 2003). For crop production, soil characterization can further provide insight on the suitability of soil for production of specific crop such as cotton because climatic and soil-site parameters play significant role on crop yield (Sehgal, 1991). Soil-site suitability classification is useful because some land attributes (soil, climate and topographic) can be suitable for specific crops but unsuitable for others (Amara Denis *et al.*, 2016). However, like in the larger part of the country, soil and other land resources information in cotton growing areas of Meatu are still unknown in terms of their properties and suitability and/or limitations for sustainable cotton production (Msanya *et al.,* 2016).

There is a wide gap between needed pedological information and actual soil information available. This situation poses a big challenge in management and sustainable cotton production because proper choice of appropriate soil and water management systems depends on the understanding of the type and fertility status of soil (Karuma *et al.,* 2014). With these facts at hand, characterization and evaluation of the soils in the area is crucial to provide necessary information and knowledge for proper decision making on best management options for economic and sustainable crop production (Msanya *et al.,* 2016).

The current study was done in the cotton growing areas of Meatu, to characterize and evaluate the suitability of the soils for cotton production so as to provide soil information necessary for establishment of sustainable cotton management practices. To achieve this the soils morphological characteristics, physico-chemical properties, classification and soil suitability evaluation was done.

2.3 Materials and Methods

2.3.1 Description of the study sites

The study was conducted in Meatu District, Simiyu Region. The area is between latitudes 3°- 4° South and longitudes 34° 8’ - 34° 49’ East at altitude of 1 000-1 500 m above mean sea level. Crop production and livestock keeping are the major economic activities where cotton is the major cash crop (URT, 2013). The study was done in four villages Mwamishali, Ng'hoboko, Sanga Itinje and Mwabagalu with their locations as indicated in Table 2-2 and in the location map of the study area (Figure 2-1).

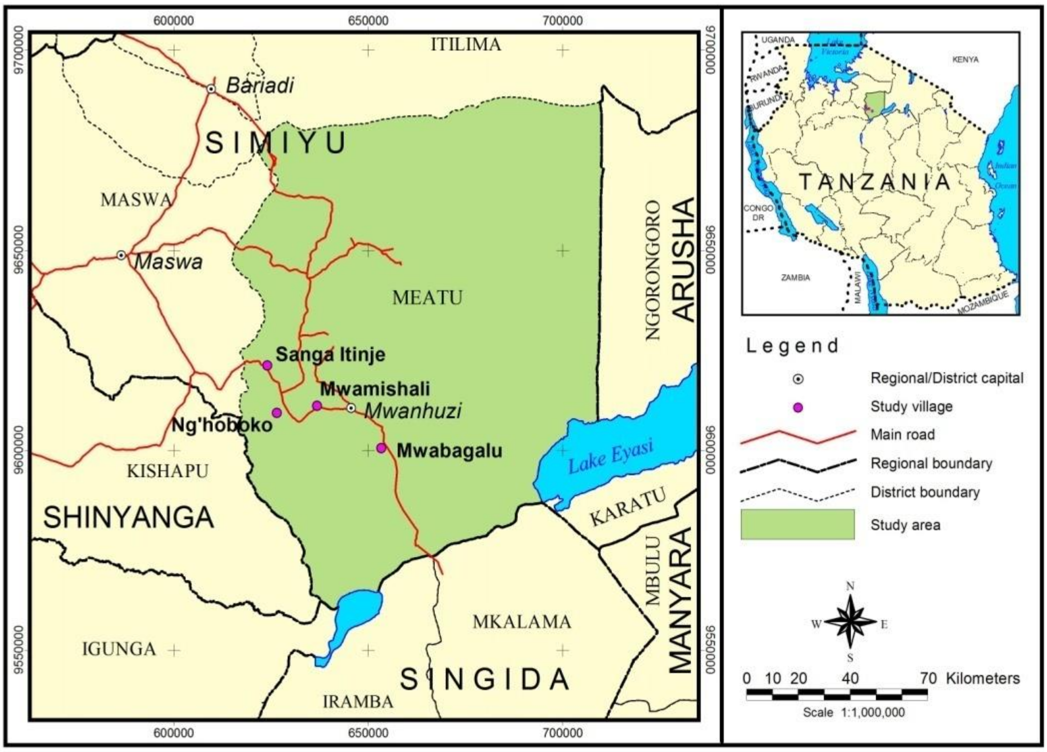

Figure 2-1: Location map of the study sites in Meatu District, Smiyu Region, Tanzania

2.3.2 Weather

The area is within the semi-arid zone, with total annual rainfall ranging from 400 mm in the north to 900 mm per year in the south. During the study period, the annual rainfall recorded at Mwamishali village (BioRe-P1) was 759 mm in 2015/16 and 522 mm in 2016/17 (Table 2-1) which were above and below the long term average of 688 mm per year for Meatu District (Kabote *et al*., 2013). The specific rainfall range for Mwamishali, Ng'hoboko and Sanga Itinje is 650 - 700 mm while for Mwabagalu is 600 - 650 mm (URT, 1997). The rain season starts in November and ends in June with intra-season dry spells (Figure 2-2).

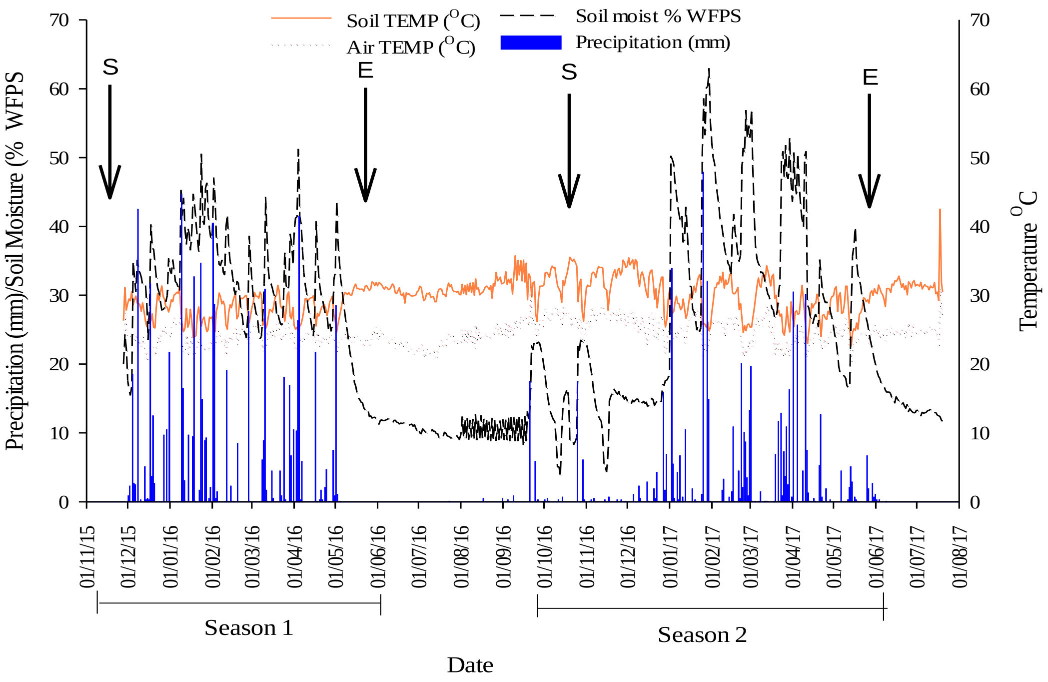

Figure 2-2: Variation in rainfall, soil moisture (% water filled pore spaces-WFPS), soil temperature (Soil TEMP) and air temperature (Air TEMP) during the experiment period for season -1(Nov 2015 to June 2016) and season 2 (Nov 2016 to June 2017).

Note: Arrows shows the start (S) and end (E) of the rain season.

Table 2-1: Summary of mean daily values for weather parameters at the experiment site, Mwamishali village, Meatu District, Simiyu Region, Tanzania

		RH (%)	Temp. (°C)	Precipitation (mm)	Solar radiation (W/m^2)	Soil Moisture m^3/m^3 (VWC)	WFPS$^{\neq}$ %	Soil temp. (°C)
Season 1	Mean	71	23.8		247.09	0.11	32.4	28.0
	min	23	20.7	0	210.59	0.05	15.3	23.8
	Max	103	27.4	45	339.3	0.18	51.3	31.5
	Total			759				
Season 2	Mean	54	24.6		258.70	0.11	32.7	29.4
	min	39	20.4	0	225.53	0.05	13.8	22.6
	Max	75	28.5	48.0	438.23	0.21	63.0	35.5
	Total			522				

$^{\neq}$WFPS = Water Filled Pore Space

2.3.3 Fieldwork

Transect walks and auger observations were done to establish representative sites for detailed profile description. The FAO guidelines for soil description (FAO, 2014) were then used to describe landforms, elevation, slope gradient, parent material, vegetation and land use and crops of the selected sites. Soil morphological characteristics (colour, texture, consistence, structure, porosity and effective soil depths) were described according to FAO guidelines for soil description (FAO, 2014). Four representative soil profile pits at each selected site were excavated to depths of 115 to 130 cm and geo-referenced using Global Positioning System (GPS) model GARMIN *etrex* 20. Disturbed soil samples were collected from each of the soil horizons whereas undisturbed soil samples (core samples) were collected from three sections of the profile (0 - 5 cm, 45 - 50 cm and 95 - 100 cm) for laboratory analysis. Soil colours were determined using soil colour chart (Munsell Color Co., 1992). Soil penetration resistance was determined by pocket cone penetrometer (Bradford, 1986) using Daiki Rika Kogyo penetrometer Model DIK-5551. The obtained penetrometer resistance values were then compared to the critical value of 2 MPa that have been adopted as a critical value for plant growth (Taylor *et al.*, 1966; Pabin et al., 1998; Hazelton and Murphy, 2007; Whalley *et al.*, 2007; Soil Science Division Staff, 2017). The site characteristics are as shown in Table 2-2.

Table 2-2: Site characteristics of the studied pedons in Meatu District, Simiyu Region, Tanzania

Attributes	Description			
	Mwamishali (BioRe - P1)	Ng'hoboko (Ng'ho-P1)	Sanga Itinje (IT-P1)	Mwabagalu (MWAB-P1)
Coordinates	03° 31′ 04.2″ S 034° 13′ 55.3″ E	03° 32′ 0.92″ S 034° 08′ 18.8″ E	03° 25′ 36.6″ S 034° 06′ 59.6″ E	03° 36′ 45.7″ S 034° 22′ 49.9″ E
Altitude (m.a.s.l)	1186	1179	1153	1153
Landform	Plain (plateau)	Plain (plateau)	Plain (peneplain), termite mound	Mbuga (closed basin)
Geology/ Lithology	Insitu weathered material	Insitu weathered material	Insitu weathered material	Insitu wethered material.
Slope %	< 1	1	5	<1
Land use / vegetation	Agriculture (cotton, maize, sorghum, greengram), settlement, charcoal burning	Agriculture (cotton, maize, sorghum, greengram), settlement, charcoal burning	Agriculture (maize, sunflower, sorghum cotton), settlement.	Agriculture (cotton, maize, sunflower, sorghum), settlement
Natural vegetation	*Acacia spp.*	*Acacia spp.*	Baobab, *Acacia spp.*	*Acacia spp.*
Natural drainage.	Moderately well drained	Somewhat to moderately well drained	Excessively well drained	Somewhat poorly drained
Flooding	None	None	None	None
Erosion	wind erosion in some period of the year	sheet/interill	slight sheet/interill	slight sheet/interill
Mean annual rainfall (mm)	650 - 700 mm	650 - 700 mm	650 - 700 mm	600 - 650 mm
SMR*	Ustic	Ustic	Ustic	Ustic
Mean annual temperature	30°C	30°C	30°C	30°C
STR≠	Isohyperthermic	Isohyperthermic	Isohyperthermic	Isohyperthermic

*SMR = soil moisture regime, ≠STR = soil temperature regime

2.3.4 Soils and physiography

As indicated in Table 2-2, the landforms at pedons BioRe-P1 (Mwamishali), Ng'ho-P1 (Ng'hoboko) and IT-P1 (Sanga Itinje) were characterized as plains (plateaux) while at pedon MWAB-P1 (Mwabagalu) the landform was described as mbuga (closed basin). Elevation ranged from 1 153 m at pedon MWAB-P1 to 1 186 m above mean sea level at BioRe-P1. The soils at Mwamishali, Ng'hoboko and Sanga Itinje were well drained, those at Mwabagalu were somewhat poorly drained. The lithology across the study sites was described as in-situ weathered materials developed from gneisses and granites of the basement complex (URT, 1997).

2.3.5 Laboratory analysis of soil samples

Bulk density, porosity and moisture retention characteristics were determined using undisturbed samples collected using core rings. Bulk density was determined by the core method (Blake and Hartge, 1986). Soil moisture characteristics were determined using sand kaolin box for low suction values and pressure plate apparatus for higher suction values (NSS, 1990) at TARI Mlingano laboratory facilities. Disturbed soil samples for chemical and physical properties were air dried, ground and sieved through a 2- mm sieve. Particle size distribution was determined by hydrometer method (Day, 1965), after dispersing soil with sodium hexametaphosphate, and textural classes determined using the USDA textural triangle (Soil Survey Staff, 2014).

Soil pH in water and 1M $CaCl_2$ was measured potentiometrically using a soil:water and soil: $CaCl_2$ ratio of 1:2.5 weight to volume basis and electrical conductivity was determined by potentiometric method (Okalebo *et al.*, 2002). Organic carbon by the Walkely and Black wet oxidation method (Nelson and Sommers, 1986), total nitrogen by Kjeldahl wet digestion-distillation method (Page, 1982), extractable P by Olsen method (Olsen and Sommers, 1986), cation exchange capacity for basic cations (Ca, Mg, K and Na) by NH_4OAc saturation method and micronutrients (Cu, Fe, Zn, Mn) by diethylenetriaminepentaacetic acid (DTPA) method (Thomas, 1986). The total exchangeable bases (TEB) were calculated arithmetically as a sum of the four exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) for a given soil sample. All chemical analyses of soil samples were conducted at Soil Science laboratory at SUA, Morogoro. The C/N ratio was calculated, and the exchangeable sodium percentage (ESP) and base saturation percentage (BS %) were also calculated using the relation ESP = Exchangeable {(Na)/(Ca + Mg + K + Na)} x 100 and . BS% = {(Ca + Mg + K + Na)/(Ca + Mg + K + Na+H+Al)} x 100, respectively (Brady and Weil, 2014). The $CaCO_3$ content in the root zone was estimated based on the field observation of effervescence (bubbles of carbon dioxide gas are produced) after reaction with HCl. The X-Ray Fluorescence Spectrometry (XRF) approach was used to determine the total elemental composition of the soil samples and this anlysis was done at geological survey of Tanzania (GST) laboratory facilities in Dodoma. In preparation of the samples for analysis, 200 g of fine earth soil samples were weighed and open air-dried by using Infrared lamps for two hours. Samples were then ground to particle size $\leq$ 177 µm (75 Mesh) using swing mill pulverizer. The pressed powder without binder technique was used to prepare pellets for XRF analysis (Takahashi, 2015). The elemental oxides were then measured using PANalytical, Minipal 4 Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRF) Model PW4030/45B. For quantification of elemental total Mg and Na, an AAS machine version 208 FS was used. A 0.2 g sample was digested in a mixture of hydrochloric, nitric, perchloric and hydrofluoric acids to near dryness, the salts were then dissolved with hydrochloric acid and made to volume with de-ionised water. The solution was then reheated at low temperature, cooled and then analysed by AAS machine version 208 FS.

2.3.6 Soil classification and suitability for cotton production

Soil classification in the study area was done to the family level of the Soil Taxonomy (Soil Survey Staff, 2014) and to Tier-2 of the WRB for Soil Resources (FAO, 2014). Soil suitability for cotton production was done using FAO guidelines for land evaluation (FAO, 1976) and the soil-site suitability criteria for cotton production (NBSS and LUP, 1994) as shown in Table 2 - 3. Based on obtained information on topography, soil and climate the simple limitation method (SLM) for land evaluation (Sys *et al.,* 1991) was used to evaluate the land suitability class for cotton. In this method, the most limiting characteristics is considered as an index for that land unit for a specific utilization type.

The relations among different soil characteristics are ignored and no combination of different characteristics is considered (Sharififar *et al.,* 2016).

Table 2-3: Soil-site suitability criteria (crop requirements) for cotton production according to NBSS and LUP (1994)

Soil-site characteristics			Rating			
Attributes		Unit	Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N)
Climate regime	Mean temperature in growing season	°C	20 - 30	31 - 35	<19 >35	-
	Mean max. temp. in growing season	°C	-	-	>36	-
	Mean min temp in growing season	°C	-	-	<l9	-
	Mean RH in growing; season	%	60 - 90	-		
	Total rainfall	mm	700 - 1000	500 - 700 1000 - 1250	<500 >1250	-
	Rainfall in growing season	mm	600 - 950	450 - 600	<450	-
Land quality	Land characteristics					
Moisture availability	Length of growing period	days	180 - 240	120 - 180	< 120	
	AWC	mm/m	200 - 250	125 - 200	50 - 125	<50
Oxygen availability to roots	Soil drainage	Class	Well to moderately well drained	Imperfectly drained	Poor Somewhat excessively drained	Stagnant/ Excessively drained
	Water logging in growing season	Days	1 - 2	2 - 3	3 - 5	>5
Nutrient availability	Texture[1]	Class	SiC, C	SiCL, CL	Si, SiL. SC, SCL, L	SL, S, LS
	pH	1:2.5	6.5 - 7.5	7.6 - 8.0	8.1 - 9.0	>9.0
	CEC	cmol (+)/kg	>55	50 - 55	30 - 50	<30
	BS	%	>80	50 - 80	35 - 50	<35
	$CaCO_3$ in root zone	%	<3	3 - 5	5 - 10	10 - 20
	OC	%	>1.00	0.75 - 1 .0	0.50 - 0.75	<0.50
Rooting conditions	Effective soil depth	cm	100 - 150	60 - 100	30 - 60	<30
	Stoniness	%	<15	l5 - 25	25 - 50	50 - 75
	Coarse fragments	vol %	<5	5 - 10	10 - 15	15 - 35
Soil toxicity	Salinity (EC saturation extract)	dS/m	2 - 4	4 - 8	8 - 12	>12
	Sodicity/ (ESP)	%	5 - 10	10 - 20	20 - 30	>30
Erosion	Slope	%	1 - 2	2 - 3	3 - 5	>5

[1] Texture: Si=Silt; C=Clay; C SiC=Silt clay; SiCL=Silt clay loam; CL=Clay loam; SiL=Silt loam; SC=Sandy clay; SCL=Sand Clay Loam, L=Loam; SL=Sandy Loam, S=Sand; Loamy Sand

2.4 Results and Discussion

2.4.1 Soil morphological characteristics

The morphological characteristics of the studied pedons are shown in Table 2-4. The pedons in the three sites Mwamishali, Ng'hoboko and Sanga Itinje are of intermediate depth (< 90 cm) and are well drained while in Mwabagalu the pedon was deep (> 115 cm) and somewhat poorly drained. The top soils of the three sites are sandy clay and sandy clay loam while that of Mwabagalu is clay (Table 2-5).

Table 2-4: Morphological features of representative soil pedons of the study areas in Meatu District, Simiyu Region, Tanzania

Profile	Horizon	Depth (cm)	Field Texture1)	Moist colour2)	Consistence3)	Structure4)	Horizon boundary5)
BioRe-1	Ah	0 - 9	gSC	bl (10 YR 2/1)	vfr, s&p	m.m.cr	gs
	BAw	9 - 50/60	gC	vdg (10 YR 3/1)	fr, s&p	m.c.sbk	aw
	C1k	50/60 - 90	vgL	white (5 YR 8/1)	fr, ns&np	massive	ds
	C2k	90 - 130+	vgL	white (5 YR 8/1)	fr, ns&np	massive	-
Ng'ho-P1	Ap	0 - 10	SC	bl(10YR 2/1)	fr, ss&sp	m.f&m.cr	cs
	BAk	10 - 60/63	gSC	bl(10YR 2/1)	fr, s&p	w.m&c.pr&ws.abk	aw
	Ck	60/63 - 120+	Rock	lg(10YR 7/2)	fr, ns&np	massive	-
IT-P1	Ap	0 - 10	SCL	drb(2.5 YR 2.5/3)	vfr, ss&sp	w.f.cr	cs
	Bts1	10 - 30	SC	drb (2.5 YR 2.5/4)	fr, s&p	w.m&f.sbk	ds
	Bts2	30 - 60	C	dr (2.5 YR 3/6)	fr, s&p	w.m&f.sbk	as
	C	60 - 120+	Rocky	Dusky red (10 R 3/4)	NA	massive	-
MWAB-P1	BAp	0 - 40	C	bl (10 YR 2/1)	fi, vs&vp	m.c.pr&ws.abk	ds
	BA1	40 - 81	C	bl (10 YR 2/1)	fi, vs&vp	m.c.pr&ws.abk	ds
	BA2	81 - 115+	C	bl (10 YR 2/1)	fi, vs&vp	m.c.pr&ws.abk	-

1) Texture: gSC = gravely sandy clay, gC = gravely clay, vgL = very gravely loam, SC = sandy clay, SCL = sandy clay loam, C=clay

2) Colour: bl = black, vdg = very dark grey, lg = light grey, drb = dark reddish brown, dr = dark red,

3) Consistence: vfr = very friable, fr = friable, fi = firm, s = sticky, p= plastic, ss = slightly sticky, sp = slightly plastic, ns = non-sticky, np = non-plastic, NA = not applicable

4) Structure: m.m.cr = moderate medium crumby; m.c.sbk= moderate coarse subangular blocky; m.f&m.cr = moderate fine and medium crumby; w.m&c.pr&ws.abk= weak medium and coarse, prismatic and wedge shaped angular blocky; w.f.cr = weak fine crumby; w.m&f.sbk = weak medium and fine subangular blocky; m.c.pr&ws.abk= moderate coarse, prismatic and wedge shaped angular blocky.

5) Horizon boundary: gs = gradual smooth; aw = abrupt wavy; ds =diffuse smooth; cs = clear smooth; as = abrupt smooth

The overlying subsoils are of varied textures from very gravely loam in Mwamishali (BioRe-P1), rocky in Ng'hoboko (Ng’ho-P1) and Sanga-Itinje (IT-P1) to clay in

Mwabagalu (Mwab-P1). Generally, the topsoil textures of the three profiles are comparable as they have similar parent materials (Table 2-2). These pedons also have friable to very friable consistence which indicates no restriction to root or water movement. However, the clay texture with firm consistence in Mwabagalu indicates restriction to root or water movement. The structures of the pedon at Mwabagalu were moderate coarse, prismatic/wedge-shaped and angular blocky throughout the profile. The observed structures in Mwabagalu soils suggest moderate restriction to root growth and water movement (Lipiec *et al.,* 1993). The structure in the other three pedons ranges from crumby to subangular blocky which promote drainage, aeration and root penetration.

2.4.2 Physical characteristics

Results for soil physical characteristics of the studied pedons are shown in Table 2-5.

2.4.2.1 Soil texture and silt/clay ratio

The soil textures of all the studied pedons were generally clayey throughout the profile. The topsoil texture in pedons BioRe-P1, Ng'ho-P1, IT-P1 and MWAB-P1 were SC, SCL, SC and C, respectively (Table 2-5). In pedon BioRe-P1, Ng'ho-P1 and MWAB-P1, the clay content increased with depth but for pedon IT-P1 there was no regularity in the variation of clay content with depth. Generally, the sand content in all the pedons decreased with soil depth while the silt contents didn't show any regularity with depth and was low throughout the pedons and profile depth compared sand and clay. The higher clay contents in subsoils as compared to topsoils is linked to clay illuviation in the lower horizon (Pal *et al.,* 2003). The results in this study are similar to results by Tenga *et al.* (2018) and Karuma *et al.* (2015) who reported increasing clay content in soils of southern Tanzania and Busia County in Kenya, respectively.

In this study, the silt/clay ratio of the topsoil of pedons BioRe-P1, Ng'ho-P1, IT-P1 and MWAB-P1 had 0.21, to 0.20, 0.15 and 0.31, respectively. The silt/clay ratio is an indicator of soil aging (Costantini *et al.,* 2002) whereby the lower the ratio the more weathered the soil is. The result of this study indicate that, the topsoil for BioRe-P1, Ng'ho-P1, IT-P1 are highly weathered compared to that of MWAB-P1. Except for pedon MWAB-P1, all other pedons had silt/clay ratio in the subsoil lower than topsoil, indicating that the subsoil are more weathered than the topsoils. Unlike the other pedons, MWAB-P1 has less weathered subsoils than topsoils as indicated by the higher silt/clay ratio in the topsoil than subsoil.

2.4.2.2 Soil bulk density and porosity

As indicated in Table 2-5, topsoils of pedons BioRe-P1, Ng'ho-P1, IT-P1 and MWAB-P1 had similar bulk density values i.e. 1.3, 1.3, 1.4 and 1.3 Mg m^{-3}. The similar bulk densities are linked to the fact that all these soils are under the same type of farming practice of cotton production. In all pedons, bulk density increased with profile depth. This is linked to the weight of the overlying layers, lower organic matter contents, less aggregation, and fewer biopores in the subsoils (Brady and Weil, 2014). Unlike bulk density, total porosity generally decreased with depth. Porosity shows an inverse relationship with bulk density as porosity is calculated from the relation between bulk density and particle density of soil (Lal and Shukla, 2004). The higher porosity in topsoils is an indication that topsoils are uncompacted with unrestricted root condition (Brady and Weil, 2014).

2.4.2.3 Penetration resistance

Penetration resistance is an important property used to evaluate the physical quality of cultivated soils, as it indicates the occurrence of problems related to compaction (Moraes, 2014) and exhibits a direct relationship with root growth. The penetration resistance values of the studied pedons are presented in Table 2-5. The topsoil penetrometer readings for

BioRe-P1, Ng'ho-P1 and IT-P1 were 0.3, 0.34, and 0.03 MPa, respectively, which are classified as low (0.1-1 Mpa) while that of MWAB-P1 was 3.7 which is classified as high (2 to < 4 Mpa) (Hazelton and Murphy, 2007). According to this classification, soils with high penetration resistance will impair root growth. The soils in Mwabagalu which are classified as very densely consolidated may restrict growth of many plant roots.

Table 2-5: Selected physical properties of the studied pedons in Meatu District, Simiyu Region, Tanzania

Pedon	Horizon	Depth (cm)	Sand	Clay	Silt	Textural class	Silt/clay ratio	BD Mgm^{-3}	PAW# (mm)	Porosity (%)	PR (MPa)
			%								
BioRe-P1	Ah	0 - 9	54	38	8	SC	0.21	1.3	2.1	61.8	0.30
	BAw	9 - 50/60	54	41	5	SC	0.12	1.4	10.0	54.9	1.64
	C1k	50/60 - 90	49	45	6	SC	0.13	nd	nd	nd	2.40
	C2k	90 - 130+	50	32	18	SCL	0.56	1.4	15.6	45.6	nd
Ng'ho-P1	Ap	0 - 10	58	35	7	SCL	0.2	1.3	2.1	56.5	0.34
	BAk	10 - 60/63	55	42	3	SC	0.07	1.6	6.4	33.0	1.16
	Ck	60/63 - 120+	45	44	11	SC	0.25	1.5	12.0	44.0	2.96
IT-P1	Ap	0 - 10	53	41	6	SC	0.15	1.4	1.7	49.0	0.03
	Bts1	10 - 30	50	45	5	SC	0.11	nd	nd	nd	1.16
	Bts2	30 - 60	44.	47	9	C	0.19	1.2	5.7	53.5	1.64
	C	60 - 120+	44	41	15	C	0.37	nd	nd	nd	3.70
MWAB-P1	BAp	0 - 40	36	49	15	C	0.31	1.3	9.2	63.6	3.70
	BA1	40 - 81	35	51	14	C	0.27	1.7	10.8	51.8	3.70
	BA2	81 - 115+	34	52	14	C	0.27	1.6	7.4	46.8	2.96

\# PAW = Plant available water nd = not determined PR = Penetration resistance
BD = Bulk density

Note:

1. Porosity=(1-(Bulk density/Particle density) x 100) assuming particle density 2.65g/cm3
2. PAW(mm)=1000 [Moisture at FC (m3/m3) - Moisture at PWP (m3/m3) x horizon depth(m)]
3. PR (MPa)=PR(kg/cm^2) x 0.0981
4. Based on penetrometer model: DIK-5551 Japanese (Daiki Rika Kogyo Co. LTD. PR(kg/cm2)=(100 x penetrometer reading(r)/0.7952(40- r)2 where r is in mm

However, this will depend on the soil moisture. Note that the penetrometer resistance test for this study was done when the soils were very dry. In all of the studied pedons, the penetrometer resistance increased with depth. Except for Mwabagalu, in all other pedons the topsoils have loose to medium consolidated resistance which do not affect root growth.

2.4.2.4 Soil moisture characteristics and plant available water (PAW)

Soil moisture retention properties and plant available water of the studied pedons are presented in Figure 2-3 and Table 2-5, respectively.As indicated in Table 2-5, the plant available water in all the pedons increased with soil profile depth. Comparing the four pedons, MWAB-P1 had higher plant available water than the other pedons. This is linked to the fact that fine textured soils hold more water than coarse textured soils. From this study, the texture of MWAB-P1 was finer than the textures of the other pedons.

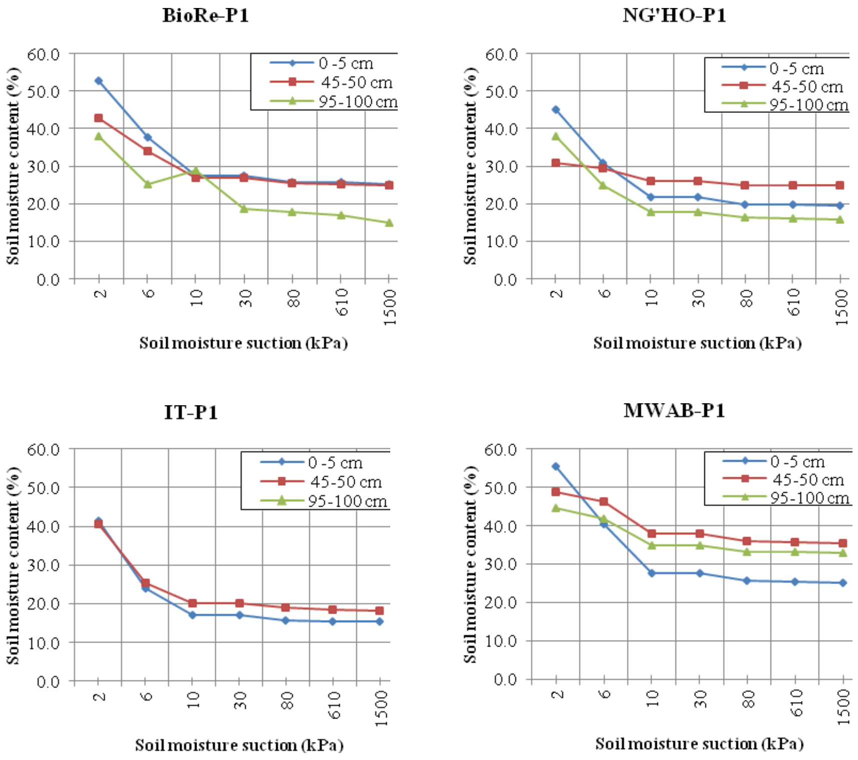

Figure 2-3: Soil moisture retention curves of the studied soils in Meatu District, Simiyu Region, Tanzania

The soil moisture content in all pedons and all profile depth sections decreased with increasing suction pressure (Figure 2-3). The water content decreased sharply between saturation and field capacity and then a steady increase is then observed between field capacity and permanent wilting point. As shown in Figure 2-2, moisture contents for the subsoils in pedons BioRe-P1 and Ng'ho-P1 between FC and PWP were lower than the overlying horizons. This trend is different from what was observed in pedon MWAB-P1 which had higher moisture content in subsoil than topsoil. This may be linked with the the subsoil textures which for BioRe-P1 and Ng'ho-P1 were sand clay while those of pedons MWAB-P1 and IT-P1 were clay.

2.4.3 Chemical properties

The important chemical properties of the studied pedons are present in Table 2-6 and discussed below.

2.4.3.1 Soil pH and electrical conductivity (EC)

The pH values in all the pedons range from 7.05 to 9.54 which are rated as neutral to very strongly alkaline (Msanya *et al.*, 2001). Although cotton grows in a wide pH range (5 - 9.5), the soil pH values in the top soil of all the studied pedons except IT-P1 were above the optimal pH ranges (5.8 - 8) for cotton production (OECD, 2008). Electrical conductivity (EC), a measure of salinity in the soil is shown in Table 2 - 6. The EC values of all the studied soils are very low (< 1.2 dS/m) and optimum for cotton growth because cotton is tolerant to salinity with critical salinity levels above 7.0 dS/m (Msanya *et al.*, 2001).

2.4.3.2 Soil organic carbon, total nitrogen and C:N ratio

The topsoil organic carbon (OC) content in the studied sites ranged between between 0.66 % to 1.56% Tbale 2 - 6. This is rated as low (0.6 - 1.25%) to medium (1.26 - 2.5%) as categorized by Msanya *et al.* (2001). Relatively higher organic carbon was found in Mwamishali site and the lowest OC in Ng’hoboko site. In all studied sites, the organic carbon content decreased with soil depth. The low to medium organic carbon content is linked to the current land use which is characterized by cleared vegetation for crop cultivation. The top soil nitrogen content in the studied sites ranged from 0.09% to 0.2% which is categorized as very low (<0.1%) to low (0.1- 0.2%) (Msanya *et al.,* 2001). The total Nitrogen decreases with soil depth. The low nitrogen levels observed is linked to continued nutrient mining by plants due to continuous cultivation. The C:N ratios of the top soil in the studied soils range between 7.1 and 9.1, which is an indication that most soils have good quality organic matter.

Table 2-6: Selected chemical properties of the studied pedons at Meatu in Meatu District, Simiyu Region, Tanzania

Pedons	Horizon	Depth (cm)	pH		EC	OC	OM	TN	C/N	Extractable P
			H_2O	KCl	(mS/cm/ dS/m)		%		ratio	mgkg-1
BioRe-P1	Ah	0 - 9	9.05	7.22	0.16	1.56	2.7	0.20	7.8	3.82
	BAw	9 - 50/60	8.41	7.32	0.15	0.51	0.9	0.13	3.9	2.39
	C1k	50/60 - 90	8.48	7.48	0.25	0.57	1.0	0.11	5.2	5.25
	C2k	90 - 130+	8.49	7.6	0.29	0.40	0.7	0.05	8.0	0.34
Ng'ho-P1	Ap	0 - 10	8.60	7.13	0.18	0.66	1.1	0.09	7.3	9.83
	BAk	10 - 60/63	9.32	8.05	0.72	0.38	0.7	0.06	6.3	5.68
	Ck	60/63 - 120+	9.54	8.24	0.76	0.17	0.3	0.06	2.8	65.91
IT-P1	Ap	0 - 10	7.05	6.37	0.18	0.99	1.7	0.14	7.1	11.55
	Bts1	10 - 30	7.29	6.36	0.19	1.13	1.9	0.08	14.1	4.54
	Bts2	30 - 60	7.16	6.8	0.14	1.19	2.1	0.08	14.9	7.54
	C	60 - 120+	7.32	6.98	0.60	0.21	0.4	0.06	3.5	22.70
MWAB-P1	BAp	0 - 40	8.12	6.71	0.13	1.09	1.9	0.12	9.1	18.84
	BA1	40 - 81	8.88	7.62	0.58	0.37	0.6	0.11	3.4	11.83
	BA2	81 - 115+	8.79	7.75	1.20	0.42	0.7	0.07	6.0	10.40

2.4.3.3 Available phosphorus

The available phosphorus of topsoils in the study area ranged between 3.8 to 18.8 mg P kg^{-1} which is rated as low (< 5) to high (>10). According to ILACO (1991), available P of 7 mg kg^{-1} in the topsoil is considered optimal below which P-deficiency symptoms are likely to occur in most crops. In the studied area, soil in Mwamishali had topsoil P of less than 7 mg/kg, other soils had medium to high P. The low P in Mwamishali is linked to continuous cultivation and nutrient mining as the area is used for grazing after crop harvest.

2.4.3.4 Cation exchange capacity (CEC)

Results for cation exchange capacity (CEC) of the studied soils are shown in Table 2 - 7. The CEC in the topsoils of the studied sites ranges from 26.6 to 37 cmol(+)kg^{-1}. This is rated as high (25 - 40 cmol(+)kg^{-1}) (Msanya *et al.*, 2001). The CEC levels in the topsoil are comparably higher than those in the subsoils. This can be related to the fact that soil organic matter content in topsoils is higher than in subsoils (Alegre and Cassel, 1986).

2.4.3.5 Exchangeable bases and base saturation (BS)

Results for exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and base saturation in the studied soils are shown in Table 2-7. Exchangeable calcium concentrations vary among profiles and with soil depth in all studied sites. The topsoil calcium concentration ranged from 14.23 to 22.12 cmol(+)kg^{-1} which according to Landon (1991) is rated as high (10.1 - 20 cmol(+)kg^{-1}) to very high (> 20 cmol(+)kg^{-1}). Exchangeable magnesium concentration in topsoils are medium to high ranging from 1.57 to 3.62 cmol(+)kg^{-1}. The Mg concentration showed no clear trend with soil depth. Exchangeable potassium concentration in topsoils range from 1.27 to 2.26 cmol(+)kg^{-1}, which is categorized as high to very high. The potassium concentration in all studied sites are higher in topsoils than in subsoils. Exchangeable sodium concentaration range from 0.1 to 0.96 cmol(+)kg^{-1}) and is rated as low (0.1 - 0.3 cmol(+)kg^{-1}) to high (0.71 - 2.0 cmol(+)kg^{-1}). The percentage base saturation in the studied soils ranged from 23 to71%. For Mwabagalu site there was higher base saturation in the top soil than in the sub soil while in all other sites the base saturation was higher in the subsoil than topsoil.

2.4.3.6 Soil sodicity

The exchangeable sodium percentage (ESP) for the topsoils of all studied pedons ranged between 0.28 to 3.62 % which is in a range of non-sodic (ESP less than 6%) (Msanya *et* *al.*, 2001) and evaluated as highly suitable (S1) for cotton production (NBSS and LUP, 1994). The ESP in the subsoil of Ng'ho-P1 and MWAB-P1 are high (21.2 to 36.3%) which is generally rated as strongly sodic to very strongly sodic. Although the high ESP in the subsoil may not directly limit the suitability of these soils for cotton production because 80% of cotton roots occur in the topsoils at a depth < 45cm (Hodgson *et al.*, 1990), caution must be taken. This caution is needed because indirect effect of the high sodicity in the subsoil can occur due to clay dispersion induced by high ESP and cause formation of hard layer or clogged pore spaces, which may cause poor infiltration and drainage (So and Aylmore, 1993).

Table 2-7: Exchangeable bases and micronutrients of the studied pedons in Meatu District, Simiyu Region, Tanzania

Pedons	Horizon	Depth (cm)	Exchangeable bases and cation exchange capacity						ES	BS	Micronutrients			
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	TEB	CEC			Cu	Zn	Mn	Fe
			(cmol(+) kg^{-1})						%	%	(mg/kg)			
BioRe-P1	Ah	0 - 9	22.1	2.7	0.10	1.4	26.3	34.0	0.3	77.2	1.41	0.43	33.6	7.86
	BAw	9 - 50/60	23.0	2.0	0.10	0.3	25.5	35.4	0.3	72.	1.12	0.4	25.3	3.82
	C1k	50/60 - 90	25.1	2.1	0.12	0.3	27.6	27.8	0.4	99.4	1.55	0.43	13.6	3.24
	C2k	90 - 130+	26.4	2.5	0.13	0.2	29.2	25.0	0.5	116.8	1.34	0.47	5.2	1.80
Ng'ho-P1	Ap	0 - 10	14.2	2.7	0.96	1.3	19.2	26.6	3.6	72.0	1.48	0.40	30.3	7.57
	BAk	10 - 60/63	11.9	3.1	7.98	0.4	23.5	32.0	24.9	73.3	2.06	0.31	16.9	3.24
	Ck	60/63 - 120+	25.7	2.9	9.11	0.67	38.4	32.0	28.5	119.9	1.70	0.62	5.2	0.94
IT-P1	Ap	0 - 10	14.2	1.6	0.06	2.3	18.1	19.0	0.3	95.4	2.49	0.81	36.9	13.34
	Bts1	10 - 30	12.9	1.4	0.10	0.9	15.3	21.4	0.5	71.6	2.06	0.74	30.3	5.84
	Bts2	30 - 60	7.8	1.5	0.20	0.6	10.1	24.6	0.8	41.2	2.13	0.71	19.4	3.82
	C	60 - 120+	8.3	1.7	0.54	0.7	11.2	26.6	2.0	42.0	2.34	1.18	66.2	10.74
MWAB-P1	BAp	0 - 40	15.1	3.6	0.73	1.6	21.1	37.0	1.9	57.0	2.13	0.40	56.1	10.16
	BA1	40 - 81	9.7	2.6	7.21	0.8	20.3	34.0	21.2	59.7	1.98	0.78	35.3	4.69
	BA2	81 - 115+	16.1	2.7	12.9	0.9	32.5	35.4	36.3	91.9	1.91	1.43	13.6	2.96

2.4.3.7 Soil micronutrients

Soil micronutrients concentrations are presented in Table 2-7. The observed copper concentration in the top soil of the study area range from 1.4 to 2.5 mg kg^{-1} with highest level being in Sanga-Itinje and lowest level at Mwamishali. Referring to the DTPA-extractable soil Cu of 0.2 mg kg^{-1} being the critical limit below which plants are likely to suffer from Cu deficiency (Viets and Lindsay, 1973; Lindsay and Norvell, 1978; Esu, 1991), soils in all studied area have sufficient Cu level for optimal crop growth. The observed Zn levels in the topsoils of the studied area ranged between 0.4 and 0.81 mg kg^{-1} with the lowest level been in Ng'hoboko and Mwabagalu. With reference to the deficiency range for Zn (DTPA) level in soils between 0.0 - 0.5 mg kg^{-1} (Silanpaa, 1982; Lindsay and Novell, 1978), soils in Ng'hoboko, Mwamishali and Mwabagalu are deficient in Zn while the soils in Sanga-Itinje are of medium level (0.5 - 1 mg kg^{-1}).

The Fe concentration in the top soil of the studied area ranged between 7.5 and 13.3 mg kg^{-1} with the lowest level been in Ng'hoboko and highest value in Sanga Itinje (Table 2-7). With reference to critical values of between 0.3 and 10 mg kg^{-1} reported by Lindsay and Cox (1985) and Mustapha and Singh (2003), the soils in the study area have adequate level of Fe required for crop growth. The Mn level in the top soil of the studied area ranged between 30.2 and 56.1 mg kg^{-1} (Table 2-7) with the lowest level been in Ng'hoboko and highest value in Mwabagalu. Comparing to the deficiency level for Mn (DTPA) in the soil (1.0 - 5.0) mg kg^{-1} and excess with values > 140 - 200 mg kg^{-1} (Lindsay and Norvell, 1978; Silanpaa, 1982; Esu, 1991), the Mn status in soils of the study area have adequate level of Mn required for crop growth.

2.4.3.8 Nutrient ratios and balance in soil.

Nutrient ratios in soils are important indicators of nutrient uptake (Edem and Ndaeyo, 2009). The Ca/Mg ratio for the topsoils ranged from 1.2 and 5.27 (Table 2-8) and was categorized as within the normal range (Landon, 1991). The higher calcium than magnesium indicates better conditions for plants growth in term of improved gas exchange and better clay aggregation and better structure stability (Dontsova and Norton, 1999, Yilmaz *et al.*, 2005). The Mg/K ratio in the topsoils ranged from 1.57 to 2.26 with the highest value being in pedon IT-P1 and the lowest in pedon MWAB-P1 (Table 2-8). The ratios are within the optimal range for plant uptake. The Ca/TEB ratios in the topsoil for studied pedons ranged from 0.48 to 0.84 (Table 2-8) and did not have well defined trend down the profile. As shown in Table 8, the observed Ca/TEB ratios in Ng'ho-P1, IT-P1 and MWAB-P1 are above the optimal level of 0.5 (Msanya *et al.*, 2001) which may affect the uptake of other bases, particularly Mg and/or K causing calcium induced deficiency of Mg and/or K.

Table 2-8: Nutrient balance in the studied pedons in Meatu District, Simiyu Region, Tanzania

Profile	Horizons	Depth (cm)	Ca/Mg	Ca/TEB	Mg/K	%(K/TEB)
BioRe-P1	Ah	0 - 9	1.42	0.48	1.96	17.17
	BAw	9 - 50/60	1.88	0.61	5.95	5.43
	C1k	50/60 - 90	10.60	0.90	6.13	1.38
	C2k	90 - 130+	9.30	0.89	11.67	0.82
Ng'ho-P1	Ap	0 - 10	5.27	0.74	2.13	6.61
	BAk	10 - 60/63	3.83	0.51	7.87	1.69
	Ck	60/63 - 120+	9.03	0.67	4.10	1.81
IT-P1	Ap	0 - 10	4.19	0.72	2.26	7.58
	Bts1	10 - 30	3.69	0.48	3.20	4.03
	Bts2	30 - 60	6.05	0.49	2.84	2.88
	C	60 - 120+	9.06	0.79	0.70	12.47
MWAB-P1	BAp	0 - 40	8.91	0.84	1.57	6.01
	BA1	40 - 81	5.13	0.77	2.74	5.50
	BA2	81 - 115+	4.99	0.74	2.41	6.17

2.4.3.9 Calcium carbonate content in the root zone

Based on field test of CaCO3 with HCl, for MWAB-P1 and IT-P1 no bubbles was formed throughout the profile indicating a non calcareous soil < 0.5 - 1% $CaCO_3$ (Hodgson, 197). For BioRe - P1 the top soil formed few bubbles which indicate slightly calcareous (2-5%) while the sub-soil formed many obvious bubbles indicating calcareous (5-10%). For Ng'ho-P1 the top-soil was non calcareous while the subsoil was calcareous. Based on the $CaCO_3$ content, the MWAB-P1 and IT-P1 are highly suitable for cotton production while BioRe - P1 and Ng'ho-P1 are marginally suitable.

2.4.3.10 Total elemental composition of the studied soils

Results on total elemental composition and chemical index of alteration of the studied pedons are presented in Table 2-9. The total soil elemental composition is useful basis for characterizing soils in a way that relates to soil-forming factors and inherent soil functional properties (Towett, 2015) and is linked to the concentration of the total element in the soil and the degree of weathering of the soil parent rock. In all the studied pedons, the abundance of the oxides is in the form of: SiO_2 >Al_2O_3 >K_2O >Fe_2O_3 > CaO >TiO_2 >MgO >MnO >CuO >Na_2O. Higher concentration of SiO_2 in the pedon reflects the dominance of quartz minerals in the area.

Table 2-9: Total elemental composition and chemical index of alteration in the studied soils of Meatu District, Simiyu Region, Tanzania

Pedon	Horizon	Soil depth	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	TiO_2	MnO	CuO	MgO	Na_2O	CIA
		(cm)						%					
BioRe-P1	Ah	0 - 9	55.1	10	4.18	2.11	3.51	0.55	0.11	0.11	1.06	0.02	64
	BAw	9 - 50/60	51	9.8	4	1.79	6.38	0.47	0.09	0.11	1.13	0.02	54
	C_1k	50/60 - 90	20.5	3.6	2.92	0.75	24.74	0.22	0.05	0.09	0.99	0.02	12
	C_2k	90 - 130+	20.4	4.1	2.96	0.78	27.36	0.27	0.06	0.08	1.06	0.02	13
Ng'ho-P1	Ap	0 - 10	65.2	6	3.69	1.82	2.03	0.4	0.1	0.12	0.86	0.04	61
	BAk	10 - 60/63	57.4	9.7	3.76	1.64	4.76	0.43	0.09	0.11	0.93	0.14	60
	Ck	60/63 - 120+	29.6	7	3.88	1.09	17.19	0.32	0.08	0.11	1.46	0.54	27
MWAB-P1	BAp	0 - 40	52.7	14	5.43	2.58	2.27	0.67	0.11	0.1	1.39	0.04	74
	BA_1	40 - 81	53	13	5.56	2.54	2.39	0.68	0.11	0.11	1.06	0.15	72
	BA_2	81 - 115+	49.9	12	5.58	2.46	2.21	0.6	0.1	0.13	1.13	0.43	70
IT-P1	Ap	0 - 10	47.1	15	5.65	1.64	1.01	0.65	0.1	0.1	0.46	0.03	85
	Bts1	10 - 30	46.5	17	7.89	1.39	1.01	1.05	0.13	0.13	0.6	0.03	87
	Bts2	30 - 60	46.2	17	7.34	1.37	1.08	0.78	0.09	0.11	0.53	0.03	87
	C	60 - 120+	40	15	7.95	1.16	1.15	0.82	0.09	0.17	0.53	0.04	86

CIA = Chemical index of alteration = $\{Al_2O_3 / (Al_2O_3 + K_2O + Na_2O + CaO)\} * 100$

The *Chemical Index of Alteration (CIA),* which is a measure of degree of weathering of minerals (Nesbitt and Young, 1982) ranged from 87% to 12%. Low CIA values indicate low weathering or unaltered minerals whereas high values indicated high degree of weathering. For all pedons except Mwabagalu the CIA values decreases with soil depth indicating that the topsoils are more weathered than the subsoils. In Mwabagalu, topsoils are less weathered than subsoils.

2.4.4 Soil classification

Soil diagnostic horizons and features, and soil names according to the USDA Soil Taxonomy and the FAO World Reference Base for Soil Resources are given in Tables 2-10 and 2-11, respectively.

Table 2-10: Diagnostic features and classification of the studied pedons according to USDA Soil Taxonomy (Soil Survey Staff, 2014)

Pedon	**Diagnostic horizon(s) / properties**	**Other diagnostic features**	**Order**	**Suborder**	**Great group**	**Subgroup**	**Family**
BioRe-P1	Mollic epipedon; Calcic horizon	Almost flat, moderately deep, clayey, moderate to strongly alkaline; ustic SMR≠, isohyperthermic STR#	Mollisols	Ustolls	Calciustolls	Pachic Calciustolls	***Almost flat, moderately deep, clayey, moderately to strongly alkaline isohyperthermic, Pachic Calciustolls***
Ng'ho-P1	Mollic epipedon; Calcic horizon	Almost flat, moderately deep, clayey, moderate to strongly alkaline, very strongly sodic; ustic SMR, isohyperthermic STR	Mollisols	Ustolls	Calciustolls	Pachic Calciustolls	***Almost flat, moderately deep, clayey, moderately to strongly alkaline, very strongly sodic, isohyperthermic, Pachic Calciustolls***
IT-P1	Ochric epipedon; Argillic horizon	Gently sloping, moderately deep, clayey, neutral to mildly alkaline, ustic SMR≠, isohyperthermic STR#	Alfisols	Ustalfs	Rhodustalfs	Typic Rhodustalfs	***Gently sloping, moderately deep, clayey, neutral to mildly alkaline, isohyperthermic, Typic Rhodustalfs***
Mwab-P1	Wedge-shaped / prismatic aggregates; presence of slickensides and deep wide cracks; very sticky and very plastic and very hard consistence	Almost flat, deep, clayey, moderate alkaline to strongly alkaline, very strongly sodic; ustic SMR≠, isohyperthermic STR	Vertisols	Usterts	Haplusterts	Sodic Haplusterts	***Almost flat, deep, clayey, moderate alkaline to strongly alkaline, isohyperthermic, Sodic Haplusterts***

≠SMR = Soil moisture regime, #STR = Soil temperature regime

As indicated in Tables 2-10 and 2-11, soils of BioRE-P1 and Ng'ho-P1 are similar soils described in the USDA Soil Taxonomy as Mollisols with great groups of Calciustolls. The soils in IT-P1 were classified in the USDA Soil Taxonomy as Alfisols with greatgroups of Rhodustalfs. For MWAB-P1, the soils were classified in USDA Soil Taxonomy as Vertisols with great group of Sodic Haplusterts. According to WRB the soils of BioRE-P1 and Ng'ho-P1 were classified as Phoeozems while IT-P1 and MWAB-P1 were classified respectively as Luvisols, and Vertisols.

Table 2-11: Diagnostic horizons and features, and classification of the studied soils according to WRB for Soil Resources (IUSS Working Group WRB, 2015)

Pedon	**Diagnostic horizons / properties / features**	**Reference Soil Group (RSG) - TIER1**	**Principal Qualifiers**	**Supplementary Qualifiers**	**WRB soil name - TIER 2**
BioRe-P1	Mollic horizon; Calcic horizon	Phaeozems	Rhedzic, Endocalcic	Clayic, Pachic	***Endocalcic Rhedzic Phaeozems (Clayic, Pachic)***
Ng’ho-P1	Mollic horizon; Calcic horizon; Very strongly sodic	Phaeozems	Rhedzic, Endocalcic	Clayic, Pachic, Sodic	***Endocalcic Rhedzic Phaeozems (Clayic, Pachic, Sodic)***
IT-P1	Argic horizon; Presence of clay cutans	Luvisols	Rhodic,	Clayic, Cutanic, Humic	***Rhodic Luvisols (Clayic, Cutanic, Humic)***
Mwab-P1	Vertic horizon; Wedge-shaped/ prismatic aggregates; Very hard consistence; Very strongly sodic	Vertisols	Pellic, Sodic	Hypereutric, Mazic, Mesotrophic,	***Sodic Pellic Vertisols (Hypereutric, Mazic, Mesotrophic)***

2.4.5 Soil-site suitability for cotton production

The soil suitability for production of cotton based on the simple limitation method is shown in Table 2-12. As indicated in Table 2-12, the soils in all studied pedon are ranked as marginally suitable for cotton production. The soils at Mwamishali (BioRe-P1) and Ng'hoboko (Ng'ho-P1) and Sanga-Itinje (IT-P1) are marginally suitable (S3fs) due to fertility limitation and soil physical properties. The soils at Sanga Itinje (IT-P1) are marginally suitable (S3fs) due to fertility limitation and soil physical properties. The soils at Mwabagalu (MWAB-P1) are marginally suitable (S3f) due to fertility limitation only (high pH). This indicates that sustainable cotton production in these areas would need specific intervention to ameliorate the soil fertility.

Table 2-12: Soil Suitability Rating of the Study Sites for Cotton Production

Land quality	Soil-site characteristics	Suitability Rating1)			
		BioRe-P1	Ng'ho-P1	IT-P1	MWAB-P1
Climate (c)	Mean temperature in growing season	S1	S1	S1	S1
	Total rainfall	S2	S2	S2	S2
	Rainfall in growing season	S2	S2	S2	S2
Topography (t)	Slope	S1	S1	S2	S1
Soil physical properties (s)	Texture	S3	S3	S3	S1
	Effective soil depth	S2	S2	S2	S1
	Stoniness	S1	S1	S1	S1
	Coarse fragments	S1	S1	S1	S1
Wetness (w)	Length of growing period	S2	S2	S2	S2
	Soil drainage	S1	S1	S1	S2
	Water logging in growing season	S1	S1	S1	S2
Fertility (f)	pH	S3	S3	S1	S3
	CEC	S3	S3	S3	S3
	BS	S3	S3	S3	S3
	OC	S1	S3	S2	S1
	CaCO3 in root zone	S2	S2	S1	S1
Soil toxicity (n)	Salinity (EC saturation extract)	S1	S1	S1	S1
	Sodicity/(ESP)	S1	S1	S1	S1
	Overall Suitability	**S3fs**	**S3fs**	**S3fs**	**S3f**

1)Suitability rating: S1=Highly suitable; S2=Moderately suitable; S3= Marginally suitable; s=soil physical properties limitations; f= soil fertility limitation

2.5 Conclusions and Recommendations

The studied pedons in Mwamishali and Ng'hoboko had similar morphological, physical and chemical properties. The soils are flat to gently sloping, moderately deep, sandy clay to sandy clay loam, neutral to strongly alkaline classified in USDA Taxonomy as Mollisols. The soils are marginally suitable for cotton production due to fertility and soil texture limitations. The soils at Sanga-Itinje are also gently sloping, moderately deep, but sandy clay to clay, neutral to strongly alkaline and classified in USDA taxonomy as Alfisols. The soils in Mwabagalu are Vertisols within a plain, they are deep, clayey, moderately alkaline to strongly alkaline. These soils are also marginally suitable for cotton production due to fertility limitations. Based on the facts above, it is recommended that for improved production of cotton in these soils soil fertility management to improve soil fertility is important.

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CHAPTER THREE

3 YIELD AND PROFITABILITY OF COTTON GROWN UNDER SMALLHOLDER ORGANIC AND CONVENTIONAL COTTON FARMING SYSTEMS IN TANZANIA

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3.1 Abstract

Agronomic and economic performance of organic and conventional cotton production systems under low input smallholder farming systems in tropical and subtropical regions is not well known. A field study was conducted over two growing seasons in the semiarid cotton production area in Meatu, Tanzania. The objective of the study was to compare yield and economic performance of cotton in response to different soil fertility and pest management practices under low input conventional and organic production systems. For soil fertility management, the treatments were 30 kg N ha^{-1} and 3 Mg FYM ha^{-1} in conventional and organic farming, respectively, higher input scenario (60 kg N ha^{-1} and 5

Mg FYM ha^{-1} for conventional and organic, respectively) and alternative practices (30 kg N ha^{-1} + 3 Mg FYM ha^{-1} for conventional and 3 Mg FYM ha^{-1} + green gram intercrop for organic). For pest management, treatments were 3 sprays of synthetic pesticide in conventional and pyrethrum spray after scouting as needed in organic, higher rate (6 sprays of synthetic pesticide in conventional and pyrethrum spray after scouting as needed in organic) and alternative practice (3 sprays of neem + cow urine for conventional and spray of Neem + cow urine as needed after scouting for organic). The results showed that, the current farming practice, organic farming practice had no significant difference in yield with seed cotton yield of 1.4 and 0.64 Mg ha^{-1} compared to the recomended conventional practice with seed cotton yield of 1.3 and 0.37 Mg ha^{-1} for season 1 and 2, respectively. The current organic farming practice had higher gross margin of USD 527 and 137 ha^{-1} compared to the conventional practice with gross margin of USD 321.2 and -74.9 ha^{-1} for season 1 and 2, respectively. However, at higher input rate (fertilizer and pesticide) conventional cotton had significantly higher yield of 1.8 and 0.51 Mg ha^{-1}) compared to the organic practice with seed cotton yield of 1.4 and 0.39 Mg ha^{-1} for season 1 and 2, respectively. The higher input conventional cotton had relatively lower gross margin of USD 463 and -85.9 ha^{-1} compared to the organic practice with gross margin of USD 477 and -81.3 ha^{-1} for season 1 and 2, respectively. For organic cotton practice the alternative practices (intercropping cotton with green gram) had low cotton yield of 1.3 Mg ha^{-1} in season 1 compared to alternative conventional (1.7 Mg ha^{-1}) but had higher gross margin (USD 616.2 ha^{-1}) than conventional (USD 476 ha^{-1}) as a result of additional revenue from green gram. In the season with less rainfall (season 2) the control had the highest GM of all treatments. It was concluded that the existing smallholder organic and conventional cotton productin had similar yield and economic return as the recommended conventional cotton. If the input level is increased, conventional cotton would have higher yield but low economic return compared to organic cotton. Cotton-legume intercrop,

fertilizer manure combination and neem + cow urine are viable farming practices for smallholder cotton farmers. Under the prevailing semi-arid conditions smallholder farmers are rational on adopting limited use of fertilizer and pesticide.

Key words: Organic cotton, conventional cotton, yield, weather variability, cost-Benefit Analysis, economic performance, smallholder farming systems.

3.2 Introduction

Cotton (*Gossypium hirsutum* L.) is among the major export crops in Tanzania. It is the second largest export crop after coffee. Cotton in Tanzania provides employment for over 500 000 rural households (TCB, 2010), and it also contributes to national export earnings. Cotton growing in Tanzania is dominated by smallholder farmers with farm size ranging between 0.5 to 10 hectares, with an average of 1.5 hectares. The production is characterised by manual operation under rain-fed conditions with minimal use of inputs such as fertilisers and pesticides. Two cotton production systems, conventional and organic are practiced in Tanzania. The conventional cropping of cotton is based on the use of synthetic fertilizers, pesticides and herbicides (Pimentel *et al.,* 2005). The majority of the cotton producing farmers in Tanzania practices the conventional system (TCB, 2010). However, most smallholder conventional farmers use little or no fertilizer, but they appreciably use pesticides for controlling the common cotton pests like aphids (*Aphis gossypii*), American bollworm (*Heliothis armigera*) and cotton stainer (*Dysdercus spp*.)

With regard to fertilizer, the recommended rates for cotton vary depending on soil type. For the western cotton growing areas of Tanzania the revised fertilizer recommendations for Tanzania show application rate of 20 to 30 kg ha^{-1} N, 10 - 15 kg ha^{-1} P and 5 Mg ha^{-1} farm yard manure (FYM) (Mowo *et al.*,1993). A general national recommended rate of 40 kg ha^{-1} N and P is also reported by IFDC (2014). No specific literature for national recommendation of pesticide use in cotton is available, and the application rates are based on guidelines from the pesticide manufacturers, which suggest 4 to 6 sprays per growing season.

Organic agriculture refers to a farming system that enhances productivity through maximizing the efficient use of local resources, while foregoing the use of agrochemicals, the use of Genetic Modified Organisms (GMO), and the use of many synthetic compounds used as food additives (FAO, 1998; Gold, 2007; IFOAM, 2014). In recent years, organic cotton production in Tanzania has picked up. In the season 2009/10, for example, Tanzania produced 2635 Mg of organic cotton, which placed the country in the 5th position in the world's leading organic cotton producers (Textile Exchange, 2010). Organic cotton production is practised in some areas in Meatu and Maswa in Simiyu region and in Singida. Usually it targes a niche market that provides premium price for certified organic produce. The production is still contract-based, where farmers enter production contracts with private companies. The contracting company provides organic seeds and bio-pesticides and offers training and extension services. In return, the company is entitled to purchase the entire crop. The organic cotton production practices for nutrient management include use of FYM, crop rotation and intercropping with legumes. For pest management the practices include trap crops (e.g. intercropping with sunflower), crop rotation, use of organic pesticides (Neem or pyrethrum). However, there is documented information in county on agronomic and environmental performance of these practices.

The average cotton yields in Tanzania vary between 560 to 750 kg of seed cotton per hectare. This low yield is associated with major yield limiting factors such as rain-fed growing conditions with infrequent rainfall, use of low yielding varieties and insufficient use of fertilizer and pesticides (TCB, 2010). To improve the yield, the government has initiatives that targeted at increasing cotton productivity from 750 kg ha^{-1} of seed cotton (260 kg ha^{-1} of lint) in 2008/09 to 1 500 kg ha^{-1} (520 kg ha^{-1} of lint) by 2014/15. Strategies for achieving this target include application of at least 2 insecticide sprays per growing season, enhanced use of improved cotton varieties (TCB, 2010). However, extensive use of inputs (fertilizers and agrochemicals) in these strategies are also associated with negative environmental impacts, such as nutrient losses causing eutrophication in water bodies, biodiversity loss, greenhouse gas (GHG) emissions and soil acidification (Gomiero *et al.,* 2011). Therefore, farming practices that would improve yield while having better environmental and economic performance should be developed and documented.

Among agricultural practices, organic farming practices are perceived to be more environmentally benign than conventional farming because of the avoidance of inorganic fertilizers, insecticides and/or herbicides and the reliance on organic nutrient cycling (Tuomisto *et al.,* 2012; Lorenz and Lal, 2016). However, it remains unclear how the crop yields and economic performance compare between organic and conventional systems for crops grown under smallholder production systems in SSA. Some authors argue that organic farming systems have lower yield than conventional farming and hence would not be able to meet the world's growing food demand (de Ponti *et al.,* 2012). They also argue that organic farming is associated with low labour productivity, high production risks and high costs due to additional costs of certification (Borlaug, 2000; Trewavas, 2001; Nelson *et al.,* 2004; Makita, 2012). Others argue that under good management, yields from organic farming can be similar to or greater than those of conventional farming (Cavigelli *et al.,* 2009; Seufert *et al.,* 2012).

Most studies comparing yields of organic and conventional farming practices have been done in temperate countries (Rosenstock *et al.,* 2013), leaving a data gap for tropical and subtropical conditions. This advocates for farming systems comparisons in SSA to provide the necessary information for recommendations for sustainable cotton production in the region (Richards *et al.,* 2016). Such a comparison needs to extend beyond agronomic information such as yield and quality, since this choice of farmers very much relies on economic performance of the different systems. It is therefore important to compliment the agronomic data with the associated economic costs and gains in the different systems to establish which farming systems provide the most economic sustainable systems. This study was undertaken in semi-arid cotton production areas in Meatu, Tanzania, to determine yield and economic performance of cotton grown under low input smallholder conventional and organic production systems under rainfed conditions.

3.3 Materials and Methods

3.3.1 Study site description

The field experiment was conducted in the Meatu District, Simiyu Region in Tanzania. The area is between latitudes 3° - 4° S and longitudes 34°8’ - 34°49’ E at an altitude of 1 000 -1 500 m.a.s.l. The area is within the semi-arid zone, rainfall ranging from 400 mm per year in the south to 900 mm in the north. The soil type at the experimental site was described to family level as almost flat, moderately deep, clayey, moderately to strongly alkaline isohyperthermic, Pachic Calciustolls in the USDA Soil Taxonomy and as Endocalcic Rhedzic Phaeozems (Clayic, Pachic) in the WRB. Crop and livestock farming are the major economic activities (URT, 2013). Cotton is the main cash crop in the area where both conventional and organic cotton production are practiced. Green gram (*Vigna radiata* (L.) R. Wilczek) is widely grown in the area and used in cotton - legume rotations in organic farming practice and to some extent for intercropping with cotton. The study was done for two cotton growing seasons, season 1 (12015/16) and season 2 (2016/17) at BioRe Tanzania demonstration farm, Mwamishali Village located at 3°31’11’’S and 34°14’05’’ E.

3.3.2 Experimental plot initial soil properties

Composite soil samples were collected prior to treatment application at a depth of 0-20 cm, air dried and sieved through 2 mm sieve and analysed for initial soil properties as described in chapter 2. The topsoil (0-20 cm) has a sand clay texture. The soil has a pH of 9.05 and 7.22 in H_2O and $CaCl_2$, respectively; bulk density 1.36 g cc^{-1}; organic carbon 1.03 %; total nitrogen 0.14%; extractable phosphorus 16.0 mg kg^{-1}; exchangeable bases in cmol $_{(+)}$ Kg^{-1} of 17.87, 3.47 1.54 and 0.11 for Ca^{2+}, Mg^{2+}, K^+ and Na^+, respectively; micronutrients in mg kg^{-1} of 1.44, 1.11, 0.40, 9.12 for Cu, Fe, Zn and Mn, respectively. As described in chapter 2, the soils are marginally suitable for cotton production due to soil fertility. The manure used had organic carbon 8%, total nitrogen 1.03%, extractable phosphorus 103 mg kg^{-1} and C:N ratio of 7.8.

3.3.3 Weather data

Weather data were recorded hourly using an automatic weather station (AWS) installed at the experimental site at the beginning of the experiment. The AWS collected data on precipitation, measured with an ECRN-100 high-resolution rain-gauge (Decagon Devices Inc.). Air temperature and humidity was measured by a VP-4 sensor (Decagon Devices Inc.), solar radiation measured by PAR sensor and soil temperature and moisture measured by 5TM sensor (Decagon Devices Inc.) at 20 cm depth. Hourly averages were logged in an Em50 data logger (Decagon Devices Inc.). The soil water filled pore space (WFPS) was calculated from the measured volumetric soil moisture (VWC) using relation $\mathrm{WFPS}(\%) = \frac{VWC}{1-\left(\frac{BD}{PD}\right)} * 100$. where BD=bulk density and PD =particle density where the value of 2.65 g cc^{-1} was assumed (Brady and Weil, 2014).

3.3.4 Field experimental design and treatments

A field experiment was conducted over two growing seasons, 2015/16 and 2016/17. The agronomic and economic performance of cotton were tested at different levels of fertilizer and pest control strategies for both conventional and organic farming. As described in

Table 3-1, the alternative cotton farming practices treatments were tested against the current recommended practices, a higher input scenario and a control without fertilizers or pesticides. For organic farming, the fertility management practices tested were two different levels of organic manure and an alternative practice of intercropping cotton and green gram (*Vigna radiata* R. Wilczek). For conventional, two application rates of N from the synthetic fertilizer Diammonium Phosphate (DAP) and Urea and an alternative practice of combining synthetic fertilizer and manure. For organic farming the pest management practices tested were the currently used pyrethrum, neem leaves and neem leaves mixed with cow urine. For conventional the pest management practices tested were the current 3 sprays, recommended 6 sprays and alternative 3 spray of Neem leaves + cow urine.

For organic pesticide preparation, neem leaves extract was prepared by soaking pounded neem leaves in water at a rate of 12.5% w/w for 24 hours. The mixture was then seaved and sunflower oil added at a rate of 1.75% v/v to improve adhesion. For neem + cow urine, cow urine was added at a rate of 2.5% v/v. The field application was done using knapsack sprayer at rates indicated in Table 3-1. For organic farming treatments the pesticide application was done after scouting to determine the pest pressure and need for spraying. The experiment was arranged as split-split-plot in the randomized block design, where production systems (organic versus conventional) were the main plots with pest management as a sub-plot and nutrient management as a sub-sub plot. Treatments were replicated in 3 blocks, with test plot size of 10 x 5 m as shown in Fig. 3-1. For organic treatments, a rotation was made in season 2 where organic plots were shifted to plots planted with sole legume in season 1, which is standard procedure for organic farmers in the area. Except for the alternative practice, the management of treatments followed the standard practices and recommended practices for cotton in the region. Organic and conventional plots were isolated by 2 m border rows planted with sorghum as indicated in Figure 3-1.

Table 3-1: Treatment description

Production System	Nutrient Management Practice	Pest Management Practice
	Fertilizer	**Pesticide**
Organic cotton (O)	i. No fertilizer **(OF-0)**	**i.** No pesticide **(OP-0)**
	ii. Current practice **-** 3 Mg FYM ha^{-1} **(OF-3)** (At planting apply 3 Mg FYM ha^{-1})	**ii.** Pyrethrum (Natural Pyrethrin extract, 0.2%v/v) **(OP-P)** (each spray: 272 ml ha^{-1} Natural Pyrethrin extract. The number of sprays determined by scouting)
	iii. Recommended **-** 5 Mg FYM ha^{-1} **(OF-5)** (At planting apply 5 Mg FYM ha^{-1})	iii. Neem leaves (12.5% w/w) **(OP-N)** (each spray: 24.8 kg ha^{-1} fresh neem leaves extract + 3.5 l ha^{-1} sunflower oil. The number of sprays determined by scouting)
	iv. Innovative 3 Mg FYM ha^{-1} + Inter-cropping greengram **-** *Vigna radiata* , – (**OF-3+L)** **(**At planting apply 3 Mg FYM ha^{-1}. At 2-4 weeks after planting cotton, plant greengram *(Vigna radiata)* between cotton rows)	iv. Neem (12.5% w/w) + cow urine (2.5% v/v)- **(OP-N+CU)** (each spray: 24.8 kg ha^{-1} fresh neem leaves extract + 3.5 l ha^{-1} sunflower oil + 5.0 l ha^{-1} cow urine. The number of sprays determined by scouting)
Conventional cotton	i. No fertilizer**(CF-0)**	i. No pesticide**(CP-0)**
	ii. Recommended 30 kg N/ha **(CF-30)** (At planting apply 75 kg ha^{-1} DAP (13.5 kg N ha^{-1}, 15 kg P ha^{-1}), at squire formation top-dress with 35.9 kg ha^{-1} urea (16.5 kg N ha^{-1}))	**ii.** Recommended rate (3 sprays of Lamdacyhalothrin 5% EC) **)(CP-3)** **(**each spray: 371 ml ha^{-1} of Ninja (50 g l^{-1} lambda-cyhalothrin))
	iii. Higher rate (60 kg N/ha **(CF-60)** (At planting apply 100 kg ha^{-1} DAP (18 kg N ha^{-1} + 20 kg P ha^{-1}), At squire formation top-dress with 91.4 kg ha^{-1} urea (42 kg N ha^{-1})	iii. High rate (6 sprays of Lamdacyhalothrin 5% EC) **(CP-6)** (each spray: 371 ml ha^{-1} of Ninja (50 g l^{-1} lambda-cyhalothrin))
	iv. Innovative FYM 3 Mg ha^{-1} +Fertilizer 30 kg N/ha, – (**CF-3+M)** (At planting apply 3 Mg FYM ha^{-1}, At squire formation top-dress with 65.2 kg ha^{-1} urea (30 kg N ha^{-1})	iv. Innovative **-** 3 sprays of Neem+cow urine– **(CP-3 -N+CU)** (each spray: 24.8 kg ha^{-1} fresh neem leaves + 3.5 l ha^{-1} sunflower oil + 5.0 l ha^{-1} cow urine)

3.3.5 Yield parameters

Cotton yield was measured by harvesting the net plot (9 x 4 m) of each plot by hand picking, with the first round of harvesting done when approximately 60% of the cotton balls were open which for season 1 and season 2, respectively, was 142 and 135 days after sowing (DAS). A total of three rounds of harvesting were conducted in both seasons. The cotton harvested from each net plot was weighed using a digital balance.

3.3.6 Cost and benefit of the farming practices

The assessment of economic performance of organic and conventional farming practices was done by limiting the economic calculations to the assessment of costs and revenue associated with the farming practice to arrive at profitability of the practices. A simple assessment of the profitability was based on the incurred cost and revenue obtained from each practice. Operational costs for every field operation were recorded at every stage of operation and total variable cost recorded at the end of all operations. Revenue was recorded at the selling time based on the selling price set by the cotton board after agreement with buyers, farmers representatives and the Government.

A cost benefit analysis (CBA) was used to evaluate the benefits associated with the farming practices and used as decision tool for best practices (Atampugre, 2014; Gatzweiler and von Braun 2016). Two CBA indicators namely, Gross margin (GM) and benefit-cost ratio (BCR), were used. The gross margin indicates the economic performance of the farming practice while the BCR indicates the viability of the farming practice. The BCR which is one of the CBA indicators used to assess viability of the agriculture technologies (FANRPAN, 2017) was used to compare the performance of the farming practices. The BCR for the different treatments were compared, and the higher the BCR the better the practice. Normally, for a technology to be adopted, the BCR should be equal to, or above, 2 (Kelly, 2006). The BCR was calculated as the ratio between the net benefit and the total variable cost (TVC) incurred in the production and selling of products:

$$\mathrm{BCR} = \frac{(\text{Total Revenue}) - \text{Total variable cost (TVC)}}{\text{TVC}}$$

The GM is an indicator of changes in farming practice that improve productivity and income (Nelson and Swindale, 2013) and a high GM implies that small-holder farmer has improved productivity through implementation of better technologies or management practices. The GM was calculated as the difference between total variable cost and revenue.

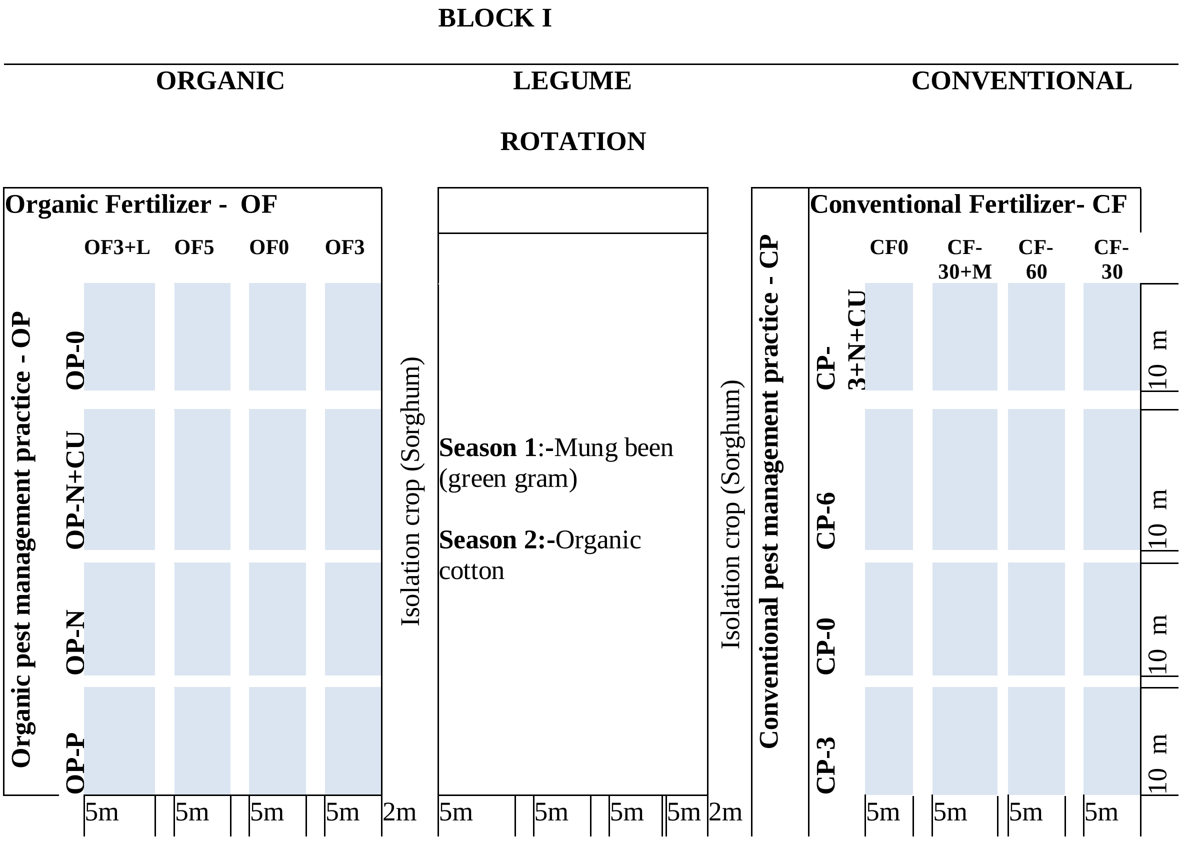

Figure 3-1: Layout of the field experiment to compare performance of organic and conventional cotton production practices in Meatu, Tanzania.

Note:- (OP0 – No pesticide used; OP-P - Organic pesticide - used Pyrethrum; OP-N – Pest control by spray of Neem crude extract after pest scouting; OP-N+CU – Pest control by spray of crude Neem extract + cow urine; OF-0 – No fertilizer use; OF-3 – Current organic practice using 3 Mg farm yard manure (FYM) ha^{-1}; OF-5 – Recommended organic fertilizer rate using 5 Mg FYM ha^{-1}; OF-3+L – Alternative organic practice, 3 Mg FYM ha^{-1} and intercropping with legume (*Vigna radiata (L.) R. Wilczek*); CP-0 – No pesticide used; CP-3 –3 sprays of Lamdacyhalothrin; CP-6–6 sprays of Lamdacyhalothrin; CP-3+CU-(3 sprays Neem + cow urine; CF-0 – Conventional farming -No fertilizer; CF-30 recommended fertilizer rate at 30 kg N ha^{-1} and 15 kg P ha^{-1}; CF-60 – higher fertilizer rate at 60 kg N ha^{-1} and 20 kg P ha^{-1}; CF-30+M – Alternative practice - 30 kg N ha^{-1} and 3 Mg FYM ha^{-1})

3.3.7 Statistical analysis

Statistical differences in yield and economic performance between treatments were analysed by ANOVA and mean comparison by Duncan's Multiple Range test at 5% significance level, using ExpDes package in R software (Ferreira *et al.*, 2013), which considers balanced experiments under fixed models (Ferreira *et al.*, 2014).

3.4 Results

3.4.1 Weather

The total rainfall recorded in the cotton growing season 1 (November 2015 to June 2016) was 759 mm, while that in season 2 (October 2016 to June 2017) was 522 mm (Table 3-2). The rainfall recorded in season 1 was above the long-term (1994-2011) annual rainfall mean of 668 mm (Kabote *et al.*, 2013), while rainfall in season 2 was below average.

Table 3-2: Summary of mean daily values for weather parameters at the experiment site for the two cotton growing seasons (Nov 2015 to Jun 2016 and Oct 2016 to Jun 2017).

		RH (%)	Temp (°C)	Precipitation (mm)	Solar radiation (W/m^2)	Soil Moisture VWC (m^3/m^3)	WFPS (%)	Soil temp (°C)
Season 1	Mean	71	23.8		247	0.11	32.4	28.0
	Min	23	20.7	0	211	0.05	15.3	23.8
	Max	103	27.4	45	339	0.18	51.3	31.5
	Total			759				
Season 2	Mean	54	24.6		259	0.11	32.7	29.4
	Min	39	20.4	0	226	0.05	13.8	22.6
	Max	75	28.5	48	438	0.21	63.0	35.5
	Total			522				

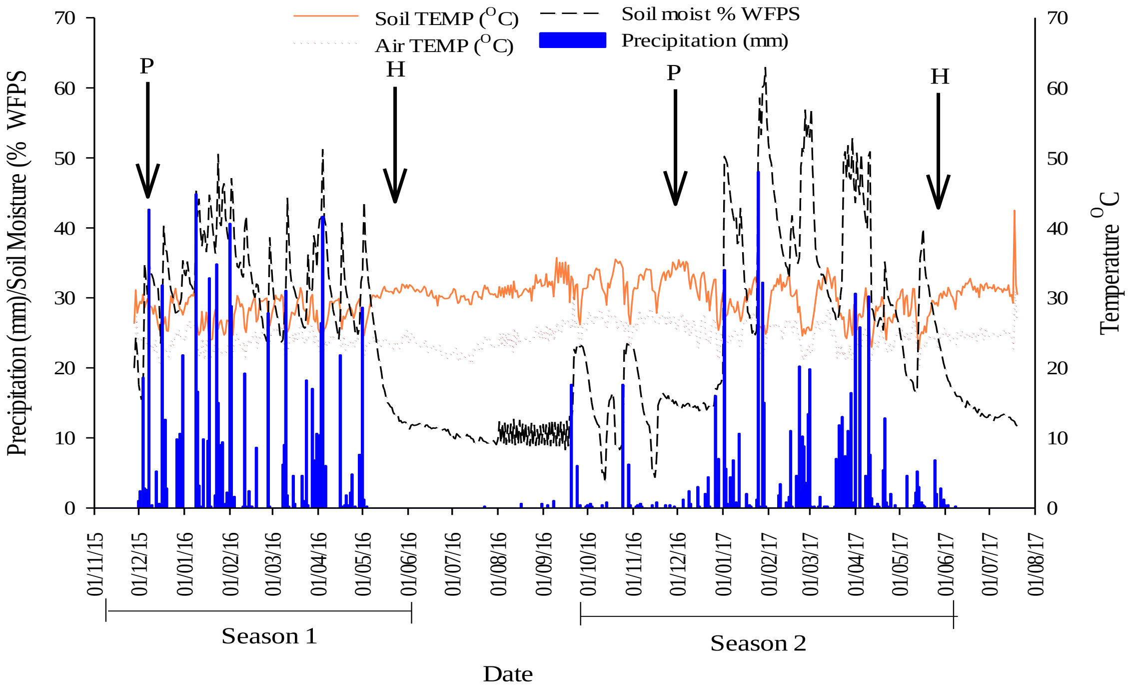

Figure 3-2: Variation in rainfall, soil moisture (% water filled pore spaces, WFPS), soil temperature (Soil TEMP) and air temperature (Air TEMP) during the experiment period for season -1(Nov 2015 to June 2016) and season 2 (Oct 2016 to June 2017).

Note: (Arrows show planting (P) and harvesting (H) time.

The mean daily soil and air temperature for seasons 1 and 2 were almost similar (Figure 3-2). There was slightly higher mean solar radiation in season 2 (226 W/m^2) than season 1 (211 W/m^2) and less soil moisture in season 2 than season 1.

3.4.2 Yield and economic performance

The yield response to soil fertility and pest management practices as well as the operational cost, revenue, gross margin (benefit) and BCR for the tested farming practices are shown in Table 3-3 and Fig. 3-3.

3.4.2.1 Current practices

The current organic practice of applying 3 Mg ha^{-1} FYM (OF-3) had no significant difference (p<0.05) on yield as compared to the current conventional farming practice of applying 30 kg N ha^{-1} (CF-30). For pesticides, the current organic practice of applying pyrethrum after scouting for pest incidences (OP-P) had no significant difference (*p*<0.05) on yield as compared to the current conventional farming practice of applying synthetic pesticides three times (CP-3).

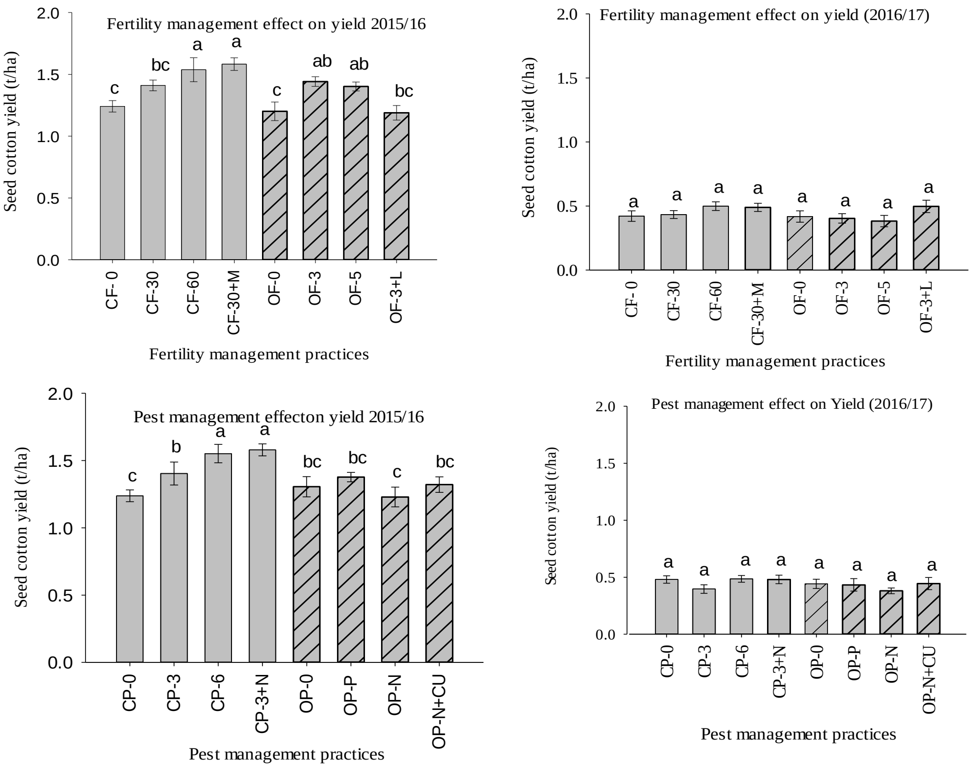

Figure 3-3: Effect of farming practices on seed cotton yield from plots under organic and conventional fertility and pest management practices for the cotton growing seasons 1 (2015/16) and 2 (2016/17).

(CF-0, 30, 60 refers to N levels (kg N ha^{-1}) in conventional farming and OF-0, 3, 5 refers to the amount of farm yard manure (Mg ha^{-1}). +M indicates conventional treatments with addition of manure and +L indicates organic treatment intercropped with green gram. CP-0, 3, 6 refers to number of sprays of conventional pesticide, +N refers to treatment with addition of Neem. OP-0, P, N and N+CU refers to no pesticide, pyrethrum, Neem and Neem + cow urine, respectively. Values with the same letters are not significantly different (p<0.05). The vertical bars extend standard error of the mean (SEM) for the mean yield.

Table 3-3: Performance of the fertility and pest management practices in terms of yield, cost, revenue, gross margin (GM), and benefit cost ratio (BCR) in Meatu, Tanzania.

	Cost USD/ha		Yield Mg/ha		Revenue USD/ha		GM USD/ha		BCR	
Treatment	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
Fertility Management Practices										
CF- 0	206 h	194 .f	1.26 c	0.46 a	573.d	210.b	353.d	15.c	1.61.c	0.1.b
CF-30	269 c	248 .c	1.43 b	0.44 a	651.c	202.b	374.cd	-46.de	1.4.cde	-0.2c
CF-60	325 a	304 .a	1.60 a	0.51 a	730.bc	233.b	397.cd	-70.e	1.19.e	-0.2.c
CF-30+M	297 b	274.b	1.53 ab	0.50 a	709.c	229.b	406.cd	-46 de	1.32.de	-0.2.c
OF-0	211 g	194 .f	1.22 c	0.49 a	664.c	271.ab	450.c	77 b	2.1.b	0.4 .a
OF-3	236 .f	216 .e	1.46 ab	0.44 a	798.b	245.b	554.b	29 c	2.3 ab	0.1 .b
OF-5	253 e	232 .d	1.42 b	0.39 a	658.c	214.b	404.cd	-18 cd	1.6.cd	-0.1 bc
OF-3+L	261 d	249 .c	1.20 c	0.50 a	941.a	401.a	666.a	151.a	2.4.a	0.6 .a
Pest management practices										
CP- 0	246.f	231.d	1.24. c	0.49.a	571.d	224.a	317.e	-6.9.ab	1.3.c	-0.02 ab
CP-3	274 c	254.c	1.40. b	0.40.a	647.cd	185.a	365.de	-68.4.b	1.3.c	-0.26.ab
CP-6	296 a	273.a	1.55 a	0.49.a	716.bc	226.a	412.cd	-46.2.ab	1.4.c	-0.16.ab
CP-3N+CU	285 b	263.b	1.58 a	0.52.a	728.abc	238 a	435 cd	-25.3.ab	1.5.c	-0.07 .ab
OP-0	222 h	205.f	1.31 bc	0.45.a	756.ab	283 a	526 ab	78 ab	2.3.a	0.4.ab
OP-P	235 g	220.e	1.38. bc	0.54.a	811.a	326 a	568.a	55.9.a	2.3 a	0.5a
OP-N	248 e	233.d	1.23. c	0.39.a	723.bc	244 a	467 .bc	106.ab	1.8.b	0.03.ab
OP-N+CU	251 d	233.d	1.32 bc	0.45.a	771.ab	279 a	513.ab	44 ab	2.0.b	0.2...ab
Interaction/Combination of selected fertility and pest management practices										
CF-0/P-0	185.7g	171.1f	1.2bc	0.44a	531.7c	205.5bc	338.3d	34.4bcd	1.75bc	0.2ab
CF-30/CP-3	265.6d	248.0d	1.3b	0.37a	594.4c	173.1c	321.2d	-74.9d	1.2de	-0.3b
CF-60/CP-6 30+M/CP-	344.3 a	320.9 a	1.8a	0.51a	820.0ab	235.1bc	463.9bc	-85.9d	1.3de	-0.3b
3N+CU	306.3b	280.9b	1.7a	0.48a	791.1ab	221.3bc	476.0bc	-59.5cd	1.5cd	-0.2b
OF-0/P-0	182.4h	174.1f	1.0c	0.47a	571.9c	264.5bc	381.8cd	89.8abc	2.0ab	0.5a
OF-3/OP-P	230.2f	217.3e	1.4b	0.64a	764.8b	354.9ab	527.0ab	137.6ab	2.2a	0.6a
OF-5/OP-P	264.1e	241.9d	1.4b	0.39a	538.1	160.7c	477.3d	-81.3d	1.1e	0.3d
OF-3+L/OP-N+CU	273.4c	260.9c	1.3b	0.67a	898.3a	486.6a	616.2a	223.0a	2.2a	0.8a

Note: Means within a column, for a particular management practices (fertility, pesticide and combination) followed by the same letter are not significantly (p<0.05) different according to Dancun New Multiple range Test

Likewise when comparing the combination of nutrient and pest management practices, the current organic practice OF-3/OP-P and current conventional practice CF-30/CP-3 had no significant difference (*p*<0.05) in yields. However, when comparing economic performance under prevailing marketing conditions, the current organic practices had significant higher (*p*<0.05) economic performance than conventional as the GM was higher in organic (USD 527 and 137.6 ha^{-1} for season 1 nad 2, respectively) than conventional (USD 321.2 and -74.9 ha^{-1} for season 1 nad 2, respectively) practice. The current organic practice is also more economically viable than the current conventional practice as the BCR for organic practice was higher than that of conventional practice (Table 3-3).

3.4.2.2 Higher input scenario

Comparing the higher input soil fertility management scenario of applying synthetic fertilizer at the rate of 60 kg N/ha for conventional (CF-60) and application of 5 Mg ha^{-1} FYM for organic (OF-5), the conventional management practice had significantly (*p*<0.05) higher yield than the organic practice. Likewise, when comparing the higher input pest management scenario of applying synthetic pesticide six times for conventional (CP-6) and that of organic of applying organic pesticide pyrethrum in response to pest incidence (OP-P), the high input conventional pesticide application scenario had significantly higher yield than the organic. Comparing the combination of soil fertility and pest management practices the high input conventional practice (CF-60/CP-6) had significantly (*p*<0.05) higher yield than the high input organic practice (OF-5/OP-P). However, when comparing the economic performance of the two higher input scenarios organic pracitces had relatively higher GM and BCR though no statistical difference was observed (Table 3-3).

3.4.2.3 Alternative practices

Conventional

Manure-fertilizer combination (CF-30+M)

In season 1, the alternative conventional farming practice of applying the recommended rate of fertilizer in combination with FYM (CF-30+M) had significantly ($p<0.05$) higher yield than the current conventional farming practice of applying 30 kg N/ha (CF-30). However, in season 2 no yield difference was observed between the two practices. For the case of economic performance, taking GM and BCR as indicators of economic performance and viability of the farming systems, respectively, the two farming practice had similar economic performance and viability as no significant difference ($p<0.05$) in GM or BCR between the two farming practices was observed (Table 3-3).

Three sprays of neem +cow urine (CP-N+CU)

In season 1, the alternative pest management practice for conventional farming of applying 3 sprays of neem and cow urine (CP-N+CU) had significantly ($p<0.05$) higher yield than the current practice of spraying synthetic pesticide 3 times (CP-3). In season 2, the yield for the practices were not significantly different ($p<0.05$). Considering economic performance for season 1, the alternative practice had relatively better performance than the common practice. However, in season two the performances were similar.

Organic

Cotton-legume intercrop (OF-3+L)

In season 1, the alternative organic farming practice of combining the current soil fertility management practice with legume intercrop (OF-3+L) significantly ($p<0.05$) decreased cotton yield as compared to current practice of applying 3 Mg ha^{-1} FMY. The yield was reduced by 18 % from 1.46 Mg ha^{-1} in (OF-3) to 1.2 Mg ha^{-1} in (OF-3+L) Table 3-3. For season 2, the two farming practices had similar yield. However, when considering economic performance the alternative practice had better performance as it had significant ($p<0.05$) higher GM and BCR for both season 1 and 2. The gross margin was increased by 20% from 554 to 666 USD /ha in season 1 and by 448% from 29 to 151 USD/ha in season 2.

Neem + cow urine (OP-N+CU)

In both season 1 and 2, the alternative pest management practice for organic farming of spraying neem and cow urine instead of the common practice of spraying pyrethrum (OP-N+CU) had similar ($p<0.05$) yield to the current practice of spraying pyrethrum (OP-P). Likewise, when considering economic performance indicated by GM for both season 1 and 2, the alternative practice and current practice had similar performance.

3.4.2.4 Interaction

Considering the combination of nutrient and pest management practices, the alternative practices were compared with current practice and high input scenarios. As shown in Table 3-3, the alternative conventional practice CF-30+M/CP-3(N+CU) had the highest yield (1.67 kg ha^{-1}) although it was statistically similar ($p<0.05$) to yield from high input scenario (CF-60/CP-6) and alternative organic (OF-3+L/OP-N+CU). The practice also had significantly ($p<0.05$) higher yield than the current practices. When considering economic performance for the selected interaction between pesticide and soil fertility management practices (Table 3-3), the interaction had significant effect on economic performance. The alternative organic practice had significantly higher economic performance than the other practices.

3.4.2.5 Yield compared to potential yield for UK MO8

The seed cotton yield ranged from 1.20 ± 0.06 to 1.46 ± 0.04 Mg ha^{-1} for organic farming practices and 1.26 ± 0.05 to 1.6 ± 0.05 Mg ha^{-1} for convention farming practices in season 1 (Table 3-3). For season 2, the yield ranged from 0.44 ± 0.03 to 0.51 ± 0.03 Mg/ha for conventional and 0.39 ± 0.05 to 0.50 ± 0.04 Mg ha^{-1} for organic. As indicated in Figure 3-3, for season 1, both nutrient and pest management practices had significant effect on cotton yield. However, for season 2 both pest and nutrient management practices had no significant effect on cotton yield. The yields observed in this study were generally considerably lower than the potential yield of the of the test variety (UK MO8) of 2.5 Mg ha^{-1} (Lukonge *et al.*, 2007) for both seasons 1 and 2. For season 1, the yield was down by 52% to 42% in the organic and 50% to 36% in the conventional system. For season 2 the yield was down by 82% to 80% in the organic and 84% to 80% in the conventional system.

3.5 Discussion

3.5.1 Yield and economic performance

3.5.1.1 Current practices

The similarity in yield between organic and conventional farming practices is linked to the fact that the current input levels between organic and conventional were also almost similar. Looking at the N input between the organic and the conventional practice, the N input for the conventional treatment was 30 kg N ha^{-1}which is comparable to the N input from the 3 Mg ha^{-1} FYM. With the N content of 1.04% in the applied manure, the N input from the organic treatment of 3 Mg ha^{-1} FYM was 31.2 kg N ha^{-1}, which is similar to the rate of 30 kg N ha^{-1} in the conventional farming system. This result is in line with that by Cavigelli *et al.* (2009) who found that wheat yield was similar between organic and conventional systems.

The results of this study, however, are contrary to many studies which indicated lower yield in organic than in conventional treatments (Foster *et al.,* 2013; Lee et *al.,* 2015; Ponisio *et al.,* 2015; Kniss *et al.,* 2016; Suja *et al.,* 2017; de Ponti *et al.,* 2012; Seufert *et al.,* 2012). These studies, however, were done in high input farming systems with high fertilizer levels in conventional farming. When considering economic performance, the relatively better performance in the organic system is linked to the lower input cost especially manure and organic pesticide and additional revenue per kilogram of seed cotton due to premium price of organic cotton.

3.5.1.2 High input scenario

For the high input scenario the high yield in the conventioal system is related to the relatively higher N input in conventional than organic farming. The increase in N level in cotton, increases seed cotton yield (Bell *et al.,* 2003; Prasad and Siddique, 2004; Saleem *et al.,* 2010) because the increased N rate increases leaf photosynthetic rate (Cadena and Cothren, 1995). This leads to higher accumulation of metabolites, thus impact boll weight and seed cotton yield. This result is in line with most studies which show higher yield in conventional than organic systems (Seufert *et al.,* 2012). Forster *et al.* (2013) in a cotton - wheat-soybean rotation in India found higher yield in conventional treatment receiving 105 kg N ha^{-1} as compared to organic treatment receiving 65 kg N ha^{-1}.

However, this was not the case in season 2 in the present study where no difference in yield between the two systems was observed regardless of the increased N input in the conventional system. This is linked to low soil moisture availability in season 2 (the rainfall received in season 2 was 26 % less than season 1), such that moisture was the most limiting factor that resulted in stunted plants which were then unable to utilize the higher applied N input. In terms of economic return, organic cotton had higher return due to low cost of production. Likewise, the higher economic return in the organic combination of soil fertility and pest management (OF-5/OP-P) than in the conventional system (CF-60/CP-6) is associated with the lower cost of the organic treatment and the premium price of organic cotton. This indicates that even for organic farming practices, if the input level is high the economic performance may decrease.

3.5.1.3 Alternative practices

Manure-fertilizer combination

The higher yield in season 1 in the alternative practice of applying the recommended rate of fertilizer in combination with FYM (CF-30+M) might be due to a synergistic interaction effect between FYM and inorganic fertilizers (Rao *et al.,* 2017), where FYM acts as a source of additional nutrients and supports moisture retention. FYM might also have supported increased microbial activity and hence nutrient availability to cotton plants (Kumari *et al.,* 2010). The higher yield for manure fertilizer combination could also be attributed to continuous supply of nutrients throughout the growing season (Lory *et al.,* 2006) whereby the inorganic fertilizers release nutrients rapidly during the early growth stages followed by gradual release of nutrients from organic manure at a later stage. Similar observations were reported by Kumari *et al.* (2010) who reported higher yield of cotton in the combination treatment of NPK+FYM 10 Mg ha^{-1} than in the treatment with NPK only. Rao *et al.* (2017) observed higher seed cotton yield in NPK +FYM at 10 Mg ha^{-1} than NPK treated plot. Hulihalli and Patil (2008) also found higher seed cotton yield in the combination of NPK fertilizer + FYM than fertilizer alone.

Thiss was also observed by Khaliq *et al.* (2006) where application of NPK in combination with OM had higher seed cotton yield than sole NPK. The economic return between the two treatments was not significantly different because of the additional input cost for the added FMY and hence higher input cost. The result from this study is contrary to results from other studies which indicated higher economic return from combination than sole application. Anwar-ul-Haq *et al.* (2014) reported higher yield and economic return of cotton from combination of 20 Mg ha^{-1} manure and NPK (at 88 kg N ha^{-1}) than sole NPK (at 175 kg N ha^{-1}) which was very high compared to that from the 30 kg N ha^{-1}in this study.

Three sprays of neem +cow urine

The three sprays of neem in combination with cow urine were likely more effective than application of three sprays of conventional pestcide (Lambda- Cyhalothrin 5 % EC) because the neem (*Azadirachta indica)* products contain biologically active components which when mixed with cow urine, the potency is increased by many folds (Gupta, 2005). The biologically active components of neem act broadly as toxicant, repellent, anti-feedant and growth disrupting substances on insect pests (Gujar, 1992) and also act as powerful Insect Growth Regulator (IGR) (Subbalakshmi *et al.,* 2012). The combinations of cow urine and neem-based products have shown significant synergistic effects to enhance product toxicity resulting in pest mortality (Gahukar, 2013) but are safe to insect predators particularly beetles Gupta (2005). In terms of economic return, the alterative practice had higher economic return because of the low cost of the locally available neem and cow urine.

Cotton legume intercrop

The low cotton yield in the cotton-legume intercrop might be attributed to resource competition from legume which however was compensated by legume yield. Jayakumar and Surendran (2017) associated this decrease with the early, vigorous growth of the intercrop that result in a smothering effect on the cotton crop. The result of this study is in line with study by Singh *et al.* (2017) who reported significant reduction in seed cotton yield in cotton-mung been and cotton-cowpea intercrop as compared to sole cotton. Several other studies have reported decreased cotton yield in cotton-legume intercrop (Khan and Khaliq, 2004; Nandini and Chellamuthu, 2004); Reddy *et al.,* 2005); Hallikeri *et al.,* 2007; Mankar and Nawlakhe, 2009); Sankaranarayanan *et al.,* 2012 and Khargkharate *et al.,* 2014). The higher economic performance in cotton-legume intercrop was due to the additional income from legume as compared to income from sole cotton and this increased the gross return and benefit cost ratio. This result is in line with results reported by Jayakumar and Surendran (2017) and Singh *et al.* (2017) who also reported higher economic return in cotton-legume intercrop than sole in cotton.

3.5.2 Yield as compared to potential yield for UK MO8

The lower yield compared to the potential yield of cotton variety UK MO8 in season 1 and 2 in this study for all treatments and their combinations is linked to the low rainfall in season 2 and soil fertility limitations. Low rainfall in season 2 severely affected the yield and hence masked the fertilizer and pesticide effect. The rainfall in season 2 (522 mm) was at the lower side of the minimum water required for cotton growth (500 mm) (OECD, 2008). With the same level of nutrient and pest management in the two seasons, soil moisture was the major limiting factor to primary productivity and biomass production. A series of intra-season dry spells were experienced in both season due to intermittent rain events (Figure 3-2). The cotton yield in season 1 was also less than potential yield of UK MO8 by 36%, which is narrower than the average yield gap in 43% for cotton in semi-arid Africa reported by Hengsdijk and Langeveld (2009).

A similar study in India reported lower than potential yield in cotton in one season with poor growing condition due to low rainfall and water logging in conventional but not in organic system (Forster *et al.*, 2013). A report by Hengsdijk and Langeveld (2009) showed that water is the main contributor to yield gap of up to 30% in semi-arid Africa region to various crops including cotton, and reported average of actual yield of 2.0 vs potential yield of 3.3 t ha^{-1}. For both season 1 and 2, the soil fertility limitations including high soil pH observed in the study area might also been a limiting factor for cotton yield to reach the potential yield for variety UK MO8. As indicated in chapter 2, the soil was categorise as marginally suitable for cotton production due to soil limitations.

3.6 Conclusions and Recommendations

Notwithstanding the different results between season 1 and 2, it was concluded that for the current practices, there is no difference in yields between smallholder organic and conventional cotton production practices. A difference would only occur if rate of N fertilizer is increased to 60 kg ha^{-1} or more in the conventional farming system. Cotton-legume intercrop reduced the yield of cotton which was, however, compensated by legume yield and economic return. Application of manure in combination with N fertilizer had relatively better yield than sole fertilizer. Neem+cow urine applied as pesticide had similar effect as pyrethrum in organic and synthetic pesticide in conventional but had higher economic return. Under condition of poor rains in semi arid areas like in the study area, moisture stress becomes limiting and hence the effect of soil fertility and pest management cannot be observed. Under the prevailing semi-arid conditions, smallholder farmers are rational on limited use of fertilizer and pesticide.

Based on the conclusions above, it is recommended that cotton-legume intercrop, fertilizer-manure combination and neem+cow urine be adopted as they are viable farming practices for smallholder cotton farmers. Further research is needed on maximising the effect of the associated legume species for effective use of the cotton-legume intercrop as a strategy for improving yield and economic performance of cotton.

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CHAPTER FOUR

4 NITROUS OXIDE EMISSION FROM SOILS UNDER SMALLHOLDER ORGANIC AND CONVENTIONAL COTTON FARMING SYSTEMS IN MEATU, TANZANIA

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4.1 Abstract

The global effort to simultaneously sustain natural resources and the supply of food and fibre is challenged by climate change which is linked to increased greenhouse gases (GHG) emissions. This study was undertaken for two growing seasons in semi arid cotton production areas in Meatu, Tanzania, and aimed at quantifying and comparing N_2O emission from soil under different smallholder organic and conventional cotton production practices. The current practices were tested against a higher input scenario and alternative practices for both organic and conventional cotton production. *In-situ* measurement of N_2O emission from soil was done using static chambers and gas analysis by gas chromatography. The results show that the current organic and conventional cotton farming practices had similar ($P < 0.05$) cumulative area-scaled N_2O emission. However, yield scaled emission were significantly higher in conventional than organic farming systems. For the high input scenario conventional cotton showed higher area-scaled and yield-scaled N_2O emission than organic cotton in season 1 which received higher rainfall (759 mm) but not in season 2 which had less rainfall (522 mm). A combination of manure and inorganic fertilizer as alternative practice reduced yield-scale N_2O emission by 17% from inorganic fertilizer. In season 1, intercropping cotton with legumes reduced area-scaled emission by 27%. The emission factor for both conventional and organic systems were < 1% of applied total N. The cummulative N_2O emission varied between 0.24 and 0.31 kg N_2O-N ha^{-1} in season 1and 0.52 and 0.60 kg N_2O-N ha^{-1} season 2. The results show that the current smallholder organic and conventional cotton farming practices had similar soil N_2O emission, which is very low compared to reported emissions from cotton fields in high input farming system (0.78 - 10.6 kg N_2O-N ha^{-1}). The current study indicates that combining manure and inorganic fertilizer as well as intercropping cotton with grain legumes has potential to be used by smallholder cotton farmers as a strategy for increasing yields while reducing the risk of higher N_2O emission from cotton fields.

Key words:- Greenhouse gases, N_2O emission, weather variability, organic farming, conventional farming, smallholder farmers, soil fertility management.

4.2 Introduction

Cotton *(Gossypium hirsutum* L.) is an important cash crop for smallholder farmers in Tanzania as it provides employment and supports livelihood of about 500,000 rural households (TCB, 2010). Improving livelihood of smallholder farmers in cotton growing areas of Tanzania and other developing countries is therefore linked to the improvement of cotton productivity. Like in other countries in Sub-Saharan Africa (SSA), cotton productivity in Tanzania is low with yields ranging between 560-750 kg ha^{-1} compared to Africa and World averages of 1.2 and 1.7 Mg ha^{-1}, respectively (UNCTAP, 2011). The low yield is caused by soil degradation, insects infestation and unfavourable weather conditions (TCB, 2010). There is limited use of fertilizer and pesticide in Tanzanian cotton growing areas compared to developed countries. In developed countries cotton is often highly fertilized with N fertilizer applications of up to 200 kg N ha^{-1} (Scheer *et al.* (2013). This compares to the recommended application rate in the Tanzania's western cotton growing area of 20-30 kg N ha^{-1} and farmyard manure applications of 5 Mg ha^{-1} (Mowo *et al.,* 1993).

To address the problem of low productivity, the government runs programs for increasing cotton productivity to 1.5 Mg ha^{-1} through among others, intensive use of fertilizers for nutrient management (TCB, 2010). Such farming practices may affect soil nutrient availability as well as soil environmental conditions, both of which directly affecting the exchange of GHG between terrestrial systems and the atmosphere (Smith *et al.,* 2007). Specifically, nitrogen fertilization is a key regulating factor for soil nitrogen and carbon dynamics and the associated exchange of N_2O with the atmosphere (Adviento-Borbe *et al.,* 2007, Mutegi *et al.,* 2010). The use of excess synthetic N fertilizers, is the dominating source of N_2O emissions from agricultural soils (IPCC, 2007). Nitrous oxide (N_2O), is a potent GHG with global warming potential 265 times that of CO_2 and almost 2/3 of the anthropogenic N_2O emission is coming from agricultural activities (Myhre *et al.*, 2013). In view of the need to increase cotton yields, good farming practices that maximize cotton productivity while keeping down GHG emission are highly required.

Among agricultural practices, organic farming practices are perceived to be more beneficial to the environment than conventional farming because chemical fertilizers, insecticides and herbicides, are avoided (Lorenz and Lal, 2016). However, it remains unclear whether this applies to GHG emissions from smallholder cotton production systems in SSA. Some studies have reported lower area-scaled emissions from organic than conventional farming (Syvasalo *et al.,* 2006; Kustermann *et al.,* 2008); however, yield-scaled emissions may be highest in organic farming (Skinner *et al.*, 2014). Studies in France showed higher N_2O emissions from conventional crop than organic crop rotations (Mathieu *et al.*, 2006; Petersen *et al.*, 2006) and the lower N_2O emission level in organic is linked to the lower N input in soils under organic management compared to those under conventional management (Muller and Aubert, 2014). Other findings indicate that organic farms had higher emission than conventional farms (Wood *et al.*, 2006; Kustermann *et al.*, 2008) and others did not find any difference (Syvasalo *et al.*, 2006).

The different results were associated to the geographical variations, type and scale of the farming system, level of inputs use and other management practices (Skinner *et al.*, 2014). However, most of these studies have only been done in developed countries with temperate climate and intensive organic and/or synthetic fertilizer use (Villanueva-Rey *et al.,* 2014; Meier *et al.,* 2015), leaving a wide knowledge gap for low input smallholder farms in tropical climate like in Tanzania. Moreover, there is only scanty information available for Africa, where only few studies have measured N_2O from conventional maize (Hickman *et al.,* 2015; Brümmer *et al.,* 2008; Gütlein *et al.,* 2018) and other cropping systems (Albanito *et al.,* 2017; Pelster *et al.,* 2017). Lack of flux data from developing countries has also dictated the IPCC GHG calculators to rely on models calibrated from measurements conducted mostly under temperate, developed country conditions (Rosenstock *et al.,* 2013). This has become challenging as the calculators may overestimate emissions in tropical developing countries, so that a strong need to broaden the scope of the underlying data has been articulated (Richards *et al.,* 2016). However, meta-anlyses have indicated that current emissions factors may also apply in tropical conditions (Albanito *et al.,* 2017).

The high level of heterogeneity of measured N_2O emissions among studies and the lack of information that address conventional and organic cotton production in smallholder farming systems, call for further studies. This study was undertaken in semiarid cotton production areas in Meatu, Tanzania to quantify and compare N_2O emission from soil under different smallholder organic and conventional cotton production practices to improve guidance on best management options.

4.3 Materials and Methods

4.3.1 Study site

The study was conducted in Meatu District, Simiyu Region, Tanzania. The area is between latitudes 3^o - 4^o South and longitudes 34^o 8’ - 34^o 49’ East at an altitude of 1 000-1 500 m above mean sea level. The area is within the semi-arid zone, with rainfall ranging from 900 mm per year in the north to 400 mm in the south. Crop and livestock farming are the major economic activities (URT, 2013). Cotton is the main cash crop in the area where both conventional and organic cotton production is practiced. Green gram (*Vigna radiata* (L.) R. Wilczek) is widely grown in the area and used in cotton - legume rotations and to some extent for intercropping with cotton. The study was done for two cotton growing seasons: 2015/16 (December 2015 to May 2016), referred here as season 1, and 2016/17 (December 2016 to May 2017), referred here as season 2. The experiment was carried out at BioRe Tanzania demonstration farm, Mwamishali Village located at 3^{o} 31’ 11’’South, 34^{o} 14’ 05’’ East).

4.3.2 Field experiment

The field experimental design is as presented in Section Chapter 3. In this study, N_2O fluxes from soils under smallholder organic and conventional fertility management practices were compared in a field experiment for two growing seasons 2015/16 and 2016/17. For organic farming, the tested fertility management practices were two different levels of organic manure and an alternative practice of intercropping cotton and green gram. For conventional farming, two application rates of N from synthetic fertilizer and an alternative practice of combining synthetic fertilizer and manure were tested. The N_2O study was part of the main study, which compared effect of both fertility and pest management on agronomic and environmental performance of cotton. For organic treatments, a rotation was established in season 2 where organic plots were shifted to plots planted with green gram in season 1, which is standard procedure for organic farmers in the area. Except for alternative practices, the management of treatments followed the standard recommended practices in the area.

4.3.3 Management of the experiments and treatments

Soil N_2O flux measurements were carried out on fertility management treatment plots with similar pest management practices, which were part of the main experiment on cotton management practices as shown in Figure 4-1 and Table 4-1.

Table 4-1: Treatment description

	Treatments (Practice)	**Treatment Application**	
		At planting	**Later in the season**
Organic	**OF-0 -** No organic fertilizer	-	-
	OF-3 - Current FYM 3 Mg ha^{-1}	3 Mg FYM ha^{-1}	-
	OF-5 - Recommended FYM 5 Mg ha^{-1}	5 Mg FYM ha^{-1}	-
	OF-3+L - FYM 3 Mg ha^{-1} + Inter-cropping green gram	3 Mg FYM ha^{-1}	At 2-4 weeks after planting cotton, plant green gram (*Vigna radiata),* between cotton rows.
Conventional	**CF-0 -** No organic fertilizer	-	-
	CF-30 – Recommended 30 kg N ha^{-1}	Apply 75 kg ha^{-1} DAP (13.5 kg N ha^{-1}, 15 kg P ha^{-1})	At squire formation top-dress with 35.9 kg ha^{-1} Urea (16.5 kg N ha^{-1})
	CF-60 - Higher rate, 60 kg N ha^{-1}	Apply 100 kg ha^{-1} DAP (18 kg N ha^{-1} + 20 kg P ha^{-1}),	At squire formation top-dress with 91.4 kg ha^{-1} Urea (42 kg N ha^{-1}).
	CF-30+M - FYM 3 Mg ha^{-1}+Fertilizer 30 kg N/ha, Alternative –	Apply 3 Mg FYM ha^{-1},	At squire formation top-dress with 65.2 kg ha^{-1} urea (30 kg N ha^{-1}).

FYM – Farm yard manure; DAP – Diammonium phosphate

The main experiment was arranged as a randomized split-split-plot block design where production systems were the main plot and pest management as a sub-plot and nutrient management as a sub-sub plot. Treatments were replicated in 3 blocks, where each block had organic plots, conventional plots and a legume rotation with test plot size of 10 x 5 m as described in Figure 4-1 and Table 4-1.

The chambers were placed in each fertility management practice within a reference pest management practice, making fertilizer the only source of variation. Land preparation was done by ox-plough in season 1 and by hand hoe in season 2. For manure treatments, manure was spread evenly in each plot and incorporated during ploughing. For N fertilizer treatments, Diammonium Phosphate (DAP) was incorporated in a planting hole at planting and side dressing of urea was done at cotton squire formation stage.

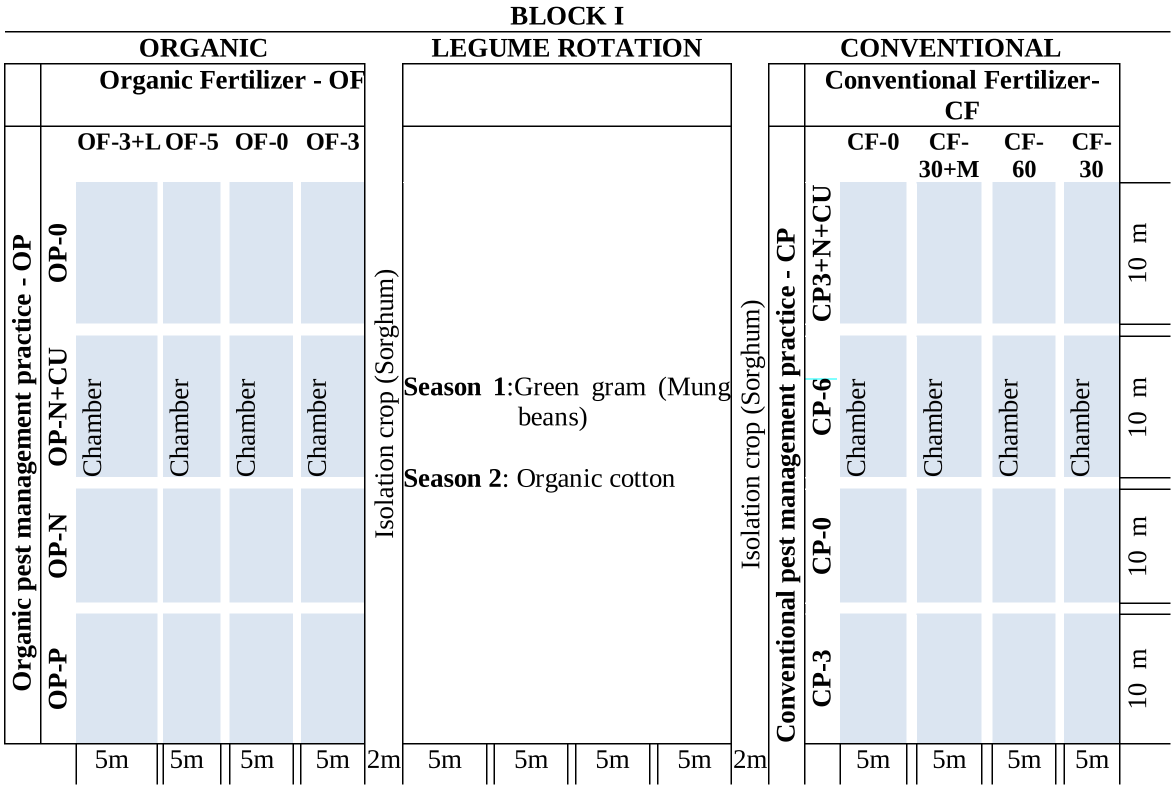

Figure 4-1: Plot layout Layout of the field experiment to compare performance of organic and conventional cotton production practices in Meatu, Tanzania.

Note:-(OP0 – No pesticide used; OP1 - Organic pesticide - used Pyrethrum; OP2 – Pest control by 3 pray of Neem crude extract; OP3 – Pest control by 3 spray of crude Neem extract + cow urine; OF-0 – No fertilizer use; OF-3 – Current organic practice using 3 t farm yard manure (FYM) ha^{-1}; OF-5 – Recommended organic fertilizer rate using 5 t FYM ha^{-1}; OF-3+L – Alternative organic practice, low rate of 3 t FYM ha^{-1} and intercropping with legume (*Vigna radiata (L.) R. Wilczek)*); CF-0 – Conventional farming -No fertilizer; CF-30 recommended fertilizer rate at 15 kg P ha^{-1} and 30 kg N ha^{-1}; CF-60 – high fertilizer rate at 20 kg P ha^{-1} and 60 kg N ha^{-1}; CF-30+M – Alternative practice - 3 t FYM ha^{-1} and 30 kg N ha^{-1})

4.3.4 Weather data

Weather and soil environmental data were measured hourly using an automatic weather station (AWS) installed at the experimental site at the beginning of the experiment. The AWS collected data on precipitation, measured with an ECRN-100 high-resolution rain-gauge (Decagon Devices Inc.), wind speed/direction measured with Davis cup anemometer, air temperature, humidity and pressure measured by a VP-4 Relative Humidity, Barometric Pressure, Air Temperature, and Vapour Pressure sensor (Decagon

Devices Inc.), solar radiation measured by PAR solar radiation sensor, and soil temperature and moisture measured by 5 TM soil moisture and temperature sensor (Decagon Devices Inc.) at 20 cm depth. Hourly averages were logged by an Em 50 data logger (Decagon Devices Inc.).

4.3.5 Soil analyses

Composite soil samples were collected prior to treatment application at a depth of 0-20 cm, air dried and sieved through 2mm sieve. The soil were then analysed for pH in water by electrode method (McLean, 1986), organic carbon by the Walkely and Black method (Nelson and Sommers 1986), total nitrogen by Kjeldahl wet digestion-distillation method, extractable P by Bray-1 method (Olsen and Sommers 1986), cation exchange capacity for basic cations (Ca, Mg, K and Na) by NH_4Ac saturation method and micronutrients (Cu, Fe, Zn, Mn) by diethylenetriaminepentaacetic acid (DTPA) method (Thomas, 1986).

4.3.6 Manure collection and analyses

Manure used in the experiment was collected from animal kraals at livestock keeper's households within the village. These farmers practice semi-extensive systems in which animals are grazed in open range during the day and at night they are kept in the animal kraal. The animals are guided to graze during the day in the available pastures and drink from nearby water bodies without any supplement feeding. The manure in the kraal is left to accumulate from the overnight droppings for up to two years before the kraal is shifted to another place. The manure is then scraped from the top surface layer of the kraal. Manure were collected from the kraal and heaped in each block before application. Three composite samples of the manure were collected from each block. The sampling was done by scooping from four random spots in the manure heap in each block (Zhang *et al.*, 2001). The manures were air dried and then ground to pass through 2 mm screen openings.

A wet digestion method followed by colorimetric determinations was used to measure total N and total P (Okalebo *et al.*, 2002). Organic carbon was determined by the Walkley-Black method (Nelson and Sommers, 1986). The manure used has organic carbon 8%, total N 1.03%, extractable phosphorus 103 mg/kg and C:N ratio of 7.8.

4.3.7 GHG collection system design and deployment

Emission of N_2O from soil in each treatment was determined by the vented closed-chamber method described by Parkins and Venterea (2010). The static chambers used in this study were mounted on rectangular hard plastic frames (0.35 m x 0.25 m) permanently inserted into the ground at 10 cm depth throughout each season. Two frames were inserted in each plot. At the time of flux measurement opaque chambers (0.35 x 0.25 x 0.125 m) were gas-tightly fitted to the frames by clips. The chambers were vented by tubes and insulated with aluminium foil. To ensure proper gas mixing in the headspace, the chambers were fitted with battery-driven fans. When plant height exceeded the chamber height, intersections of 15cm height were added between the frame and the top chamber. When the plants further grew beyond the size of the lid and the extension (75 days after planting), the plants in the position of the chambers were pruned at a height that fitted the extended chamber.

4.3.8 Gas sampling and analysis

Flux measurement were carried out fortnightly, taking into account time of fertilizer application and rain events. During chamber deployment and sampling, gas samples (60 mL) were collected from the headspace at approximately 0, 15, 30 45 and 60 minutes after deployment, using a syringe through a rubber septum. Out of the 60 mL of gas sample, the first 40 mL of the sample were used to flush the 10 mL sealed glass vials through a rubber septum, while the final 20 mL was retained into the 10 mL vials to achieve an over-pressure condition and minimize the risk of contamination by ambient air. Sampling was done between 8:00 and 16:00 hrs where four plots with total of eight chambers were sampled at a time. Block 1 which consisted of plot 1 – 8 were sampled between 8:00 and 10:00 hrs block II (plot 9-16) between 11:00 – 13:00 hrs and block III (plot 17-24) between 14:00-16:00 hrs. The effect of sampling time is thus confounded with the block effect. The gas samples were stored at room temperature and later sent to ILRI Nairobi for analysis at the earliest possible time within 10 days. The analysis of N_2O concentrations was done by an SRI 8610C gas chromatograph (2.74 m Hayesep-D column) fitted with an electron capture detector for N_2O. Details on analytical conditions and gas sampling is as described by Pelster *et al.* (2017).

Flux calculation and statistical analyses

The N_2O flux was calculated assuming a linear relationship between the N_2O concentration in the headspace and chamber deployment (Velthof and Oenema, 1995). The flux calculation were done using the HMR package in R (Pedersen *et al.*, 2010; R Core Team, 2013). The cumulative flux from each treatment for the two growing season was calculated by linear interpolation of the measured time point fluxes. Global warming potential was calculated by multiplying the N_2O flux by 265, the CO_2 equivalent global warming potential for N_2O (Myhre *et al.*, 2013). Yield scaled N_2O emissions, which express the cumulative soil N_2O emissions per unit of seed cotton yield, was calculated by dividing the cumulative N_2O emissions by seed cotton yield (Van Groeningen *et al.*, 2010). The cotton yield was obtained by harvesting seed cotton at sixty percent ball opening. The harvesting was done in a net plot of 4 m by 9 m by excluding the guide raws. The N_2O emission factor was calculated as percentage of applied N (organic and/or synthetic) emitted as N_2O-N, thereby deducting N_2O emissions from the background emission from unfertilized control (CF-0/OF-0).

Normally, the N_2O soil emissions from applied fertilizer and manures are estimated by using a default emission factor (EF) provided in the IPCC 2006 guidelines. The updated default EF for N inputs from mineral fertilizers, organic amendments and crop residues (EF1) is 1% (IPCC, 2006; De Klein *et al.,* 2006), which means the direct fertilizer-derived N_2O soil emission is equal to 1% of the amount of N applied. The emission factor obtained from this study was compared to the 1% IPCC threshold (IPCC, 2006) and emission from other farming systems obtained from global survey of peer-reviewed literature resulted in the selection of 38 studies including 422 observations at 43 sites in 12 countries done by Charles *et al.* (2017). Statistical differences in cumulative N_2O emission between treatments were analysed by ANOVA and pairwise comparison by Duncan's new multiple range test at 5% significance level using ExpDes package in R (Ferreira *et al.,* 2013) which considers balanced experiments under fixed statistical models (Ferreira *et al.,* 2014).

4.4 Results

4.4.1 Weather

The total rainfall recorded in the cotton growing season 1 (November 2015 to June 2016) was 759 mm while that in season 2 (October 2016 to June 2017) was 522 mm. The rainfall recorded in season 1 was above the long term (1994 - 2011) annual rainfall mean of 668 mm (Kabote *et al.,* 2013) while season 2 had below average rainfall.

The mean daily soil and air temperature for were almost similar for the two seasons. The air and soil temperatures varied considerable during the day (Figure 4-2). During the sampling period 08:00 and 16:00 soil temperature ranged from 24 ^{o}C at 8:00 to 38 ^{o}C at 16:00. There was relatively higher mean solar radiation in season 2 (226 W m^{-2}) than season 1 (211 W/m^2) and relatively less soil moisture in season 2 than season 1 (Table 4-2, Figure 4-3).

Table 4-2: Summary of mean daily values for weather parameters at the experiment site

		RH (%)	Temp (°C)	Precipitation (mm)	Solar radiation (W/m²)	Soil Moisture VWC (m³/m³)	WFPS (%)	Soil temp (°C)
Season 1	Mean	71	23.8		248	0.11	32.4	28.0
	Min	23	20.7	0	211	0.05	15.3	23.8
	Max	103	27.4	45	339	0.18	51.3	31.5
	Total			759				
Season 2	Mean	54	24.6		259	0.11	32.7	29.4
	Min	39	20.4	0	226	0.05	13.8	22.6
	Max	75	28.5	48	438	0.21	63.0	35.5
	Total			522				

A remarkable soil and air temperature difference was observed at different times within a day with highest temperature between 13 hrs and 16 hrs (Figure 4-2) Throughout the day, higher soil temperature than air temperature was recorded.

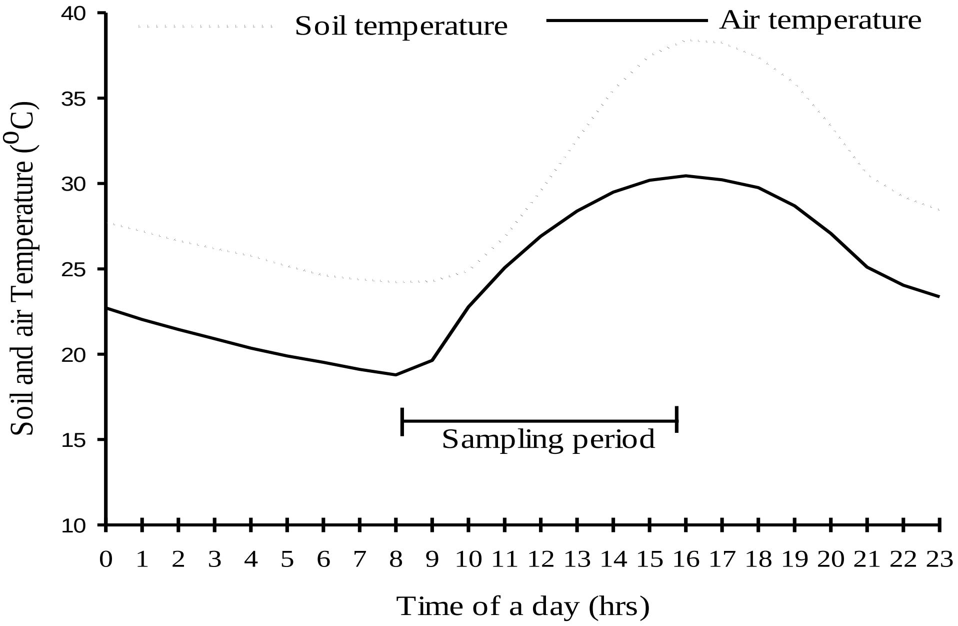

Figure 4-2: Variation in mean soil and air temperature with time in the sampling days.

(Note sampling always started at 08:00 hrs and ended at around 16:00 hours).

4.4.2 Soil and manure properties

At a depth of 0-20 cm, the soil at the experimental site was mostly black with a sand silty clay texture with 27, 4 and 68 percent clay silt and sand respectively. The soil has a pH of 7.84 and 6.91 in H_2O and $CaCl_2$ respectively; bulk density 1.36 g cc^{-1}; organic carbon 1.03 %; total N 0.14%; extractable phosphorus 16.0 mg kg^{-1}; exchangeable bases in cmol $_{(+)}$ Kg^{-1} of 17.87, 3.47 1.54 and 0.11 for Ca^{2+}, Mg^{2+}, K^+ and Na^+ respectively; micronutrients in mg kg^{-1} of 1.44, 1.11, 0.40, 9.12 for Cu, Fe, Zn and Mn, respectively.

4.4.3 Seed cotton yield

The seed cotton yield for the two season are shown in Table 4-3. As shown in the Table, the seed cotton yield in season 1 was higher than yield in season 2. Yield in season 1 ranged between 1.2 and 1.6 Mg ha^{-1} while in season 2 ranged between 0.39 and 0.51 Mg ha^{-1}.

4.4.4 Nitrous oxide flux

As shown in Fig. 4-3, the N_2O flux varied with time for both season 1 and 2. High fluxes were observed at the beginning of the season and after application of fertilizer and manure. First emission peaks were observed following planting and fertilizer application for conventional treatments (F1) and manure application for organic treatments (M). N_2O fluxes were also high after top dressing of urea (F2) in conventional treatments (Figure 4-3).

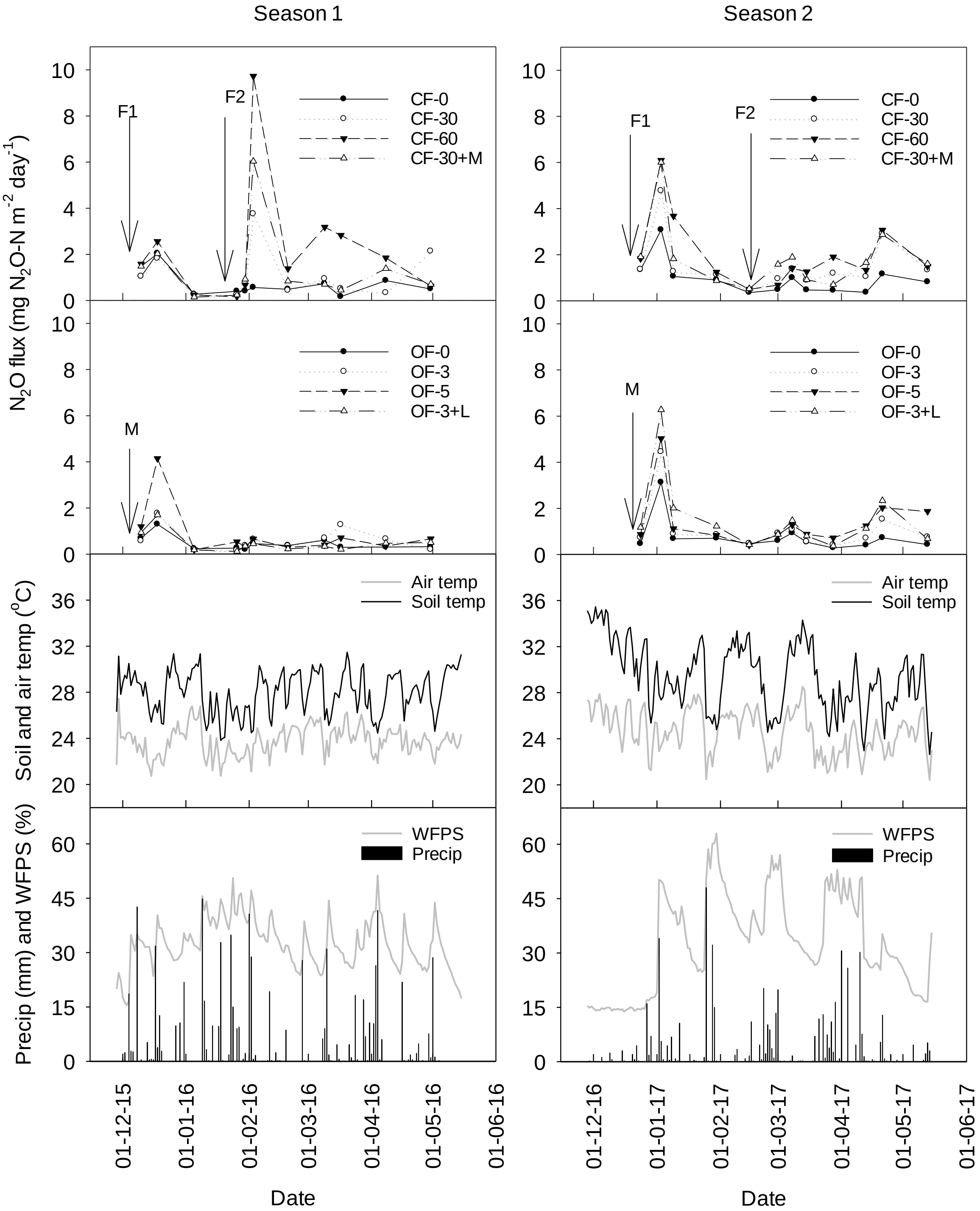

Figure 4-3: Seasonal variation in rainfall, soil moisture (water filled pore space), average daily soil and air temperature, and daily N_2O-N flux for season 1 (Nov 2015 to June 2016) and season 2 (Nov 2016 to June 2017).

Note:- Arrows shows fertilizer and manure application dates.

Table 4-3: Nitrous oxide emission factor (EF) and cotton seed yield for the different conventional and organic treatments (Mean ± SEM (standard error of the mean), n=3)

EF (kg N_2O-N kg^{-1} total-N)			Yield (Mg ha^{-1})		
Treatment	**Season 1**	**Season 2**	**Treatment**	**Season 1**	**Season 2**
CF-0	-	-	CF-0	1.26±0.05 c	0.46±0.06a
CF-30	0.79 ± 0.29 a	1.18± 0.23a	CF-30	1.43± 0.04b	0.44±0.03a
CF-60	0.69 ± 0.10 a	0.68± 0.11a	CF-60	1.6± 0.05a	0.51±0.03a
CF-30+M	0.32 ± 0.11 a	0.81± 0.18a	CF-30+ M	1.53± 0.1ab	0.50±0.03a
OF-0	-	-	OF-0	1.22 ±0.08c	0.49±0.08a
OF-3	0.42 ± 0.31a	0.61± 0.12a	OF-3	1.46± 0.04ab	0.44±0.06a
OF-5	0.39 ± 0.07a	0.56± 0.14a	OF-5	1.42± 0.04b	0.39±0.05a
OF-3+L	0.25± 0.05 a	0.53± 0.41a	OF-3+L	1.20 ±0.06c	0.50±0.04a

Note: Different letters within the same column indicate significant differences between treatments at $p < 0.05$.

4.4.4.1 Cumulative seasonal N_2O Fluxes and emission factor

During the first cotton growing season (November 2015 to June 2016) the area scaled N_2O flux varied with the farming practices from 0.11 to 0.31 kg N_2O-N ha^{-1} in organic farming practice and 0.08 to 0.49 in N_2O-N ha^{-1} in conventional cotton production. For the second growing season (November 2016 to June 2017), the N_2O flux ranged from 0.34 to 0.62 kg N_2O-N ha^{-1} in organic and from 0.26 to 0.73 kg N_2O-N ha^{-1} in conventional. The yield scaled N_2O flux for season one ranged between 0.09 to 0.22 g N_2O-N kg^{-1} seed cotton in organic and 0.06 to 0.31 g N_2O-N kg^{-1} seed cotton in conventional. In season 2 it ranged from 0.76 to 1.65 g N_2O-N kg^{-1} seed cotton in organic and from 0.55 to 1.48 g N_2O kg^{-1} seed cotton in conventional. The emission factor in Table 4-3 shows that for the high input scenario, the emission factor for convention farming practices was 0.69±0.10 in season 1 and 0.68±0.11 for season 2. For organic farming, the emission factor was 0.39±0.07 and 0.56±0.14 for seasons 1 and 2, respectively.

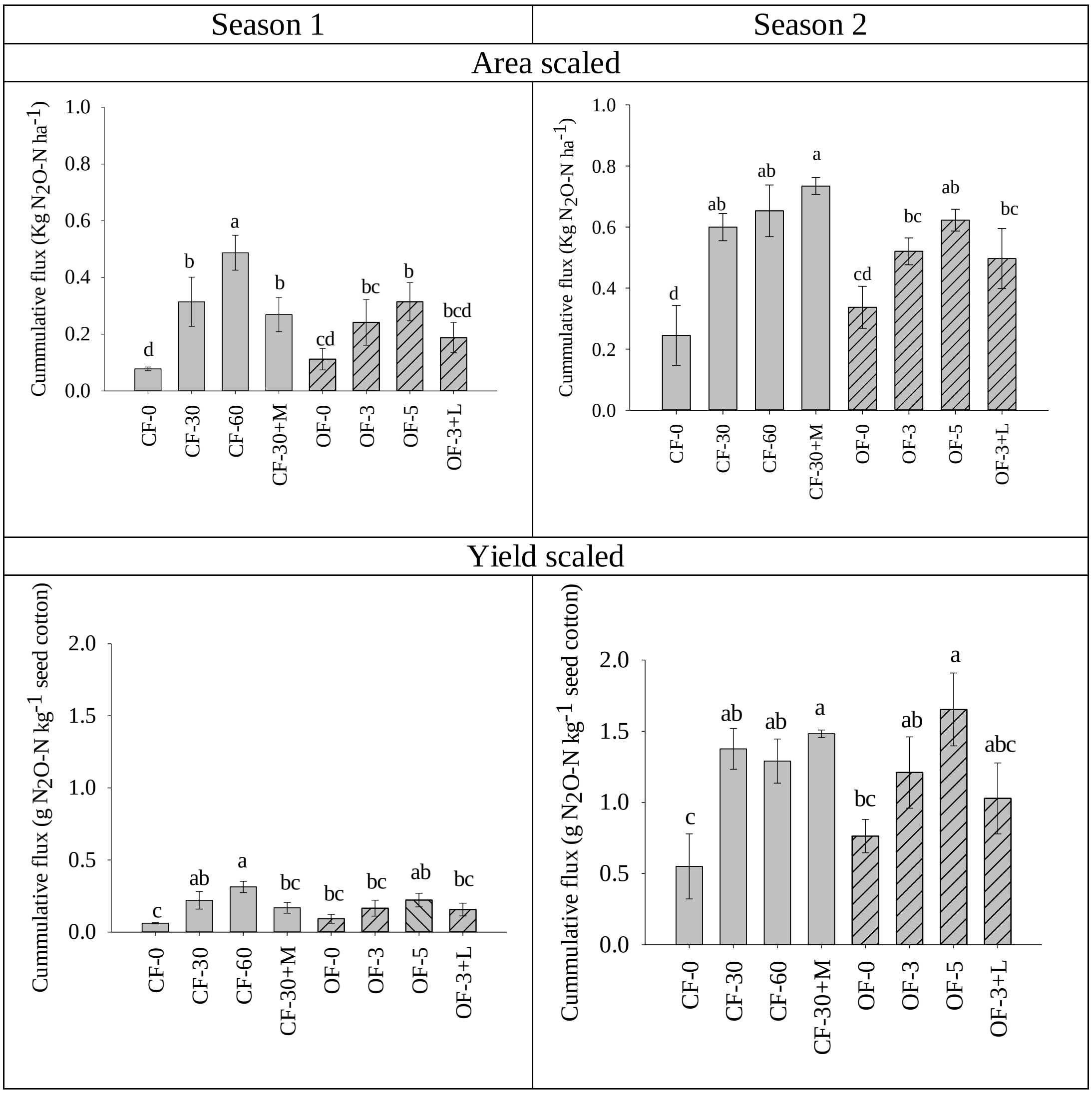

Figure 4-4: Effect of different cotton farming practices on cumulated N_2O-N flux from soils under organic and conventional fertility management practices for the cotton growing season 2015/16 (season-1) and 2016/17 (season 2).

Note: (CF-0,30, 60 referrers to N levels (kg N ha^{-1}) in conventional farming and OF- 0,3,5 amount of farmyard manure (t/ ha^{-1}). +M indicates conventional treatments with addition of manure and +L indicates organic treatment with legume. Values with the same letters are not significant different ($p < 0.05$). The vertical bars extend standard error of the mean (SEM) for the mean cumulative flux).

4.4.4.2 Current practices

Nitrous oxide emission from the existing organic farming practice of applying 3 ton ha^{-1} farmyard manure (OF-3) and recommended convention practice of applying 30 kg N ha^{-1} (CF-30) resulted in comparable N_2O emissions across the two investigated seasons (Fig. 4-4). For both seasons no significant difference ($P<0.05$) was observed in cumulative seasonal soil N_2O emission between organic and conventional farming practices, for both area-scaled and yield-scaled emission. For season 1, the area-scaled N_2O flux was 0.24 and 0.31 kg N_2O-N ha^{-1} for organic and conventional cotton, respectively, while the yield-scaled emission was 0.17 and 0.22 N_2O-N kg^{-1} seed cotton for organic and conventional. For season 2, the area-scaled emission was 0.52 and 0.60 kg N_2O-N ha^{-1} for organic and conventional cotton, respectively, while the yield-scaled emission was 1.21 and 1.38 N_2O-N kg^{-1} seed cotton for organic and conventional management.

4.4.4.3 High input scenario

Increasing N inputs as manure or chemical fertilizer in organic and conventional farming, respectively, affected N_2O flux from soil differently (Fig. 4-4). For conventional farming systems, increase in mineral N fertilizer rate from the recommended practice of 30 kg N ha^{-1} (CF-30) to higher levels of 60 kg N ha^{-1} (CF-60) significantly ($P<0.05$) increased both the area- and yield-scaled N_2O flux in season 1. The area-scaled flux was increased by 58% from 0.31 to 0.49 kg N_2O-N ha^{-1} and yield-scaled flux by 41% from 0.22 to 0.31 g N_2O-N kg^{-1} seed cotton. However, in season 2, enhancing N inputs compared to current farming practices did not significantly ($P<0.05$) affect soil N_2O fluxes.

For organic farming system, the increase in the N inputs in organic cattle manure from the current practice of 3 ton ha^{-1} (OF-3) to the recommended practice of 5 ton ha^{-1} (OF-5) in season 1 did not significantly ($P<0.05$) increase soil N_2O fluxes, neither if scaled to area or yield. However, for season 2, a relative increase in yield-scaled flux by 36% from 1.21 to 1.65 g N_2O-N kg^{-1} seed cotton was observed, while area-scaled fluxes did not differ statistically as compared to the conventional farming system.

4.4.4.4 Manure fertilizer combination

For conventional farming system, in both season 1 and 2, the area- and yield-scaled N_2O emission from the alternative farming practice of combining 3 ton ha^{-1} farmyard manure with an additional fertilization of 30 kg N ha^{-1} urea (CF-30+M) resulted in no significant changes in soil N_2O fluxes ($P<0.05$) as compared to treatments fertilized with 30 kg urea N ha^{-1} only (CF-30) (Figure 4-4). However, emissions varied seasonally with lower soil N_2O emissions in season 1 as compared to season 2, in particular for the C-30+M treatment.

4.4.4.5 Cotton legume intercropping

For organic farming, the alternative practice of intercropping cotton with green gram (OF-3+L) did in both seasons not significantly ($P<0.05$) affect soil N_2O emissions as compared to current organic farming practices. However, the practice reduced area-scaled N_2O emission by 21% from 0.24 in OF-3 to 0.19 kg N_2O-N ha^{-1}in OF-3+L.

4.4.5 N_2O Emission factor (EF)

The comparison of EF from this study to that of other studies and IPCC threshold is shown in Table 4-4. As indicated in table, for both conventional and organic farming practices, the emission factors obtained from this study were below the global estimate from other studies as well as below the IPCC threshold of 1.

Table 4-4: Emission factor from this study, global estimates of N_2O emission factors (N_2O EF) according to fertilization type and IPCC threshold.

Fertilizer Source	**This study**				**Other studies** Charles *et al.*, 2017		**IPCC Threshhold**
	Treatment	N rate Kg N ha^{-1}	EF		N rate Kg N ha^{-1}	EF	1
			Season 1	Season 2			
Organic	OF-3	31	0.42 ± 0.3	0.61± 0.1	154	0.82	
	OF-5	52	0.39 ± 0.1	0.56± 0.1			
	OF-3+L		0.25± 0.1	0.53± 0.4			
Organic and synthetic	CF-30+M	61	0.32 ± 0.1	0.81± 0.2	150	1.5	1
Synthetic	CF-30	30	0.79 ± 0.2	1.18± 0.2	130	1.34	1
	CF-60	60	0.69 ± 0.1	0.68± 0.1			

4.5 Discussion

4.5.1 Weather and yield

There was a marked difference in rainfall between the two growing season with 759 and 523 mm for seasons 1 and 2, respectively. Consequently, mean soil moisture was significantly higher in season 1. The rainfall in season 2 was below the long term average (668 mm). Season 1 had yields ranging from 1.2 to 1.6 t ha^{-1}, while in season 2 yields ranged from 0.4 to 0.5 t ha^{-1}. The low rainfall in season 2 was just above the minimum rainfall requirement for cotton of 500 mm (OECD, 2008), and this is likely the reason for the low yield in this season. The rainfall was also not evenly distributed through the growing season, also affecting cotton growth. Season 2 experienced much longer intra-season dry spells associated with low moisture as compared to season 1 (Figure 4-3).

4.5.2 Cumulative seasonal N_2O emissions

The average seasonal soil N_2O fluxes varied with farming practices from 0.11 to 0.31 kg N_2O-N ha^{-1} for organic treatments and 0.08 to 0.49 kg N_2O-N ha^{-1} for conventional treatment, which is relatively low compared to soil N_2O fluxes observed for other crops in other studies in smallholder tropical farming systems (Albanito et al., 2017). A study by

Rosenstock *et al.* (2016) in Kenya and Tanzania reported an annual N_2O flux of 0.4 and 3.9 kg N_2O ha^{-1} yr^{-1} for cassava and pasture, respectively. The N_2O flux obtained in this study is also low compared to the N_2O fluxes reported for high fertilizer input cotton production.

For Australia, Scheer *et al.* (2013) reported N_2O fluxes of 0.80 to 1.07 kg N_2O-N ha^{-1} for irrigated cotton fertilized at a rate of 200 kg N ha^{-1} and low to high irrigation intensity, respectively. This compares to N_2O fluxes of 0.9 to 6.5 kg N_2O-N ha^{-1} reported by Scheer *et al.* (2008) for a study carried out in irrigated cotton fields in Uzbekistan, which were fertilized at a rate of 162 to 250 kg N ha^{-1}. In Australia also, Macdonald *et al.* (2015) measured 0.8 and 10.6 kg N_2O-N h^{-1} in response to 200 and 320 kg N ha^{-1} ; Scheers *et al.* (2014) measured 1.91 kg N_2O-N h^{-1} in response to 200 kg N ha^{-1} Scheers *et al.* (2013) measured up to 1.07 kg N_2O-N h^{-1} and Grace *et al.*, 2010 measured 0.64 to 0.97 kg N_2O-N h^{-1}.

This means, that N_2O emissions in the present study for organic (0.11 to 0.31 kg N_2O-N ha^{-1}) and conventional farming practices (0.08 to 0.49 kg N_2O-N ha^{-1}) are smaller by a factor of 3-10 as compared to observed N_2O fluxes for high input cotton farming systems elsewhere. The low magnitude of emissions in our study is very likely linked to the low rate of N application (30 - 60 kg N ha^{-1}) and low values of soil moisture, which only occasionally approached a value of 60% WFPS, i.e. a threshold value which is widely thought to be needed to support soil denitrification activity (Linn and Doran, 1984; Bouwman, 1998; Schindlbacher *et al.,* 2004). For season 1, which received annual rainfall 759 mm, and considered to be a good year in terms of rainfall, the soil water-filled pore space (WFPS) was below 60 (ranging between 15% and 51%). In season 2 total rainfall was 523mm and soil moisture ranged between 13% and 63% WFPS, indicating that in some instances conditions for anaerobiosis and denitrification might be given. Comparing the two seasons, generally season 2 had relatively higher fluxes than season 1. This is linked to a large rain pulse in season 2 (Figure 4-3), which promoted high soil moisture and, thus, favorable moisture condition for denitrification, a dominant source of N_2O (Bouwman, 1998; Butterbach-Bahl *et al.*, 2013).

4.5.2.1 Current practice

As shown in Figure 4-4, the current organic practice OF-3 and current conventional practice CF-30, showed no significant ($P<0.05$) difference in both area-scaled and yield-scaled N_2O emissions. The result in this study is not in line with results for high input farming system where higher area-scaled N_2O emissions were observed in conventional farming system than organic (Petersen *et al.*, 2006; Syvasalo *et al.*, 2006; Kustermann, *et al.*, 2008; Skinner *et al.*, 2014). This difference is probably due to climate, soil conditions and N-input levels in our study. In the study by Petersen *et al.* (2006) in five European countries the total N input for conventional arable systems ranged between 100 - 300 kg N ha^{-1} yr^{-1} while, that of organic arable systems ranged between 80 - 180 kg N ha^{-1} yr^{-1}. These levels of N fertilization are 10 and 6 times higher than N input in the current study for conventional and organic farming systems, respectively.

The lack of differences between the two management practices is associated to the fact that the low N input rates in conventional farming had almost similar total N input as the organic management. With the N content of 1.04% in the applied manure, the N input from the organic treatment of 3 t ha^{-1} FYM was 31 kg N ha^{-1}, which is equivalent to the rate of 30 kg N ha^{-1} used in the conventional cotton growing system in our study. Furthermore, in both system the N rate is still low compared to the suggested minimum N application rate for high N_2O emissions from oxic soils of 100 kg N ha^{-1} (Hickman *et al.*, 2015). The results for this study indicates that under the current farming practices organic and conventional, have similar and insignificant soil N_2O fluxes.

4.5.2.2 Higher input scenario

Increasing the application rate of fertilizer and/or manure as a fertility management practice enhanced N_2O emissions in both organic and conventional cotton production. The enhanced N_2O flux is associated to the fact that applying mineral N fertilizer and livestock manure enhances the availability of N and C in soil which are essential substrate for N_2O production via denitrification (Bouwman *et al.*, 2002; Akiyama and Tsuruta, 2003; Akiyama *et al.*, 2006; Mori and Hojito, 2012). Addition of manure increases the organic C content and stimulates microbial activity and thus N_2O emissions (Drury *et al.*, 1991; Chadwick *et al.*, 2000). The manure applied in our experiment was of low C:N ratio (7.8). The increase in N_2O emissions may thus be linked to easily decomposability of the manure (Toma and Hatano, 2007). The result of this study is in line with result by Allen *et al.* (2010) and Shcherbak *et al.* (2014), who indicated exponential increases in N_2O emissions with increasing levels of N fertilizer application. Though the trend in season 1 and 2 was not very similar, the results indicates that, if the smallholder conventional farmer increase fertilizer use from the recommended rate of 30 kg N ha^{-1} to a higher level, say 60 kg N ha^{-1} or above, the N_2O flux for conventional farming would be higher than that from organic systems.

4.5.2.3 Fertilizer-manure combination

The relative reduction in soil N_2O fluxes in the alternative farming practice of combining 3 t ha^{-1} manure and recommended rate of 30 kg N ha^{-1} (CF-30+M) in season 1 is in line to findings by Das and Adhya (2014) who found that the mix of compost and urea-N reduces N_2O emission from rice fields in India. Other studies in China and Zimbabwe also showed that combining inorganic NPK and compost as an integrated fertilizer management practice has the potential to significantly reduce N_2O emissions compared to compost or NPK fertilizer alone (Cai *et al.*, 2013; Ding *et al.*, 2013; Nyamadzawo *et al.*, 2014). Graham *et al.* (2017) in a review suggested that combining inorganic N fertilizer with organic amendments having low to medium C:N (<8) may reduce N_2O emissions by avoiding stimulation of soil microbial communities and rapid inorganic N mineralization. Microbial activity and resulting N_2O emissions from INM treatments not only depend on C:N ration of the organic amendments, but also the amount of inorganic N in soil from added fertilizer.

The relatively higher N_2O emissions in season 2 from the combined manure and fertilizer treatment may be linked to residual effect of manure applied in season 1. Although, combining inorganic fertilizer and organic amendments is no guarantee for low N_2O emissions from agricultural soils (Graham *et al.*, 2017), the results from our study indicates the potential for smallholder farmers to increase N supply in the soil by mixing organic and low rate of inorganic fertilizer without risk of increasing N_2O flux.

4.5.2.4 Cotton legume intercrop

For organic cotton production, intercropping green gram and cotton in addition to common practice of manure application reduced N_2O emission. Though not statistically significant (p <0.05), N_2O emission was reduced by 27%. Similar results were reported by Pappa *et al.* (2011), Kyer *et al.* (2012), Huang *et al.* (2014) and Senbayram *et al.* (2016) who, in their studies, reported reduced N_2O emission in intercrops of different legume and non-legume species compared sole crops. There is limited data available on GHG emission from cotton-legume intercrops and nothing was found on cotton-green gram intercrop. However, some researchers argue that there is a beneficial effect when legumes are intercropped with non-legumes (Cardoso *et al.,* 2007), The reduced N_2O flux in cotton-green gram intercrop indicates that using legume as an intercrop in cotton can reduce N_2O flux from soils planted with cotton and therefore, smallholder farmers may use intercropping as strategy for lowering N_2O emission while increasing cotton productivity. However, further studies are needed on suitable legume species, mechanisms by which this influences N_2O emissions, and conditions necessary for effective use of the strategy.

4.5.3 N_2O Emission factor (EF)

Fertilizer induced soil N_2O emissions from fertiliser and manure applications in all farming practice in this study were lower compared to results from higher input farming systems (Table 4-4). This is probably due to the comparable low level on N input in this study. The N input of between 30 and 60 in this study is not comparable to the high rate of between 130 to 154 kg N ha^{-1} in the other studies. Furthermore the N_2O emission factors from this study are less than the IPCC default value (1%). This study is consistent with other empirical studies in sub-Saharan Africa which showed limited soil EFs below the default IPCC's 1% in the region (Chapuis-Lardy *et al.,* 2007; Brümmer *et al.,* 2008; Mapanda *et al.,* 2011; Pelster *et al.,* 2017; Tully *et al.,* 2017; Ortiz-Gonzalo *et al.,* 2018). This indicates the need for the available GHG calculators that rely on EFs and empirical models calibrated in temperate regions to be calibrated for these regions. More EF data from these region are important for calibration of emission factors (EFs) and models to reduce uncertainties of soil GHG emissions estimations.

4.6 Conclusions

The study shows that for low input smallholder cotton farming system in Tanzania the N_2O emission does not differ between organic and conventional cotton production practices as the N input in the two system is almost the same. However, if the rate of N fertilizer is increased to 60 kg N ha^{-1} or more in the conventional farming system, the N_2O emission from conventional farming are likely to increase significantly. Nevertheless, observed soil N_2O emissions from all systems investigated, low as well as “high” (60 kg N ha^{-1}) are low as compared to soil N_2O emissions from other intensively managed arable soils elsewhere and the emission factors for both systems are low camapred to the IPCC default value of 1%. Cotton-legume intercrops have a potential to improve the N status of soils while also limiting soil N_2O emission. Application of manure in combination to N fertilizer can also be used to avoid increase of N_2O emissions from cotton fields with higher N application rates. Further research is needed on the legume species and other contributing factors for effective use of the strategy.

4.7 References

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CHAPTER FIVE

5 EFFECTS OF FARMING PRACTICES ON MICROBIAL ACTIVITY IN SOILS UNDER SMALLHOLDER ORGANIC AND CONVENTIONAL COTTON FARMING SYSTEME IN MEATU, TANZANIA

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5.1 Abstract

Farming practices such as use of organic and synthetic fertilizers and pesticides can change the soil environment and hence microbial activity and soil quality. In this study a comparative assessment was done for two growing season (2015/16 and 2016/17) on microbial activity in cotton plots under organic and conventional soil fertility and pest management practices. Enzyme activity (arylsulfatase), potential nitrification (PN) and basal respiration from plots under current practice, recommended practice, higher input scenario and alternative organic and conventional practices were tested against each other and no fertilizer and pesticide control. The result showed that for the current levels of fertilizer and pesticide use, there was no significant (p <0.05) difference in microbial activity between organ and conventional cotton production practices. However, increasing N level as fertilizer or manure increased microbial activity. Manure + fertilizer combination as an integrated practice increased arylsulfatase activity and PN but reduced basal respiration in conventional farming in both seasons. Intercropping with grain legume increased microbial activity (arylsulfatase) but reduced PN and basal respiration and hence had no clear trend on improving soil microbial activity. Pest management had no effect in microbial activity under both organic and conventional farming practice and there was no significant difference between the organic and conventional practice. It was therefore concluded that the existing smallholder organic and conventional cotton farming practices in the experimental area have similar effect on soil microbial activity. However, manure and fertilizer combination as an integrated practice is a viable options for improving microbial activity and hence soil quality. Further studies are required on the effect of cotton-legume intercrop on soil microbial activity in these areas to clarify the viability of this practice in improving microbial activity and soil quality.

Key words: Microbial activity, organic cotton, conventional cotton, soil quality, Birch effect, Arysalfatase activity, Basal respiration, potential nitrification

5.2 Introduction

In Sub-Saharan Africa (SSA), cotton (*Gossypium hirsutum* L.) is among the most important cash crops, supporting the livelihoods of millions of smallholder farmers (Staritz and Tröster, 2015). In Tanzania, for example, cotton provides employment and supports livelihoods of about 0.5 million rural households (Tanzania Cotton Board, 2010) and is ranked second (after tobacco) in terms of the agricultural export value (URT, 2016). Cotton production in SSA is dominated by smallholder farmers and is characterised by low productivity. In Tanzania, cotton yields typically range between 560-750 kg ha^{-1} compared to world average of 1700 kg ha^{-1} (UNCTAP, 2011). The low yield may be attributed to site specific factors like soil degradation and unfavourable weather conditions, but in particular also to the limited use of fertilizer and pesticides compared to high input farming systems (Tanzania Cotton Board, 2010).

The recommended fertilizer application rates in Tanzania's western cotton growing area are 20-30 kg ha^{-1} mineral nitrogen (N) and 5 Mg ha^{-1} farmyard manure (Mowo *et al.*, 1993), which are much less than the rates of up to 200 kg N ha^{-1} applied in high input farming systems. To sustain the livelihoods of smallholder farmers, who depend on cotton farming, in Tanzania and other developing countries, sustainable improvement of cotton productivity is required. However, increased use of N fertilizer and pesticides may not be a feasible option for smallholder farmers and in particular not for organic cotton production, which currently represent 5% of the farming practise (Tanzania Cotton Board, 2010).

The intrinsic links between soil fertility and soil microbial activity need to be exploited and optimized for yield improvement. Microorganisms sustain fundamental processes and ecosystem services in the soil, and respond quickly to natural and environmental stress

(Barrios, 2007). This allows the use of microbial biomass and activity as indicators of productivity of soil and agricultural land (van der Heijden *et al.,* 2008) and as early indicators of changes in soil quality (Kennedy and Smith, 1995; Pankhurst *et al.,* 1995).

In arid and seasonally dry ecosystem like in the study area, seasonal rainfall which fall after a long dry period causes rewetting pulses that causes high CO_2 flux (Wang *et al.,* 2015). This phenomenon, referred to as "Birch effect" (Birch, 1958; Fraser, 2016) is linked to the immediate release of microbial osmolytes upon rewetting and/or rapid metabolism of organic substrates released by disruption of soil structure (Unger *et al.,* 2010; Moyano *et al.,* 2013). Fertility management practices have influence on soil adaphic and biotic factors which upon rewetting have influence on the CO_2 flux. Since the rate of the CO_2 flux upon rewetting relates to the active organic pool in the soil (Franzluebbers *et al.,* 2000) and hence fertility management practice, the birch effect can be used as an indicator of the performance of a given farming practice and useful indicator of soil quality (Marumoto *et al.,* 1982; Sparling *et al.,* 1995).

Studies of microbial activity in soils under organic and conventional management are scanty in smallholder farming systems in tropical SSA. Reviewed on a global scale, Lori *et al.* (2017) indicated that organic farming enhanced total microbial abundance and activity in agricultural soils. Also, several studies concur that manure, as typically applied in organic systems, have positive effects in enhancing microbial diversity and activity due to the combined input of labile carbon (C) substrates and N (Araujo *et al.,* 2009; Lovieno *et al.,* 2009; Chauhan *et al.,* 2011; Järvan *et al.,* 2014; Chaudhary *et al.,* 2015). For example, higher rates of soil enzyme activity (Bandick and Dick, 1999; Diacono and Montemurro, 1999), potential nitrification (Chirinda *et al.,* 2008; Edesi *et al.,* 2013; Wu *et al.,* 2017) and soil respiration (Araujo *et al.,* 2009; Zheng *et al.,* 2014; Ren *et al.,* 2017) have been reported in organic than in conventional farming systems, typically linked to enhanced availability of labile organic matter in organic systems, stimulating the metabolism of soil microorganisms (Saffigna *et al.,* 1989; Zheng *et al.,* 2014).

However, some studies have reported similar soil respiration in organic and conventional treatments (Edesi *et al.,* 2013) or even decreased soil respiration with organic manure application compared to inorganic fertilizer when soil total N was less than 1 g kg^{-1} (Ren *et al.,* 2017). This underlines that the effect of management systems in terms of stimulating soil microbial activity and fertility depends on variations in local parameters, such as type and rate of amendments, as well as soil and climatic characteristics. In this respect, the microbial responses to organic management and changes in conventional management are largely unknown in soils under cotton production in SSA.

The present study was performed in the semi-arid cotton producing areas in Meatu, Tanzania, to assess the effect of organic and conventional farming practices on microbial activities (enyzme activity, basal respiration, potential nitrification and birch effect) in soils under different smallholder cotton production practices. Specifically the study aimed to trace potential differences in soil microbial activity and fertility, which could be useful for advancing recommendations of the best cotton farming practices for sustainability of cotton production.

5.3 Materials and Methods

5.3.1 Study site and field experiment

The study site was located at the BioRe Tanzania demonstration farm, Mwamishali Village (3^{o}31'11"S; 34^{o}14'05"E) in the Meatu District, Simiyu Region, Tanzania. The area is within the semi-arid zone, 1 000-1 500 m above mean sea level, with annual rainfall ranging from 400 mm in the south to 900 mm in the north. Crop and livestock farming are the major economic activities (URT, 2013), and cotton is the main cash crop in the area where both conventional and organic cotton production is practised. green gram (*Vigna radiata* (L.) R. Wilczek) is widely grown in the area and used in cotton-legume rotations and to some extent for intercropping with cotton.

The study covered two cotton growing seasons representing December 2015 to May 2016 (Season 1) and December 2016 to May 2017 (Season 2). In each season, soils were collected from a block-designed (*n* = 3) field experiment, set up to study agronomic and ecological effects of various organic and conventional management practices. The study represented (i) organic treatments with two different rates of organic manure (3 Mg FMY ha^{-1} and 5 Mg FMY ha^{-1}) and an alternative practice of intercropping cotton fertilized by 3 Mg FMY ha^{-1} and green gram, and (ii) conventional treatments with two different rates of mineral N fertilizer (30 kg N ha^{-1} and 30 kg N ha^{-1}) and an alternative practice of combining of manure at 3 Mg FMY ha^{-1} and mineral fertilizer at 30 kg N ha^{-1} (Table 5-1).

For organic treatments, a rotation was established in Season 2 where organic plots were shifted to plots planted with green gram in Season 1, which is standard procedure for organic farmers in the area. Except for alternative practices, the management of treatments followed the standard recommended practices in the area. For pest management practices, different levels and type of pesticide were tested against recommended pesticide levels for organic and conventional practises.

Table 5-1: Treatment description

Production System	Nutrient Management Practice	Pest Management Practice
	Fertilizer	**Pesticide**
Organic cotton (O)	v. No fertilizer(**OF-0**)	**v.** No pesticide (**OP-0**)
	vi. Current practice FYM 3 Mg ha^{-1} (**OF-3**) (At planting apply 3 Mg FYM ha^{-1})	**vi.** Pyrethrum (Natural Pyrethrin extract, 0.2%v/v) (**OP-P**) (each spray: 272 ml ha^{-1} Natural Pyrethrin extract. number of sprays determined by scouting)
	vii. Recommended FYM - 5 Mg ha^{-1} (**OF-5**) (At planting apply 5 Mg FYM ha^{-1})	vii. Neem leaves (12.5% w/w) (**OP-N**) (each spray: 24.8 kg ha^{-1} fresh neem leaves extract + 3.5 l ha^{-1} sunflower oil. The number of sprays determined by scouting)
	viii. Innovative FYM 3 Mg ha^{-1} + Inter-cropping greengram - *Vigna radiata* , – (**OF-3+L**) (At planting apply 3 Mg FYM ha^{-1}. At 2-4 weeks after planting cotton, plant greengram *(Vigna radiata)* between cotton rows)	viii. Neem (12.5% w/w) + cow urine (2.5% v/v)- (**OP-N+CU**) (each spray: 24.8 kg ha^{-1} fresh neem leaves extract + 3.5 l ha^{-1} sunflower oil + 5.0 l ha^{-1} cow urine. The number of sprays determined by scouting)
Conventional cotton	v. No fertilizer(**CF-0**)	v. No pesticide(**CP-0**)
	vi. Recommended 30 kg N/ha (**CF-30**) (At planting apply 75 kg ha^{-1} DAP (13.5 kg N ha^{-1}, 15 kg P ha^{-1}), at squire formation top-dress with 35.9 kg ha^{-1} urea (16.5 kg N ha^{-1}))	**vi.** Recommended rate (3 sprays of Lamdacyhalothrin 5% EC))(**CP-3**) (each spray: 371 ml ha^{-1} of Ninja (50 g l^{-1} lambda-cyhalothrin))
	vii. Higher rate (60 kg N/ha (**CF-60**) (At planting apply 100 kg ha^{-1} DAP (18 kg N ha^{-1} + 20 kg P ha^{-1}), At squire formation top-dress with 91.4 kg ha^{-1} urea (42 kg N ha^{-1})	vii. High rate (6 sprays of Lamdacyhalothrin 5% EC) (**CP-6**) (each spray: 371 ml ha^{-1} of Ninja (50 g l^{-1} lambda-cyhalothrin))
	viii. Innovative FYM 3 Mg ha^{-1} +Fertilizer 30 kg N/ha, – (**CF-3+M**) (At planting apply 3 Mg FYM ha^{-1}, At squire formation top-dress with 65.2 kg ha^{-1} urea (30 kg N ha^{-1})	viii. Innovative - 3 sprays of Neem+cow urine– (**CP-3 -N+CU**) (each spray: 24.8 kg ha^{-1} fresh neem leaves + 3.5 l ha^{-1} sunflower oil + 5.0 l ha^{-1} cow urine)

5.3.2 Sampling and chemical analyses of soil and manure

Prior to establishment of experimental plots, composite topsoil (0-20 cm) samples were collected in December 2015 for baseline analyses of soil properties. The soil samples were air-dried and sieved through a 2 mm sieve to remove gravel and plant residues. Subsequent soil analyses included pH measured by electrode in soil:liquid suspensions (1:5, wt/wt) with demineralised water or 0.1 mM $CaCl_2$ (McLean, 1986), organic C was measured by the Walkely and Black method (Nelson and Sommers, 1986), total N measured by Kjeldahl wet digestion-distillation (Bremner and Mulvaney, 1982), extractable phosphorous (P) determined by the Olsen method (Olsen and Sommers, 1986), cation exchange capacity for basic cations (Ca, Mg, K and Na) measured following the NH_4Ac saturation method (Thomas, 1986), and micronutrients (Cu, Fe, Zn, Mn) measured by the diethylenetriaminepentaacetic acid (DTPA) method (Thomas, 1986).

In each season, manure from kraals (mainly cattle) was collected according to current practises in the study area and placed in three heaps (one at each block) before application. Three composite samples (500 grams) from each heap were pooled from four subsamples taken at random spots. The resulting manure samples (n = 9) were air-dried and ground to pass a 2- mm sieve. A wet digestion method followed by colorimetric determinations was used to measure total N and total P (Okalebo *et al.,* 2002). Organic C was determined by the Walkley-Black method (Nelson and Sommers, 1986).

5.3.3 Determination of microbial activities

Soil samples for determination of microbial activity were sampled from the plough layer (0-20 cm) of 24 individual plots representing the eight treatments replicated in three blocks. For each plot a 500 g composite sample was made from 3 randomly sampled soil. The soil samples were air-dried and then sieved through a 2 - mm sieve to remove gravel and plant residues. The soils were then stored at room temperature in closed polythene zipper bags and determination of microbial activitey performed within four weeks after sampling.

5.3.3.1 Arylsulfatase activity

Arylsulfatase activity was measured by spectrophotometric quantification of *p*-nitrophenol (NP) liberated from hydrolysis of *p*-nitrophenyl sulphate (NPS) in soil-buffer solutions (Tabatabai and Bremner, 1970). Assays were performed according to a simplified procedure (Elsgaard *et al.*, 2002) with sample extraction by centrifugation (rather than filtration), without toluene as bacteriostatic and plasmolytic agent, and with mechanical shaking of the assay mixture. For each soil sample, three 2- g subsamples were transferred to 10 mL test tubes and amended with 4 mL acetate buffer (0.5 M, pH 5.8) and 1 mL 20 mM NPS. The test tubes were stoppered and incubated with shaking (150 rev min^{-1}) at 20°C for 2 h. After incubation, 2 mL NaOH (1 M) and 1 mL $CaCl_2$ (0.5 M) were added, and the samples were mixed, to inhibit further enzyme activity and promote colour development. The samples were centrifuged for 10 minutes at 4 000 rev min-1 and 3 mL clear supernatant was transferred to disposable cuvettes for absorbance measurement at 400 nm (Spectronic Helios Alpha, Fisher Scientific). One of the three 2 g soil subsamples served as reference for background absorbance; this sample was amended with NPS only after the addition of NaOH and $CaCl_2$. Standard curves were prepared using NP stock solutions diluted in acetate buffer (0-80 µg NP mL^{-1}). For zeroing the spectrophotometer demineralised water was used.

5.3.3.2 Potential nitrification

Potential nitrification (PN) activity was measured by incubation of soil samples in ammonium phosphate buffer with $NaClO_3$ to inhibit nitrite (NO_2^-) oxidation (Belser and Mays, 1980). Assays were performed with duplicate 10 g soil samples in 250 mL Erlenmeyer flasks amended with 100 mL ammonium/phosphate buffer (0.5 mM $(NH_4)_2SO_4$ in 1 mM K_2HPO_4, pH 7.2). Soil-free incubations were included as blanks. The flasks were swirled by hand, to briefly mix the contents, and incubated on an orbital shaker (150 rev min^{-1}) at 20°C in darkness. After 15 min, and again after 4 h, 3 mL of the assay mixture was sampled and transferred to 10-mL test tubes and vortexed (5 s) with 3 mL of 4 M KCl to stop biological activity. The test tubes were centrifuged (10 min, 4 000

g) and 2 mL of filtered (0.45 µM) supernatant was transferred to new 10-mL test tubes for quantification of NO_2^- by the diazotization method (Hanson and Phillips, 1981).

To this end, 50 µL of reagent 1 (1.0 g sulphanilamid in 60 mL 1.2 M HCl) was added to the sample and vortexed (5 s). After minimum 2 min (but not longer than 8 min), 50 µL of reagent 2 (0.1 g N-(1-naphtyl)-ethylenediamine dihydrochloride in 100 mL H_2O) was added and the sample was vortexed (5 s) and placed in darkness for 10 min. The resulting absorbance was measured at 543 nm and NO_2- concentrations were calculated from freshly prepared standard curves with 0-80 µg NO_2- mL^{-1} also correcting for blanks. The rate of potential nitrification (i.e., ammonium oxidation) was calculated from the net NO_2^- production during the time interval from first (15 min) to second (4 h) sampling of the incubated soil/buffer suspensions.

5.3.3.3 Basal soil respiration

Basal soil respiration was done in the fertility management treatment only and was measured as the rate of CO_2 production from rewetted soil samples after a pre-incubation period of 1 week to establish equilibrium (Jarvis *et al.*, 2007). Soil samples (20 g air-dry soil) were incubated in 330 mL bottles, rewetted using demineralized water to 75% water holding capacity (WHC), and allowed to equilibrate at 20°C in the dark. After one week, the bottles were equilibrated with ambient air (outdoor) for 10 min and closed by butyl rubber stoppers. Headspace gas was then sampled daily for CO_2 analysis by gas chromatography (GC) during an incubation period of six days at 20 °C in the dark. Gas sampling was done by withdrawing 2 mL headspace gas with a syringe and hypodermic needle; to avoid pressure changes this was preceded by injection of 2 mL of dinitrogen (N_2) gas. The withdrawn headspace gas samples were transferred to 7-ml Extainer vials that were pre-evacuated and filled with N_2. GC analysis of CO_2 was done using an Agilent

7890 GC (Agilent, Nærum, Denmark) connected to a CTC CombiPAL automatic sample injection system; configuration and calibration of the GC was described in detail by Petersen *et al.* (2012).

5.3.3.4 Birch effect

The difference in responses of the Birch effect after re-wetting of soil from plots under organic and conventional farming practices was determined using Infra red gas analyser (IRGA). Air dry soil weighing 20 g was added in a 330 mls bottle, then CO_2 concentration in the sample were measured using infrared gas analyzer (IRGA) LI-COR 840 (LI-COR, Inc., Lincoln, NE) coupled to a pump (0.01 L s^{-1}) and a data logger (Kandel *et al.*, 2016). After 2 minutes water was added based on the water holding capacity of each block. The CO_2 production was further measured for 10 minutes. Measurements were done by connecting the IRGA to individual sample flasks via inlet and outlet tubing (inner diameter, 5mm) inserted through a rubber stopper fitting the flasks. CO_2 concentrations were recorded at 1 second intervals for 10 min. CO_2 production rates were calculated for rolling 2-min periods during the incubation periods and the 2 min periods are offset by 1 s. The maximum rate of CO_2 flux after soil re-wetting was recorded and compared between treatments. Two blanks one without water and the other with water were also included

5.3.4 Statististical analysis

All datasets complied with assumptions of normality and equal variance as tested by Shapiro-Wilk's test and Barltett's test, respectively ($P < 0.05$). Two-way ANOVA was used to test for effects of nutrient and pest management practices on soil enzyme activity and potential nitrification for each season. One-way ANOVA was used to test for effects of nutrient management on basal soil respiration. Significant ANOVA tests ($p < 0.05$) were followed by post-hoc pair-wise multiple comparisons using the Duncan Multiple range test (Zar, 2010). All analyses were performed using R version 3.0.2 (R Core Team, 2013).

5.4 Results

5.4.1 Weather and soil properties

Cotton growing season 1 and 2 represented rather normal weather conditions in the study area, yet with total rainfall of 759 and 522 mm, respectively (Table 5-2), as compared to the long-term average of 688 mm.

Table 5-2: Summary of mean daily values for weather parameters at the experiment site

		RH (%)	Temp (°C)	Precipitation (mm)	Solar radiation (W/m^2)	Soil Moisture VWC (m^3/m^3)	WFPS (%)	Soil temp (°C)
Season 1	Mean	71	23.8		247.09	0.11	32.4	28.0
	Min	23	20.7	0	210.59	0.05	15.3	23.8
	Max	103	27.4	44.8	339.3	0.18	51.3	31.5
	Total			758.66				
Season 2	Mean	54	24.6		258.70	0.11	32.7	29.4
	Min	39	20.4	0.00	225.53	0.05	13.8	22.6
	Max	75	28.5	48.0	438.23	0.21	63.0	35.5
	Total			522.4				

Mean daily air and soil temperatures were 23.8 and 28°C in growing season 1 and 24.6 and 29.4°C in growing season 2, respectively; for air temperatures this was comparable to the long-term average of 24.2°C (Kabote *et al.*, 2013). Weather conditions in the two growing seasons could potentially influence microbial biomass and activity; however, the focus of the present study was treatment effects, which were analysed separately in each growing season. As shown in Table 5-3, the soil had a mildly alkaline pH (7.84), medium organic carbon (10.3 mg g^{-1}), low total N (1.4 mg g^{-1}) and medium CEC (19.5 cmol kg^{-1}).

Table 5-3: Texture and physico-chemical properties of topsoil (0-20) at the study site

Material	Clay (%)	Silt (%)	Sand (%)	BD (g cm^{-3})	OC (mg g^{-1})	N (mg g^{-1})	P (mg g^{-1})	SO_4^{2-} (μg g^{-1})	CEC (cmol kg^{-1})	pH (H_2O)	pH ($CaCl_2$)
Soil	27	4	68	1.4	10.3	1.4	16	4.5	19.5	7.8	6.9
Manure	-	-	-	-	80.0	10.3	103	-	-	-	-

5.4.2 Arylsulfatase activity

5.4.2.1 Current practice

Comparing the current practices, no significant difference ($p<0.05$) in arylsulfatase activity was observed in season 1 between organic and conventional fertility management practices (Fig. 5-1).

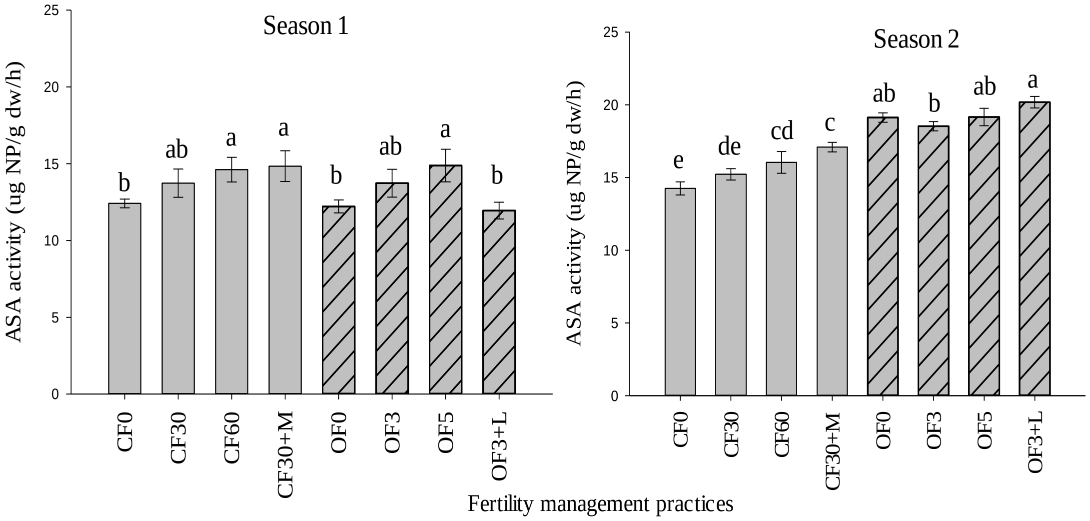

Figure 5-1: Effect of fertility management on arylsulfatase (ASA) activity in soils from conventional (grey bars) and organic (hatched bars) cotton fields in growing season 1 and 2.

Note: (CF-0, CF-30, and CF-60; conventional treatments with mineral N rates of 0, 30, and 60 kg N ha^{-1} yr^{-1}, respectively. CF-30+M; CF-30 combined with manure (3 Mg ha^{-1} yr^{-1}). OF-0, OF-3, and OF-5; organic treatments with manure rates of 0, 3, and 5 Mg ha^{-1} yr^{-1}, respectively. OF3+L; OF3 combined with legume as intercrop. Data are means with standard error bars ($n = 3$). Values with the same letters are not significant different within each growing season ($P < 0.05$)).

However, in season 2, a significant higher arylsulfatase activity was observed in organic fertility management (OF-3) than conventional practice (CF-3). A 28 % increase in arylsulfatase activity from 15.2 µg NP g^{-1} dw h^{-1} in conventional to 18.5 µg NP g^{-1} dw h^{-1} in organic was observed. Likewise, for pesticide management practices (Fig.5-2) no significant difference was observed between current organic (OP-P) and conventional (CP-3) farming practice in season 1. However, a significant difference was observed in season 2 where an increase of 28 % from 15.0 µg NP g^{-1} dw h^{-1} in conventional to 19.2 µg NP g^{-1} dw h^{-1} in organic was observed.

5.4.2.2 High input scenario

The increase of fertilizer level from 30 kg N ha^{-1} (CF-30) to 60 kg N ha^{-1} (CP-60) in conventional had no significant increased in arysulfatase activity.

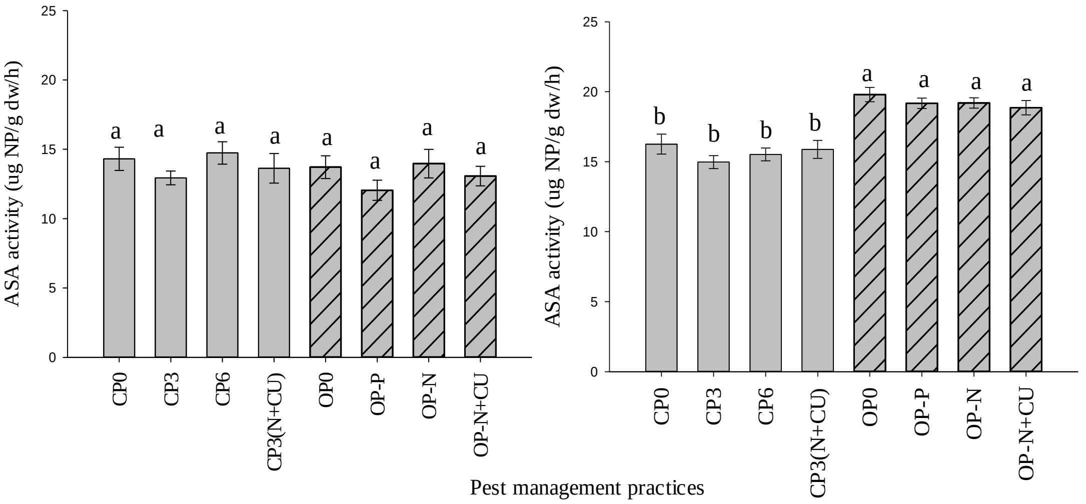

Figure 5-2: Effect of pest management on arylsulfatase activity (ASA) in soils from conventional (grey bars) and organic (hatched bars) cotton fields in (a) growing season 1 and (b) growing season 2.

Note: (CP-0, CP-3, and CP-6; conventional treatments with 0, 3, and 6 times pesticide application, respectively. CP-3+NE/CU; CP-3 combined with neem/cow urine mixture. OP-0, OP-P, OP-NE, and OP-NE/CU; application of no pesticide, pyrethrum, neem, and neem/cow urine mixture, respectively. Data are means with standard error bars (n = 3). Values with the same letters are not significant different within each season ($P < 0.05$). NP, nitrophenol.)

However, a relative increase of 7 % from 13.7 to 14.6 µg NP g^{-1} dw h^{-1} and 5% from 15.2 to 16 µg NP g^{-1} dw h^{-1} was observed in season 1 and 2, respectively. Likewise, for organic farming practice the increase in manure level from 3 tonne FYM ha^{-1} (OF-3) to 5 tonne FYM ha^{-1} (OF-5) did not have significant ($p<0.05$) increase in arysulfatase activity in both season 1 and 2 though it had a relative increase of 9 % from 13.7 to 14.9 µg NP g^{-1} dw h^{-1} and 4% from 18.5 to 19.2 µg NP g^{-1} dw h^{-1} season 1 and 2, respectively.

5.4.2.3 Alternative practice

For conventional farming practice manure and fertilizer combination increased arylsulfatase activity as compared to sole fertilizer application in both season 1 and 2. In season 1 a relative increase of 8% from 13.7 µg NP g^{-1} dw h^{-1} in sole fertilizer to 14.8 µg NP g^{-1} dw h^{-1} in fertilizer manure combination was observed, while in season 2 a significant ($p<0.05$) increase of 12.1 % from 15.2 µg NP g^{-1} dw h^{-1} in sole fertilizer to 17.1 µg NP g^{-1} dw h^{-1} in manure fertilizer combination was observed. For the organic farming practice, the cotton- legume intercrop in season 1 reduced arysulfatase activity by 12 % from 13.7 in sole cotton to 12.0 µg NP g^{-1} dw h^{-1} in cotton - legume intercrop. In season 2, however, a significant ($p<0.05$) increase of 9% in arylsufatase activity from 18.5 µg NP g^{-1} dw h^{-1} in sole cotton to 20.2 µg NP g^{-1} dw h^{-1} in legume cotton intercrop was observed.

5.4.3 Potential nitrification

5.4.3.1 Current practice

Comparing the current practices, no significant difference was observed between the organic (OF-3) and conventional (CF-30) farming practice in season 1 (fig 5-3). However, a significant ($p<0.05$) difference was observed in season 2 where the potential nitrification rate observed in conventional farming practice (20.9 nmol NO_2^- g^{-1} dw h^{-1}) was 27 % higher than potential nitrification recorded in organic (16.4 nmol NO_2^- g^{-1} dw h^{-1}). For pest management (fig.5-4), no significant difference was observed between current organic (OP-P) and conventional (CP-3) farming practice in both season season 1 and 2.

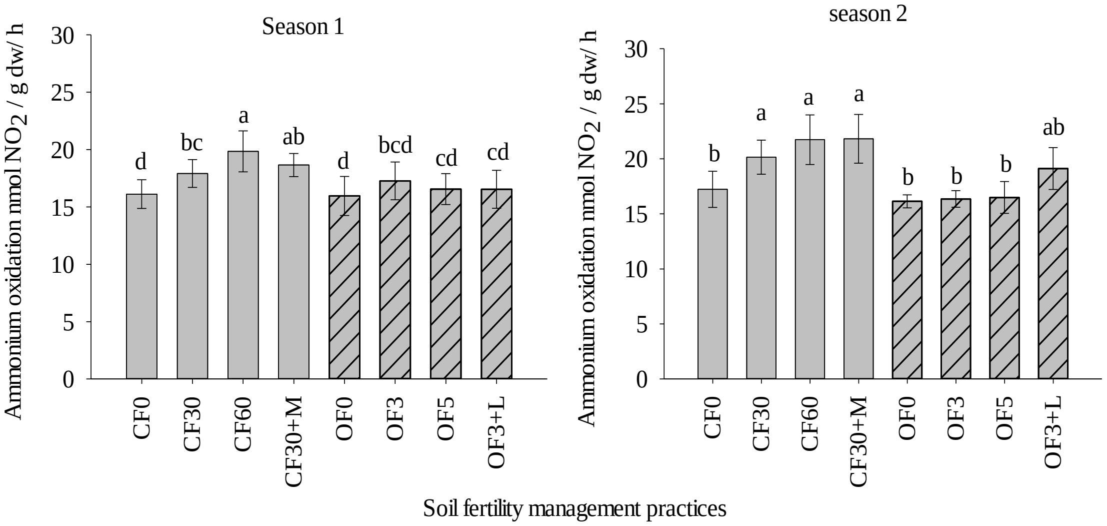

Figure 5-3: Effect of fertility management on Ammonium oxidation in soils from conventional (grey bars) and organic (hatched bars) cotton fields in growing season 1 and 2.

Note: (CF-0, CF-30, and CF-60; conventional treatments with mineral N rates of 0, 30, and 60 kg N ha^{-1} yr^{-1}, respectively. CF-30+M; CF-30 combined with manure (3 Mg ha^{-1} yr^{-1}). OF-0, OF-3, and OF-5; organic treatments with manure rates of 0, 3, and 5 Mg ha^{-1} yr^{-1}, respectively. OF3+L; OF3 combined with legume as intercrop. Data are means with standard error bars ($n = 3$). Values with the same letters are not significant different within each growing season ($P < 0.05$)).

5.4.3.2 High input scenario

The increased fertilizer level in conventional practice from 30kg N ha^{-1} (CP-30) to 60kg N ha^{-1} (CP-60) significantly ($p<0.05$) increased potential nitrification in season 1. An 11% rise in potential nitrification from 17.9 to19.9 nmol NO_2^- g^{-1} dw h^{-}1 was observed. However, no difference was observed in season 2. For organic farming practice, increase in manure level in organic treatment from 3 tonne FYM ha^{-1} to 5 tonne FYM ha^{-1} did not result in any difference in potential nitrification (Fig. 5-3). Likewise, for pest management practices in both seasons and farming systems increase in pesticide level had no significant difference in Potential nitrification (Fig. 5-4).

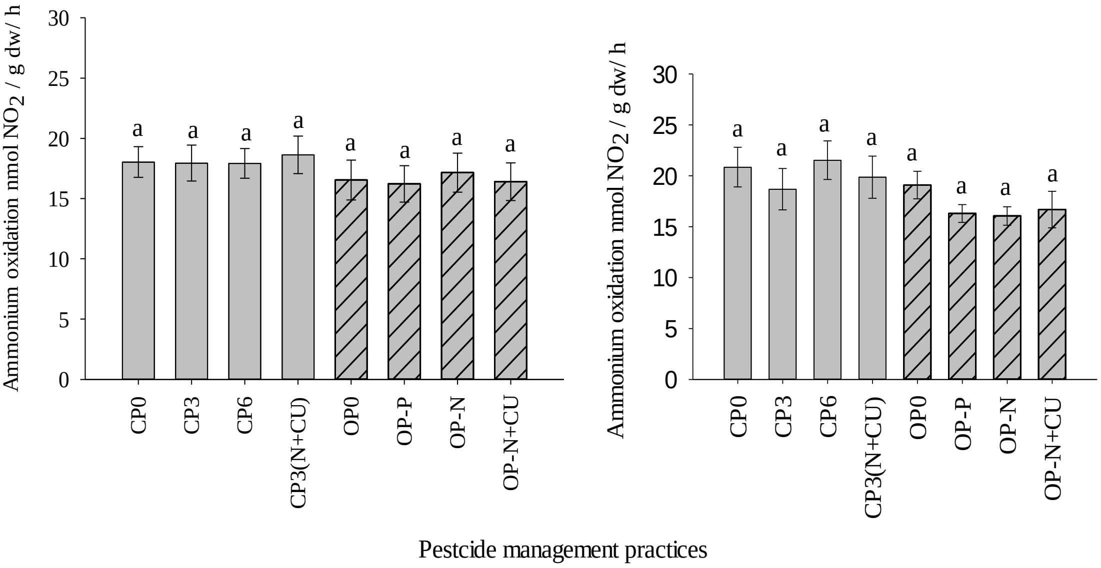

Figure 5-4: Effect of pest management on Ammonium oxidation in soils from conventional (grey bars) and organic (hatched bars) cotton fields in (a) growing season 1 and (b) growing season 2.

Note: (CP-0, CP-3, and CP-6; conventional treatments with 0, 3, and 6 times pesticide application, respectively. CP-3+NE/CU; CP-3 combined with neem/cow urine mixture. OP-0, OP-P, OP-NE, and OP-NE/CU; application of no pesticide, pyrethrum, neem, and neem/cow urine mixture, respectively. Data are means with standard error bars (n = 3). Values with the same letters are not significant different within each season ($P < 0.05$). NP, nitrophenol).

5.4.3.3 Alternative practice

For the conventional farming practice, the alternative practice of combining manure and fertilizer (CF+M) had no significant ($p<0.05$) difference in potential nitrification compared to sole fertilizer application in both season 1 and 2. However, a relative increase of 5% from 17.9 to 18.7 nmol NO_2^- g^{-1} dw $h^{-}1$ was observed in season 1 and an a relative increase of 6% from 20.9 to 22.2 nmol NO_2^- g^{-1} dw $h^{-}1$ in season 2. Likewise, for organic farming practice the alternative practice of cotton - legume intercrop (OF+L) did not have significant ($p<0.05$) difference in potential nitrification rate as compared to sole cotton with fertilizer alone (OF3) in both season 1 and 2. In season 1 a relative lower potential nitrification rate was observed in the alternative practice compared to sole cotton with fertilizer. In season 2 however, a relative 16% increase in potential nitrification in cotton - legume intercrop (16.4 nmol NO_2^- g^{-1} dw h^{-1}) compared to sole cotton (19.1 nmol NO_2^- g^{-1} dw h^{-1}) was observed.

5.4.4 Basal soil respiration

Basal respiration was determined in the soil fertility management treatments only due the trend observed in enzyme activity and ammonia oxidation where pesticide was observed to have no effect on microbial activity (Fig. 5 - 2 and 5- 4). For both conventional and organic farming systems, the soil fertility management practices (fertilizer and manure application) had significant effect on basal respiration in both season 1 and 2, as described below.

5.4.4.1 Current practice

Comparing the current practices (Fig. 5-5), the organic farming practice (OF-3) in season 1 had significant ($p<0.05$) higher basal respiration (123.9 µg CO2 g^{-1} Soil day^{-1}) as compared to the conventional farming practice (98.3 µg CO2 g^{-1} Soil day^{-1}). In season 2 organic and conventional farming practices had no significant ($p<0.05$) different. However, organic farming practice had a slightly higher (77.4 µg CO_2 g^{-1} soil day^{-1}) basal respiration than conventional farming practice (73.1 µg CO_2 g^{-1} soil day^{-1}) by 6 percent.

5.4.4.2 High input scenario

The increase in fertilizer level in the conventional practice from 30kg N ha^{-1} (CF-30) to 60 kg N ha^{-1} (CF-60) significantly ($p<0.05$) increased basal respiration in season 1 by 27%

from 98.3 to 124.5 µg CO2 g^{-1} soil day^{-1}. In season 2 the increase in fertilizer level in conventional caused no significant ($p<0.05$) difference in basal respiration. For organic farming practice, increase in manure level in the organic treatment from 3 Mg FYM ha^{-1} (OF-3) to 5 Mg FYM ha^{-1} (OF-5) significantly ($p<0.05$) reduced basal respiration by 20% in season1 from 123.9 to 99.5 µg CO_2 g^{-1} soil day^{-1}. However, the increase caused no significant ($p<0.05$) difference in season 2. In this season a slight increase of 4% from 77.4 to 80.7 was observed.

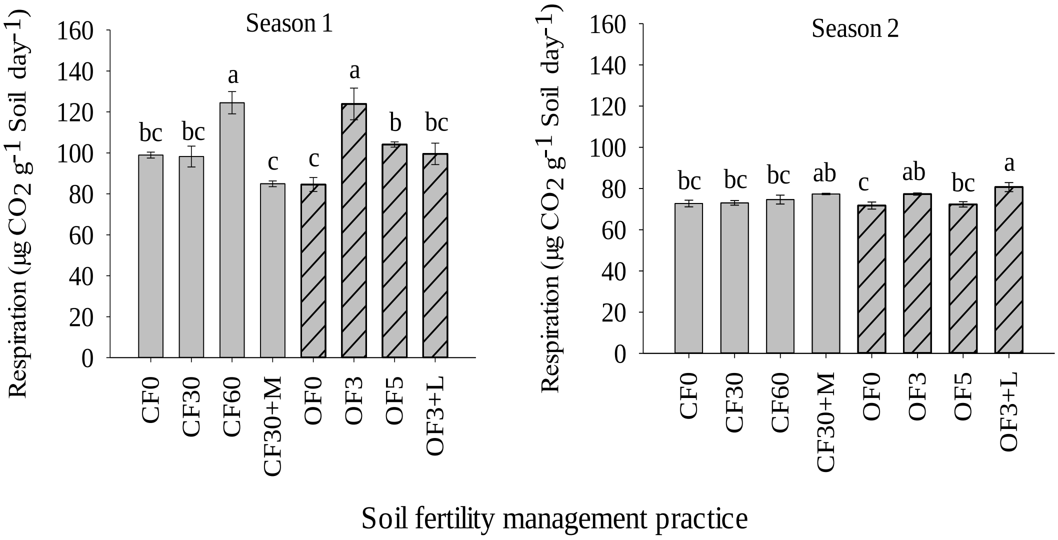

Figure 5-5: Effect of fertility management on basal respiration in soils from conventional (grey bars) and organic (hatched bars) cotton fields in growing season 1 and 2.

Note: (CF-0, CF-30, and CF-60; conventional treatments with mineral N rates of 0, 30, and 60 kg N ha^{-1} yr^{-1}, respectively. CF-30+M; CF-30 combined with manure (3 Mg ha^{-1} yr^{-1}). OF-0, OF-3, and OF-5; organic treatments with manure rates of 0, 3, and 5 Mg ha^{-1} yr^{-1}, respectively. OF3+L; OF3 combined with legume as intercrop. Data are means with standard error bars (n = 3). Values with the same letters are not significant different within each growing season ($P < 0.05$)).

Comparing the high input scenario between organic and conventional farming practice, the higher input conventional farming practice (CF-60) had significant ($p<0.05$) higher basal respiration than the higher input organic farming practice (OF-5) in season 1. But in season 2 the two practices had similar basal respiration.

5.4.4.3 Alternative practice

For conventional farming practice, the alternative practice of combining manure and fertilizer did not cause significant ($p<0.05$) difference in basal respiration. However, a relative 14 % reduction in basal respiration from 98.3 µg CO_2 g^{-1} soil day^{-1} in sole fertilizer to 84.9 µg CO2 g^{-1} soil day^{-1} in fertilizer manure combination was observed in season 1. Unlike season 1, a relative 6 % increase in basal respiration from 73.1 µg CO_2 g^{-1} soil day^{-1} in sole fertilizer to 77.4 µg CO2 g^{-1} soil day^{-1} in fertilizer manure combination was observed.

For organic farming practice the, cotton- legume intercrop had significant ($p<0.05$) lower basal respiration (104.1 µg CO_2 g^{-1} soil day^{-1}) than sole cotton (123.9 µg CO_2 g^{-1} soil day^{-1}) in season 1. In season 2, no significant difference ($p<0.05$) was observed. However ,a relative 7% reduction in basal respiration from 77.4 µg CO_2 g^{-1} soil day^{-1} in sole fertilizer to 72.4 µg CO2 g^{-1} soil day^{-1} in fertilizer manure combination was also observed in season 2. Compared to conventional farming system cotton legume intercrop had no significant difference in basal respiration as compared to the recommended 30 kg N ha^{-1} but had significant lower basal respiration as compared to high N rate (60 kg N ha^{-1}).

5.4.5 Birch effect

The result from this study indicates that Fertility management had significant effect on the rate the CO_2 flux after soil re-wetting and both organic and conventional treatments had relatively higher rates than the control.

5.4.5.1 Current practice

For the current practice no significant different between the current organic and conventional practice was observed. However, both had higher CO_2 flux rate after rewetting than the control treatment (Fig. 5-6).

5.4.5.2 Higher input scenario

For the higher manure and fertilizer rates, no significant different between organic and conventional practice was observed. However, both had higher CO_2 flux rate after rewetting than the control treatment.

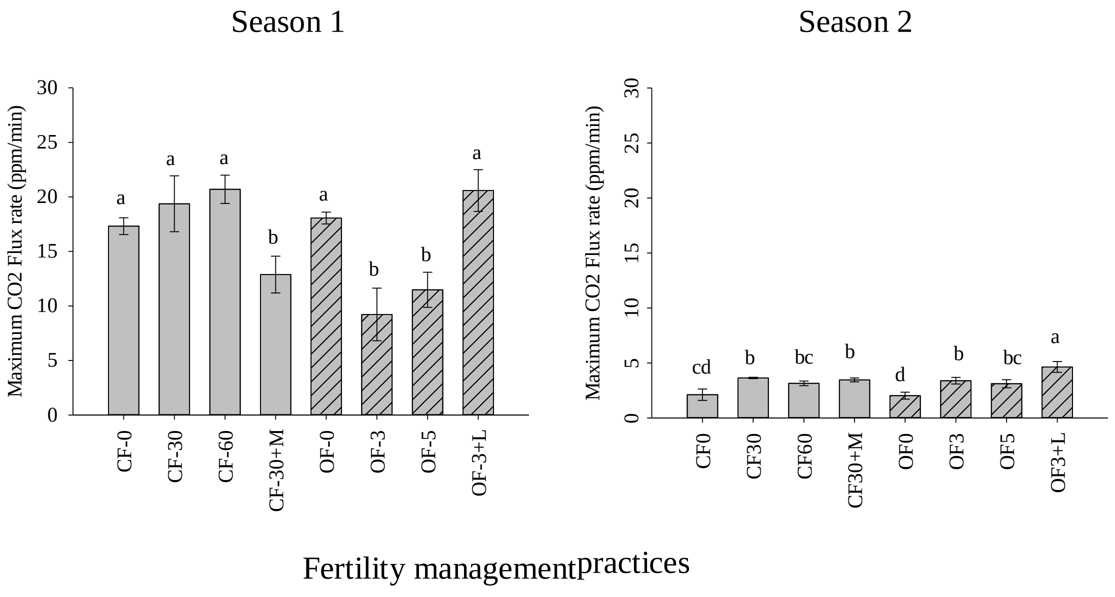

Figure 5-6: Effect of fertility management on birch effect in soils from conventional (grey bars) and organic (hatched bars) cotton fields

Note: (CF-0, CF-30, and CF-60; conventional treatments with mineral N rates of 0, 30, and 60 kg N ha^{-1} yr^{-1}, respectively. CF-30+M; CF-30 combined with manure (3 Mg ha^{-1} yr^{-1}). OF-0, OF-3, and OF-5; organic treatments with manure rates of 0, 3, and 5 Mg ha^{-1} yr^{-1}, respectively. OF3+L; OF3 combined with legume as intercrop. Data are means with standard error bars (n = 3). Values with the same letters are not significant different within each growing season ($P < 0.05$)).

5.4.5.3 Alternative Practice

For organic treatments, intercropping with legume had significant higher rate than the rest of the other current organic and conventional practice. For conventional farming practice combining manure and fertilizer had no significant different in CO_2 flux after rewetting as compared to other conventional treatments but it had significant higher CO_2 flux after rewetting as compared to control (CF0).

5.5 Discussion

5.5.1 Arylsulfatase activity

5.5.1.1 Current practices

The non significant difference in arylsulfatase activity between the current organic and conventional farming practice in this study is contrary to results by other studies which showed that manured soils had significantly greater concentrations of soil enzymes, and higher microbial activity, than un-manured soils (Czurak-Dainard, 2005). For this study in the first year probably manure was not yet well decomposed and hence its effect not revealed. On the other hand, as the arysufatase activity in soil is highly correlated to N and C input (Li and Sarah, 2003) the N input in the two treatment were similar which likely had similar arysufatase activity.

For pesticide, both organic and conventional pesticide treatments were applied as foliar application and in low rate such that insignificant or no pesticide was washed to the soil. The significant higher arylsulfatase activity in organic than conventional in season 2 is therefore not linked to pesticide effect but rather to the previous legume crop in the organic plots. Legume cropping increases abundance of soil bacteria and archaea and hence microbial activity (Paungfoo-Lonhienne *et al.*, 2017). Ghosh *et al.* (2007) linked improved soil properties in the succeeding crops in legume rotation to the carryover N from the N fixing legume. This could also be the case in this study as in season 2 the organic practices were rotated to plots which were under grain legume fallow in season 1. The results of this study are supported by other reports like Hartmann *et al.* (2015) who in a review study concluded that pesticides were of subordinate importance on microbial activity as plant protection regime are characterized by moderate and targeted application of pesticides.

5.5.1.2 High input scenario

The increase in enzyme activity in response to increased level of N and manure in conventional and organic farming respectively is linked to the increased soil total nitrogen and soil organic carbon from addition of fertilizer and manure as substrate for enzyme activity (Monkolo *et al.,* 2012). The quality and quantity of substrate influences the growth and activity of soil microorganisms. The increased N in the conventional treatment and increased rate of FYM of narrow C:N ratio in the organic treatment probably increased Arylsulfatase activity. The results of this study are also supported by the findings by Siwik-Ziomek *et al.* (2016), who reported higher activity of arylsulphatase in soil in the plot with high farmyard manure rate of 60 Mg ha $^{-1}$. This indicates that cotton growers in the study area can improve microbial activity and soil functions by improved use manure and fertilizer.

5.5.1.3 Alternative practices

The increase in soil enzyme activity in the alternative practice with organic amendments in the first year and second year as a result of elevated soil organic matter content in treatments with combination of fertilizer and manure compared to fertilizer only. Study by Loviero *et al.* (2009) suggest that microbial activities are limited by SOC rather than N availability. In their study they found that integration of the lowest dose of compost with mineral N did not increase soil microbial activities relative to compost only. The result of this study is in line with findings by Bandick and Dick (1999) who also found that in cultivated systems, enzyme activity was higher where organic residues were added as compared to treatments without organic amendments. This was also found true for other soil enzyme activities (Stark *et al.*, 2007) as well as for microbial growth rate (Aldén *et al.*, 2001). The finding in this study indicates then that fertilizer manure combinations is an option for improving microbial activity and soil functions for conventional cotton growers in the study area.

The increase in enzyme activity in the alternative organic practice of cotton legume intercrop is related to the fact that inclusion of legume as intercrop or rotations increases belowground inputs of C and N that increase microbial populations, diversity, biomass and activity above those observed for conventional management using commercial fertilizers (Lupwayi *et al.*, 1998; Biederbeck *et al.*, 1999). Management systems that include legumes and organic amendments improve soil microbiotic properties that support soil organic carbon accumulation (Ghimire, *et al.*, 2014). The existence of legumes in the intercrop probably enhanced bacterial and fungal biomass in the soil as compared to the sole crop, indicating that legumes play a dominant role in soil microbial community changes in the intercrop (Chen *et al.*, 2008). In this study, the effect was more conspicuous in season 2 because in season 2 there were more advantage from the previous legume crop in the rotation.

5.5.2 Potential nitrification

For both conventional and organic farming systems the fertility management practices (fertilizer and manure application) had significant effect on potential nitrification activity in both season 1 and 2. For the case of pesticide application, for both conventional and organic farming systems, pest management practices had no significant effect on ammonium oxidation in both season 1 and 2.

5.5.2.1 Current practices

In this current study, the higher PN rate observed in conventional than organic in season 2 and similar PN rate between organic and conventional in season 1 is contrary to other studies which reported significant difference between organic and conventional practices after a long period. Fan *et al.* (2011) reported that potential nitrification rate was found to be suppressed by long-term mineral fertilizer treatment but was enhanced by long term manure treatment. Probably the similar rate in season one is due to the short duration and the low rate of manure applied under current practice. For pest management, no significant difference was observed between current organic and conventional farming practices in season both season 1 and 2. This is related to the low rate of pesticide applied and the targeted nature of application where just trace amount of pesticide ends up in the soil.

5.5.2.2 High input scenario

The increased PN rate in the conventional treatment in response to increased level of N from 30 kg N ha^{-1} to 60 kg N ha^{-1} is due to the fact that fertilizer application stimulates the transformation of NH_4^+ to NO_3^- (nitrification) (Sehy *et al.*, 2003; Subbarao *et al.*, 2009). The observed increase in PN is in line with other studies which had the similar findings. Bi *et al.* (2017) reported that application of N fertilizer significantly increased net nitrification rate and the abundance of Ammonium Oxidising Bacteria (AOB) in an intensively caltivated vegetable soils. However, other findings found that potential nitrification rate was found to be suppressed by long-term mineral fertilizer treatment but enhanced by manure treatment (Fan *et al.*, 2011).

For organic farming practice, the similar potential nitrification rate between low (3 Mg FYM ha^{-1}) and high (5 Mg FYM ha^{-1}) manure level is contrary to results from other studies which reported that increased application of manure either with or without mineral fertilizer promotes the growth of ammonium oxidisers and thus nitrification potential (Ceccherini *et al.*, 1997).

5.5.2.3 Alternative practices

For conventional farming practice, the relative increase in potential nitrification in manure fertilizer combination as compared to sole fertilizer application is in line with other studies (Gurlevik *et al.*, 2004; Zaman *et al.*, 2004; De-Zhi *et al.*, 2006; Sharifi *et al.*, 2007, Wu, *et al.*, 2017) which also found that manure plus chemical fertilizer resulted in a higher N mineralization and nitrification potential. The higher N mineralization in organic material-treated soils is linked to the higher availability of organic N, organic C, and higher enzyme activities (Zaman *et al.*, 2004; Sharifi *et al.*, 2007) and presence of an active nitrifying bacterial community in the soils as a result of the applied manure (Laanbroek and Gerards, 1991). Laanbroek and Gerards (1991) linked the stimulated nitrification in manure + fertilizer with increased mineralization of ammonium which is not immediately taken up by the crop or immobilized by the organotrophic microflora in the soil.

For organic farming practice the relative reduction in PN in Cotton - legume intercrop compared to sole cotton with fertilizer, manure and manure fertilizer combination is related to alteration of soil microbial community composition as a result of presence of legume whereby abundances of ammonia oxidisers is reduced (Paungfoo-Lonhienne *et al.*, 2017). In a study on sugercane legume rotation Paungfoo-Lonhienne *et al.* (2017) found that the ammonia oxidisers were 24–44% less abundant in the legume cropped soils as compared to the bare fallow.

5.5.3 Basal respiration

Basal respiration was only determined for fertility management treatments due the trend observed in enzyme activity and ammonia oxidation where pesticide was observed to have no effect on microbial activity. For both conventional and organic farming systems the fertility management practices (fertilizer and manure application) had significant effect on basal respiration in both season 1 and 2 as described below.

5.5.3.1 Current practices

The higher BR in organic practices as compared to conventional practices in this study is linked to C inputs from manure which increase soil organic carbon and microbial carbon content (Araújo *et al.,* 2009). The increased soil organic carbon increases the amount of substrates for soil microorganisms and soil microbial activity is enhanced and hence soil respiration (Kirchmann, *et al.,* 2004; Li, *et al.,*2013). The result of this study is in line with other studies (Araújo *et al.,* 2009; Glover *et al.,* 2000) involving conventional and organic systems increased soil microbial respiration was reported under organic management. The higher soil respiration in the organic practice indicates higher soil microbial activity as a result of addition of an external source of labile organic matter to the soil that stimulates activities of heterotrophic microorganisms (Saffigna, 1989). This indicates that for smallholder cotton farmers in the study area, organic amendments to is a viable option for improving microbial activity and hence soil quality.

5.5.3.2 High input scenario

The increase in basal respiration in conventional in response to increased fertilizer level from 30 kg N ha^{-1} to 60 kg N ha^{-1} is linked to the fact that the nitrogen addition stimulates root respiration especially under N limited environments (Gao *et al.,* 2014; Hyvönen *et al.,* 2007). The finding of this study is in contrast with many studies which report reduction in soil respiration with N additions (Bowden *et al.,* 2004; Craine *et al.,* 2007; Treseder, 2008; Janssens *et al.,* 2010; Ramirez *et al.,* 2010; Ramirez, *et al.,* 2012). However, the study is in line with other studies that have shown increase in soil respiration with N additions (Craine *et al.,* 2001; Cleveland and Townsend; 2006; Yoshitake *et al.,* 2007; Hasselquist *et al.,* 2012). The higher N rate in our study (60 kg N ha^{-1}) is in the low range and the N status in the study soil (0.41%) is considered as N limited soil, hence the increase in soil respiration with this increase in N input. Cusack *et al.* (2011) reported decreasing soil respiration with N additions in N-rich environments.

The reduction in basal respiration in the organic farming practice in response to increase in manure level from 3 to 5 Mg FYM ha^{-1} in season 1 is contrary to other studies which indicated that adding manure significantly increased soil respiration and enzyme activities (Araújo *et al.,* 2009; Glover *et al.,* 2000) as a result of increased amount of cultivable microorganisms and microbial biomass, thus enhancing soil respiration (Zheng *et al.,* 2014).

The higher basal respiration in conventional than organic farming practice in season 1 and the similar basal respiration in season 2 is counter to basic stoichiometric decomposition theory, where soil respiration is enhanced by the organic practices as compared to the conventional practice (Araújo *et al.,* 2009). This may be related to the low N rates and hence low N availability in our study, which possibly increased decomposition as microbes need to use labile substrates to acquire N from organic matter. This ‘‘microbial nitrogen mining’’ is consistently suppressed by increased soil N supply or substrate N concentrations as it may be in high input farming system (Craine *et al.,* 2007).

5.5.3.3 Alternative practices

The application of alternative practice of fertilizer and manure combination for conventional farming practice manure did not show specific trend for season in basal respiration in season 1 and 2. The relative reduction in basal respiration in season 1 is contrary to other studies (Salehi *et al.*, 2017; Zhang *et al.*, 2009; Iovieno *et al.*, 2009) which reported that integrated application of cattle manure and inorganic fertilizer increased microbial biomass carbon, soil organic carbon, total N, mineral N, and CO_2 flux as compared to sole fertilizer application. Salehi *et al.* (2017) linked this increase to the available C substrate and easily mineralizable organic compounds, and other essential nutrients (P and N) for soil microorganisms that are available in cattle manure.

The reduction in basal respiration for the cotton-legume intercrop compared to sole cotton in this study is contrary to results by Sarathambal *et al.* (2015) who found that basal respiration was significantly highr in treatments of legume intercropping systems than in sole crop.

5.5.4 Birch effect

The observed significant effect of the fertility management practice on the rate of CO_2 flux after soil re-wetting is linked to the fact that the rate of CO_2 flux after rewetting depends on the amount and type of soil organic substrates (Borken and Matzner, 2009) amendments. In this study, the different types of soil amendment influenced differently the amount of CO_2 produced after rewetting. The relatively higher rates in organic practice than conventional practice is due to the increased organic pool by the organic amendments which after re-wetting provides substrates for CO_2 production (Araújo *et al.*, 2009).

5.5.4.1 Current practice

The similar CO_2 flux between current organic and conventional is linked to the fact that the current level of manure in organic (OF-3) was low so that it did dot enhance much more microbial metabolism (Kim *et al.,* 2012) than conventional after rewetting. However, the enhanced microbial metabolism was much higher than the control treatment.

5.5.4.2 Higher input scenario

The similar CO_2 flux rate in the higher rates of organic and conventional practice compared to the current practice is linked to the fact that these higher rates in this study are in the lower levels of manure and fertilizer application. This study is in line with result by Fares *et al.* (2017) who also found no difference in soil CO_2 flux after rewetting between treatment with different level of chicken manure. This indicates that for much higher rates of fertilizer and manure application need to be tested.

5.5.4.3 Alternative practices

The significant higher CO_2 flux rate after rewetting for organic treatment with cotton-legume Intercrop could be linked to higher microbial biomass and mineralizable C and N (Franzluebbers *et al.,* 2000) in this treatment resulted from the added manure and the legume.

5.6 Conclusion and recommendations

From this study, it is concluded that for the current farming practice organic and conventional farming systems have no difference in ASA and PN, but higher BR was observed in the organic than in the conventional systems. This indicates generally that microbial activity in soil under existing smallholder organic and conventional farming practices are similar. Integration of manure and fertilizer as an alternative farming practice also increased ASA and PN but reduced BR, indicating generally that manure-fertilizer combination elevated soil microbial activity. Legume-cotton intercropping increased ASA but reduced PN and BR; this does not give a clear indication on the effect of this farming practice on soil microbial activity. For the case of birch effect, the current practice had similar birch effect. Cotton legume intercrop had higher birch effect than the others treatments.

From these results, it is recommended that smallholder farmers should integrate manure and fertilizer to improve soil microbial activity. It is also recommended that further studies be done that include higher rates of manure and fertilizer and also on the effect of cotton-legume intercrop to determine the trends in microbial activity under this practice.

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CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The soils in Mwamishali and Ngh'oboko were classified at order level as Mollisols according to the Soil Taxonomy and that of Sanga Itinje and Mwabagalu were classified as Alfisols and Vertisols respectively. In all studied sites the soils were described as marginally suitable for cotton production due to fertility limitations. The current organic and conventional farming practice have similar yield and economic performance. However, at higher input rate (fertilizer and pesticide), conventional cotton had higher yield than organic but with less economic performance. The alternative organic cotton practice practices (intercropping cotton with green gram) lowered cotton yield but higher economic performance as a result of the extra revenue from green gram. The alternative conventional cotton practice (combining fertilizer and manure) outperformed the current practice by having both better yield and gross margin. In the season with less rainfall (season 2), the control outperformed other treatments in terms of economic return indicating that under the prevailing semi-arid conditions small holder farmers are rational on limited use of fertilizer and pesticide.

The current organic and conventional cotton farming practices had similar cumulative area-scaled N_2O emission. However, yield scaled emission were significantly higher in conventional than organic farming systems. For the high input scenario, conventional cotton showed higher area-scaled and yield-scaled N_2O emission than organic cotton in season 1 with good rainfall but not in season 2 which had less rainfall. Manure and fertilizer combination as alternative practice reduced yield-scale N_2O emission while intercropping cotton with legumes reduced area-scaled emission.

The current smallholder farming practices (both organic and conventional) also had very low N_2O emission compared to reported emissions from cotton fields in high input farming system. The emission factors for both conventional and organic systems were <1% of applied total N, which is low compared to the high input farming systems.

The current farming practice (fertilizer and pesticide) had similar effect on microbial activity. However, increasing N level as fertilizer or manure increased microbial activity. Manure fertilizer combination as an integrated practice increased arylsulfatase activity and PN but relatively reduced basal respiration in conventional farming in both seasons. Intercropping cotton with legume increased microbial activity (arylsulfatase) but reduced PN and basal respiration and hence had no clear trend on improving soil microbial activity. Pest management had no effect in microbial activity in both organic and conventional farming practice. Smallholder organic and conventional farming practices have effect on soil CO2 production after re-wetting.

6.2 Recommendations

6.2.1 Recommendation for application

Due to the fact that the soils are marginally suitable for cotton production because of soil fertility limitations, sustainable cotton production in these areas would need interventions for soil fertility improvement. Cotton legume intercrop, fertilizer manure combination and neem and cow urine are viable farming practices to be adopted by smallholder cotton farmers, for increasing yields while reducing the risk of higher N_2O emission and improving soil microbial activity and soil quality as well as economic performance.

6.2.2 Recommendation for further studies

The following recommendations are put forward for further studies:-

- Long term study to determine long term effect of studied manure treatments as this study was only done for two years with different weather conditions.
- Further study to include higher input levels as the levels applied in this study were far below high input farming system.
- Future study for cotton-legume intercrop that include other legume species.