LIVE AND DEAD MULCH FOR WEED AND SOIL FERTILITY MANAGEMENT IN ORGANIC PRODUCTION OF SWEET PEPPER (*Capsicum annuum* L.)

ADOLF GERALD SARIA

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

2019

EXTENDED ABSTRACT

The study was conducted for three seasons aimed at developing a strategy that combines weed control with soil fertility enhancement using live and dead mulch for increased productivity of organic sweet pepper. Synchronization experiments were set to evaluate release patterns and availability of nutrients by leguminous green manures in soil. A randomized complete block design (RCBD) with a plot size of 3 m x 3 m replicated four times was used. Mucuna and greengram materials in mesh bags were buried 10 cm in soil. Replicated bags were removed weekly and analysed to determine decomposition rates and quantities of nutrients released into soil. The grown cover crops were slashed at the stage of 50% flowering and used as dead mulch for weed control and their influence on weeds dynamics evaluated when greengram and mucuna cover crops were used as live and dead mulch. Weed density, weed biomass and crop mineral contents were analysed each season and soil weed seed bank data were determined from different depths 0–10, 11-20 and 21-30 cm from plots managed with hand hoe weeding, mixed grass mulch and cover crops treatment in four replicates. Farmers assessed the efficacy of each treatment and their preference by identifying the criteria for selecting the best treatment for weed control and soil fertility improvement. Different treatments were ranked depending on their effectiveness on weeds control and soil fertility improvement, its single use for the live and dead mulch, availability and costs of the materials and the amount of labour required for the specific treatment application. Mucuna decomposition was faster compared with greengram, from third to twelfth week of incubation. This implies that greengram has relatively more resistant materials to decomposition as compared with mucuna. Maximum effect on soil nutrient content occurred in sixth and seventh weeks after application of green manures. Total organic C in soils treated with cover crops increased by a factor of 2.3 to 3.2. Total N increased significantly from 1.28% to 2.64% at sixth week in soil with greengram and to 2.83% at seventh week in soil with mucuna. Available P content of soil increased from 0.03 to 0.39 and 0.37 mg kg^{-1} in soil treated with greengram and mucuna, respectively. Optimum microbial population was attained from fifth to seventh week after manure application, with 2.3 x 10^8 in soil with greengram and 3.08 x 10^8 with mucuna, significantly improved compared with original population. Plots planted with greengram and mucuna cover crops reduced weed species to 13 and 12, respectively, from 17 weed species identified at the beginning of the experiment. Mucuna cover crop reduced weed biomass from 33.1 g/m^2 to 9.1 g/m^2 and weed seed bank density from 17922 to 9418 per metre square. However, *Cyperus rotundus*, *Cynodon dactylon* and *Elangia codifolia* remained to be the most observed weeds in both treatments throughout the experimental period. Growth of sweet pepper plants planted in plots with mucuna cover crop was improved by increasing stem branches to 22, leaves to 157 and high number of fruits per plant (25). The highest total N and P in vegetative parts were recorded in crops planted with mucuna having 2.81 and 1.63% and those planted with greengram 2.48 and 1.09%. In farmers' assessment, farmers' criteria for selecting the best weed and soil fertility management treatment were sweet pepper yield, fruit quality, weeds control and soil fertility improvement. Farmers preferred the two green manure cover crops in terms of absolutely ranking, matrix ranking and pairwise ranking. The cover crops were also preferred due to their cost effectiveness, sustainability and availability, giving the farmers more profit compared with other treatments. Results from this study have shown the suitability of the cover crops on weed control and improving soil fertility. It has been observed that the two cover crops mucuna and greengram can suppress different types of weeds above ground and below ground in terms of weed seed bank. However, this depends much on the type of weeds available in site, as results indicate that sedge and grasses were not completely suppressed and few managed to grow passing the live cover

crops mulch and dead mulch. Furthermore, one year application of cover crops for weed control did not significantly reduce weed and weed seeds population. Therefore, to obtain sustainable benefits of using cover crops, it is important to use these cover crops frequently in more than one season. This will help building residue effects within the field for sustainable profit.

DECLARATION

I, **Adolf Gerald Saria**, do hereby declare to the Senate of Sokoine University of Agriculture that, this dissertation is the result of my own original work done within the period of registration and that it has neither ben submitted nor being concurrently submitted for a degree award in any other University.

Adolf Gerald Saria **(PhD Candidate)**	**Date**

The above declaration is confirmed

Prof. K. P. Sibuga **(Supervisor)**	**Date**
Prof. E. Semu **(Supervisor)**	**Date**

COPYRIGHT

ACKNOWLEDGEMENTS

I humbly give thanks to God almighty, for granting me His abundant blessings and life. He has been a friend, a royal guard, a comforter and a provider in times of need and even in times of abundance. His protection has never fall short in my entire life. Through His grace this work has been possible, in Him I trust and to Him be the glory.

I am indebted to my supervisors, Professor Sibuga, K. P. and Prof. Semu, E. of Sokoine University of Agriculture (SUA) and Professor Henning Høgh-Jensen of the National Food Institute of Technical University of Denmark for devoting their valuable time to supervise this work. I thank them for their tireless professional guidance, constructive comments, productive criticisms and support in facilitating the accomplishment of this work. Through them I have learned to work hard to achieve my goals.

I sincerely thank the Danish International Development Agency (DANIDA) through the Productivity and Growth in Organic Value-chains (ProGrOV) project, collaborated between Sokoine University of Agriculture (SUA)-Tanzania, Makerere University-Uganda, University of Nairobi-Kenya and Danish (UCPH) and Aarhus University, for providing me with financial assistance, academic references and supplementary training through different workshops and study visits at Copenhagen Universities and Technical University of Denmark.

I am grateful to the Tushikamane farmers group of Morogoro and Sokoine University for allowing me in their fields during my study and for all the assistance they provided for making this study a reality. I am also thankful to the Tanzania Organic Movement

(TOAM) for their very special and professional assistance during my study. Their knowledge in organic farming practices had been of much help in all these achievements.

I would also like to express my true appreciations to my loving mother Mwl. Mary Mashishanga, my brother James and his wife, sisters Bahati and Dorica, for all their prayers and encouragement during this study. The love, support, kindness and patience they showed whenever I could not meet their expectations throughout my study time was remarkable. I thank all of them for their understanding.

Lastly, I genuinely thank all my supervisors and fellow students within and outside the projects and all workers at SUA Crop Museum who in one way or the other helped me in accomplishing this work.

DEDICATION

To my lovely wife Dr. Catherine Reuben Shari whose love surpassed everything and my lovely mother Mwl. Mary Gigwa Mashishanga who gave all for my life. To my beloved son James and daughter Jennifer-Maria, whom I expect to grow in God’s fear and become a great man and woman and do all the best in achieving what I couldn’t. So help them God.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Introduction

Vegetables are horticultural plants that are highly valued as sources of vitamins, provitamins, dietary minerals, fibers, carbohydrates and little amounts of proteins and fats in human diets (Rubatzky and Yamaguchi, 2012). Vegetables are produced by using conventional as well as organic agriculture systems. Conventional agriculture is an agriculture system which makes use of synthetic chemical fertilizers, pesticides and other industrial materials (Horrigan *et al.,* 2002). Several literatures accounts have associated conventional agriculture with soil erosion, water and soil pollution (Montgomery, 2007), and poor human health as it contains less antioxidants (Stracke *et al.,* 2009) and higher concentration of heavy metal (Rembialkowska, 2000). Therefore, conventional agriculture is typically a highly resource and energy intensive agriculture system.

Alternatively, in contrast to conventional agriculture system, organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activities. Agro-ecosystem health is accomplished by using, where possible, agronomical, biological and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system (FAO, 1999). Therefore, organic agriculture is based on minimizing the use of synthetic chemical inputs, avoiding the use of synthetic fertilizers and pesticides (FAO/WHO, 2001). Organic agriculture takes care of the site-specific conditions through fostering resources cycling, promote ecological balance and conserve biodiversity. Since 1990, the market for organic products has grown from virtually nothing to more than $ 80 billion with 43.7 million hectares of agricultural land cultivated (Willer and Lernoud, 2016).

Organic agriculture popularity has been growing with years due to the public concerns on environmental degradation and regarding human health effects of pesticides. This has led to an increasing interest in application of sustainable agriculture system specifically organic agriculture as a solution to the two problems because of its all-natural approach. The organic agriculture systems aim at making the best use of environmental goods and services whilst conserving natural, social and human capitals (Shreck *et al.,* 2006). Sustainability in agricultural systems incorporates the concept of both resilience which is the capacity of the system to resist shocks and stresses, and persistence which is the capacity of the system to tolerate shocks and stresses (Pretty and Waibel, 2005). Therefore, organic agriculture is considered inherently sustainable system since it represents a deliberate attempt to make the best use of local natural resources. The organic farming system aims at creating an integrated humane, environmentally and economically viable agricultural system in which maximum reliance is put in local or on farm renewable resources, as well as the management of ecological and biological processes.

Organic agriculture productivity and its potential contribution to global food security is challenged by different constraints, among them are soil fertility improvement (Carr *et al.*, 2012) and weed pest management (Bàrberi, 2002; Kruidhof *et al.*, 2008). In order to avert poor soil fertility and weeds in organic production systems, organic mulch is among potential solutions which can be used as a multipurpose solution for both weed control and soil fertility improvement. Organic mulches such as cover crops, straw, leaves or wood chips have regulating effects in soil which can offer advantages such as conservation of soil moisture, reduced soil erosion, as well as suppression of weeds and plant disease (Sinkeviciene *et al.,* 2009). Alharbi (2015) has reported the positive effects of mulch in improving soil quality. Mulching using organic mulch usually leads to stimulation of soil microbial communities due to its addition of organic matter into the soil (Saria *et al.*, 2018).

In Tanzania, organic agriculture history dates back to 1898 in Ruvuma region with a garden of different vegetables (UN, 2006). This agriculture system has been recorded to extend and to be practiced in different regions in recent years. These regions are Arusha, Kilimanjaro and Kagera for organic vegetables, coffee, banana, papaya and pineapples; Iringa and Njombe for organic tea, vegetables and avocado; and Tanga and Morogoro where famers produce different types of vegetables and cocoa under organic practices. According to a UN report, organic cotton was recorded in Meatu and Kishapu districts, in Simiyu and Sinyanga regions, respectively (UN, 2008).

1.2 Problem Statement

Organic vegetable production in Tanzania still faces constraints of lack of capital, poor soil fertility, pests control, drought, inputs availability, poor physical and chemical quality of the produces (Ngowi *et al.,* 2007; Ngereza and Pawelzik, 2016). Among pests, weeds appear to have the most negative effects. Kumar *et al.* (2015) reported 13-78% yield reduction in different crops, including vegetables, due to weeds. In Tanzania, organic farmers control weeds mostly by hand hoeing or pulling which increases labour by 30-45% hence limiting the acreage of land a farmer could cultivate (Chianu and Akintola, 2003). Loss in soil fertility is a major problem facing most of Africa Sub-Saharan agriculture leading to low production (AGRA, 2013). Furthermore, securing supply of optimal quantities of phosphorus (P), potassium (K) and nitrogen (N) supply from farm yard manures, crop residues, compost, dead and live mulch like cover crops manures used in organic farming is a major challenge (Johnston, 1991; Frøseth, 2016; Raviv, 2010). Therefore, organic agriculture is facing a challenge of identifying appropriate materials which can supply optimal levels of mineral nutrients required by the soil and specific crop for its optimal growth and development. Lack of synchrony between mineralization of organic N from organic manure sources and plant N requirements leads to low productivity in organic agriculture despite application of different nutrient sources (Robertson *et al.,* 2012; Crews *et al.,* 2016). Lack of synchrony has forced farmers to try using different techniques including incorporation of the manure in to the soil, decomposing manure before application to the farm and timing of planting later after manure application to overcome this problem.

1.3 Justification Statement

Mulching is a multipurpose strategy mainly used for both pest control and soil improvement for increasing plant production in organic systems. Mulching will help farmers to increase soil organic matter content which can support microorganisms that destroy common weed seeds (Tian *et al.*, 2016). Mulching plays a great role of conserving soil moisture, providing nutrients, suppressing weeds in organic agriculture and conserving natural enemies of insect pests by providing them with suitable habitat, humidity, protection and alternative prey (Mochiah and Baidoo, 2012). Mulching especially with legume plants provides Nitrogen (Zotarelli *et al.,* 2012) which is among major factors mostly limiting soil productivity either alone or with P in different agriculture systems (Bouwman *et al.,* 2013). Yet, cover crops mulch have advantages of reducing the ability of weeds to germinate (Mirsky *et al.,* 2013) and improving chemical and physical characteristics of the soil (Abdollahi and Munkholm, 2014).

Increasing beneficial insect activities has been reported in organic farms under cover crop mulching which help in controlling nematodes and other pathogens (Danne *et al.,* 2010). Beneficial insects to a greater extent are favoured by mulching materials by providing habitat, nests for reproduction and protection from predators and hash conditions. Some studies have shown the possibility of using organic mulches in vegetable production for reducing production costs (Sharma *et al.,* 2011; Saria, 2014) and enhancing environmental characteristics. Therefore, organic farmers can use mulching technology like cover crop legumes and mixed grass in order to improve organic agriculture production and furthermore conserve natural, social and human capitals.

1.4 Objectives

1.4.1 Overall objective

To develop a strategy that combines weed control with soil fertility enhancement using live and dead mulch for increased productivity of organic sweet pepper.

1.4.2 Specific objectives

i. To determine soil fertility dynamics of ultisol as influenced by greengram and mucuna applied as live cover crop green manures.
ii. To evaluate effects of live and dead mulching materials on weed occurrence, seed bank and diversity and their potential for improving sweet pepper physical and chemical attributes.

iii. To determine farmer's criteria on selection and preference of mulching technologies and their economic benefit in organic sweet pepper production.

1.5 General Literature Review

1.5.1 Organic agriculture

Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activities. Agro-ecosystem health is accomplished by using, where possible, agronomical, biological and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system (FAO, 1999). Organic agriculture aims at making the best use of environmental goods and services whilst conserving important resources, particularly natural, social and human capital (Reganold and Wachter, 2016). Organic agriculture contends on holistic sustainability of the system which is usually attained through incorporating both the concept of resilience and persistence (Darnhofer *et al.*, 2010). This is the agriculture system which is based on minimizing the use of synthetic chemical inputs and avoiding the use of synthetic fertilizers and pesticides. It is considered inherently sustainable since it represents a deliberate attempt to make the best use of local natural resources by reducing the use of external inputs in production and pest control.

The ability of organic agriculture's productivity and potential contribution to feeding the world population has been a matter of discussion for many years, with many people sceptical on its ability. However, Badgley *et al.* (2007) argue that organic production can contribute substantially to feeding the current and future world population, and that it may even be possible to reduce the agricultural land base to be comparable to conventional production. Different studies and reports have shown that organic agriculture is a farming system that will be of increasing importance in global food and ecosystem security. The number of organic farms, land size under organic farming and the market size for organic foods has been progressively increased (Willer and Lernoud, 2016). Many farms in both developed and less-developed countries implement organic practices but are not certified organic. Reganold and Wachter (2016) explained an increasing number of farmers who turn to certified organic farming systems as a way to provide verification of production methods, decrease reliance on non-renewable resources, capture high-value markets and premium prices, and boost farm income. Furthermore, organic produces are considered safer for human health than conventional produces (Smith-Spangler *et al.,* 2012).

Insect pests can cause direct loss of the crop or can be vectors of disease pathogens in both organic and conventional agriculture. Pest control in agriculture, especially in conventional agriculture, has been a major source of environmental pollution (Sun *et al.,* 2012). Replacing conventional pest control practices with organic agriculture practices, which avoid the use of synthetic chemicals like pesticides, would substantially reduce environmental pollution and associated environmental impacts. In organic control insect pests are controlled through promotion of natural enemies like spiders and wasps, which can compensate for the absence of pesticides, and these natural enemies can control pests like aphids (Birkhofer *et al.,* 2016). Birkhofer *et al.* (2013) observed higher abundance of spiders in organically managed fields compared to conventionally managed fields. In addition to that, Thies *et al.* (2011) highlighted the importance of beneficial insects like web-building spiders which are predators of insect pests like aphids and are used as biocontrol.

However, very few studies have been conducted to develop insecticides acceptable in organic agriculture. Also, there are no any studies done to develop herbicides recommendations acceptable in organic agriculture.

1.5.2 Weeds' effects on plants

Weeds are among major production constraints in agriculture, as they deprive the crop plants of available nutrients, space, light, and moisture. Weeds can cause loss in crop yields amounting to 34% in average even in organically produced crops if not effectively managed (Oerke, 2006). In solanaceae crops, including sweet pepper, weeds appear to have most deleterious effects. Amare et al. (2015) quantified a loss of up to 91% in yield caused by weeds. However, these losses can be reduced up to 0% if weeds in organic farms are managed properly (Armengot *et al.*, 2013). Vegetable crops vary widely in their response to weed competition, ranging from non-competitive crops, such as onion, to moderately competitive ones, such as potato and transplanted cabbage (Pimentel *et al.*, 1991; Uzo and Currah, 2018). Studies have shown that vegetable yields were increased by up to 16% when mulch was applied during the first week after transplanting (Hossain, 2007).

Weeds can affect crops in different ways including competing with crops for mineral nutrients, water and light in the field (Swanton *et al.*, 2015) and also by acting as alternative hosts for insect pests and disease pathogens (Zachrisson *et al.*, 2017). Kaur *et al.* (2018) described weeds as serious competitors for water and are a major cause of reduced crop yield or crop failure worldwide in non-irrigated areas, denying the crop 1 250 tonnes of water from one hectare in a wet season leading to poor crop germination, growth and even production (Lim *et al.*, 2015). Chauhan (2013) explained the ability of some weeds such as *R. cochinchinensis* to tolerate drought condition than crops by increasing leaf weight ratio and hence increasing its competitive advantage over crops. The result of this competition is that, when water becomes limiting, crops with fibrous root systems show wilting symptoms earlier than associated weeds (Kaur *et al.,* 2018).

Soil mineral content is another important competition factor between weed pests and crops, which affects crop growth, development and production. Weeds are in upper hand when it comes to soil minerals competition, nutrient absorption is faster and higher in weeds than in crop plants (Akhtar *et al.,* 2017). Edelfeldt *et al.* (2016) observed the ability of weed plants to utilize nitrogen earlier in their development than the main crop plants, making them better competitor during crop development period. Nitrogen alone or with P is the nutrient that most commonly limits productivity of different agroecosystems including organic farming (Zhang *et al.,* 2015).

Weeds also act as alternative host for different pests during and off the main crop season, enabling the pathogen to complete their life cycle even in the absence of crop host. Due to weeds diversity, it can harbour more different type and species of pathogens and allowing them to mutate, making it more difficult to control them (Linde *et al.,* 2016). Thompson *et al.* (2015) found weeds to be the host and habitat of most of the *Diaporthe* species crop pathogens. Weed canopies provide humid and cool microclimate in which fungi and bacteria infect their vegetable hosts and also weeds provide shelter for pest insects and other types of animals, such as rabbits and rodents. A study done by Saeed *et al.* (2015) showed the importance of alternative host plants as reservoirs of the cotton leaf hopper *Amrasca devastans*.

With organic farming which protects and nurture the environment, studies are needed to determine the changes in weed behavior in response to agronomic practice changes.

1.5.3 Mulching

The use of mulch is a common practice for weed and soil fertility control on organic farms. Mulches such as cover crops and leaves have been documented to offer advantages such as conservation of soil moisture, reduced soil erosion, weed and disease suppression from the field (Altieri, 2018). Studies have indicated the importance of live mulch in organic agriculture as it was observed that, organic cropping system heavily rely on cover cropping for weed management (Mirsky *et al.,* 2013). Live and dead mulching have been an effective method of manipulating crop growing environment to increase yield and quality by controlling weed growth, ameliorating soil temperature, conserving soil moisture, reducing soil erosion, improving soil structure and enhancing organic matter content (Kader *et al.,* 2017; Lowry and Smith, 2018). Tomato crops mulched with Faba beans were observed to have improved tomato crop physiology as well as minerals concentration in fruits, with significantly highest magnesium concentrated in fruits (Galieni *et al.,* 2017). Sujatha *et al.* (2018) supported the findings on the ability of mulch to increase fruits quality as they reported an increase in total soluble solid (8.83 °Brix), juice percentage (83.05%), specific gravity (1.15 g/cm^3), vitamin C content (58.88 mg/100 g), total sugars (9.50%) and minimum physiological loss in weight (13.5% at 1 DAH and 25.30% at 2 DAH), titrable acidity (0.61%) and very less albinism disorder (0.28%) when the field was mulched by rice straw mulch.

Slashing and defoliation of legume cover crops has been found to substantially increase mineralization of N. Ayres *et al.* (2007) quantified the increase in mineralization up to five times following legume cover crops defoliation which also led to an increase of microbial population by 77%. These findings indicate that, slashing of legume cover crops after attaining sufficient biomass in organic fields may have great impact on soil fertility and improve synchronization between nutrients release by these cover crops and plant uptake. Also, cover crops can be used as means of increasing land productivity following a decline due to the increase of weed infestation, pests and diseases (Yates *et al.,* 2011). Some cover crops have an advantage of having allelopathic effects on weeds increasing their effectiveness on weeds control (Kunz, 2016).

Awodoyin and Ogunyemi (2005) reported weed control efficiency of 27-97% in pepper production depending on the mulching materials used, while Thankamani *et al.* (2016) reported an efficiency of up to 72% weed control when mulch was applied in ginger fields. A study by Dube *et al.* (2012) indicated that cover crops managed to control weeds of *Eleusine indica* (L.) Gaertn., *Amaranthus palmeri* S. Wats, and *Ipomoea lacunose* L. throughout the season by reducing their biomass, and also reduced the weed seed bank in conservation till systems. For example, the cover crops hairy vetch and oat effectively reduced seed banks to about 30-70% of weeds, including *Datura stramonium* L., *Digitaria sanguinalis* (L.) Scop., *Amaranthus retroflexus* L., and *E. indica* in the upper soil layer (Dube *et al.,* 2012). Therefore, live and dead mulch like cover crops and mixed grass can be the best alternative to help in reducing weed infestation in field crops (Király *et al.*, 2018).

Mulching is another alternative for controlling insect pests in organic agriculture. Oerke (2006) estimated yield losses for major food and cash crops due to infestation of different pests reached 32.1% of total yield, however mulch can be used to control some of these pests like weeds and insects. In India, insect alone caused a loss of up to 21.5 US dollars in 2007 to 2008 in major agricultural crops (Dhaliwal *et al.,* 2010). When vegetables are grown in living cover crop mulches they are found to reduce insect pests and the damage caused by them (Hooks and Johnson, 2006). Genger *et al.* (2018) observed reduced number of potato leafhopper pests in straw mulched plots than mechanically cultivated plots in organically potato production. Quintanilla-Tornel *et al.* (2016) found higher abundance and richness of detritivores, predatory arthropods, parasitoids and beneficial free-living nematodes (particularly bacterivores and fungivores) densities in cover crop mulched plots compared with bare plots. These beneficial insects had negative correlation to insect pests limiting aphid populations. Skidmore *et al.* (2017) reported reduced striped cucumber beetle and squash bug numbers in row cover mulch organic cucumber production leading to increased cucumber marketable yield.

Studies have indicated the ability of mulch to manage weeds and soil fertility. However, most of these studies have been done in other crops, and therefore, few studies have been done in sweet pepper crops. Furthermore, they are hardly any studies relating mulch application to the quality of crop produced.

1.5.4 Influence of live and dead mulch on soil fertility and microbial population

Cover crops mulch has been used as green manure and for weed management since the origin of agriculture (Williams, 2006). Cover crops green manure and mulch are used for soil fertility control to replenishing soil nitrogen that had been taken up by crops and to provide organic matter for maintaining soil fertility and improve its properties (Sarwar *et al.,* 2010). Studies have revealed the advantage of cover crops in increasing soil water content to the following crop in the following season through increased surface residue cover and infiltration after their termination (Unger and Vigil, 1998). A study done by Mwango *et al.* (2016) in Tanzania in the Usambara mountains showed significant improvement in soil fertility status under Tughutu (*Vernonia subligera* O. Hoffn) mulching than under sole soil, with 0·46 versus 0·38% total N, 37 versus 22 mg kg^{-1} P and 0·6 versus 0·2 cmol kg^{-1} K. Furthermore, the *Tughutu* mulch significantly controlled soil loss through erosion from 35 in sole soil to 8 $Mgha^{-1}$ y^{-1}. Prosdocimi *et al.* (2016) observed the reduction of median water loss from 52.59 to 39.27% and median erosion rate from 2.81 to 0.63 Mg ha^{-1} h^{-1} when straw mulch was applied in vineyard farms.

Decreases in soil organic matter lead to a decline in agricultural and biomass productivity, poor environmental quality, soil degradation and nutrient depletion, and finally to food insecurity (Lal, 2015). Conventional practices like deep tillage, inorganic fertilizers and pesticides used to control pests and poor soil fertility problems are not accepted in organic farming (Sainju *et al.*, 2002). This is due to their potential ability of degrading soil and water quality by increasing soil erosion, soil organic matter mineralization and nitrogen concentration on surface and ground waters (Carrera *et al.*, 2007).

Results from a study done by Altieri *et al.* (2011) also confirmed that cover crops improved soil moisture retention, soil fertility, and crop productivity. Mbuthia *et al.* (2015) demonstrated that long-term no-till and use of cover crops under a low biomass monoculture crop production system results in significant shifts in conditions that favor C, N and P cycling compared with those under conventional tillage practices. These practices also led to 5% increase in soil quality in cover crop mulched fields compared with fields with no cover crop mulch. The study by Reynolds *et al.* (2017) showed the greatest acid phosphatase activity due to effect of oat cover crop on soil phosphatase enzymes, concluding that cover crops could be a potential means to enhance soil phosphorus cycling. In addition, cover crops increase soil organic carbon without causing a decline in yields, nor carbon losses like what organic manure applications may do (Poeplau and Don, 2015). In addition, the benefit of organic fertilizers to the soil are of twofold, the materials supply nutrients in soil for organic agriculture and in long run they improve soil physical characteristics and favour macro and micro-organisms populations (Gellings and Parmenter, 2016). Therefore, the system becomes self-sufficient as it is sustainable in terms of nutrient supply and soil nurturing.

Another way in which mulch is beneficial to the soil and crops is through its influence on the soil microbial community by reducing soil temperature and moisture evaporation from the soil and therefore moisture dynamics (Lange *et al.,* 2014). Cover crops and mulch increase the potential population of macro and microorganisms, and their activities in the soil because they increase the total inputs of organic materials to the soil. Saria *et al.* (2018) reported the ability of mulches to stimulate soil microbial communities due to organic matter addition. Muhammed *et al.* (2015) described the influence on the population of bacteria, fungi and actinomycetes in mulched plots of Okra as compared with unmulched plots.

Zhang *et al.* (2017) explained the ability of rice straw mulching in both strengthening the retention ability of soil microbial residues dominantly contribute to soil organic matter accrual enhanced by rice straw used as mulch. Reddy *et al.* (2003) reported the increase in total bacterial and fungal population density in the soil after three years with the application of crimson clover or cereal rye cover crop compared with the soil without cover crop. The increase was ascribed to the ability of cover crops and mulch to provide conducive environments like increased water content, moderate soil temperature changes, provide food sources at soil surface and retention of burrows to the macro and microorganisms' favour (Mele and Carter, 1999). Lundquist *et al.* (1999) reported an increase of 24 to 52% of active bacteria and 400 - 600% of bacterial feeding nematodes in just 14 days when rye was applied. Therefore, on achieving these, agricultural technologies as no-till farming, application of compost, mulching for both live and dead mulch and legume cover crops have been cited as possible alternatives in organic agriculture system (Altieri, 2018).

However, addition studies should be done on the effect of to identify which type of mulch is relevant for benefiting a specific type of soil. Also, it is important to evaluate the long term effect of mulch in the soil organic carbon accumulation.

1.5.5 Criteria for selection of weed and soil fertility management by farmers

Sweet pepper farmers are faced with pest, soil fertility and water challenges (Ngereza and Pawelzik, 2016). In order to overcome these challenges, cultivation of sweet pepper becomes labour and input intensive and associated with high capital investments. Therefore, farmers always look for a technology to control pets which is time and labour effective, and therefore cost-effective (Martinsen *et al.,* 2017). Furthermore, farmers select a technology which when used as mulch for pest control can be of great potential to improve soil physical properties, prevent erosion, regulate soil temperature and water retention, supply organic matter and other soil nutrients, as well as increase the biological activity (Bhardwaj, 2013). Also farmers prefer a technology which is simple in application and will reduce management costs and other logistics to farmers (Waller *et al.,* 1998). Eckert and Bell (2005) concluded that any technology that does not consider farmer's strongly held values, beliefs and on-farm decision making needs is less likely to be adopted by farmers.

REFERENCES

Abdollahi, L. and Munkholm, L. J. (2014). Tillage system and cover crop effects on soil quality: I. Chemical, mechanical, and biological properties. *Soil Science Society of America Journal* 78(1): 262-270.

AGRA (2013). Africa Agriculture Status Report: Focus on Staple Crops. Alliance for a Green Revolution in Africa (AGRA). Nairobi, Kenya. [http://www.agra-alliance.org] site visited on 26/10/2018.

Akhtar, P., Kumar, A., Kumar, J., Sharma, N., Stanzen, L., Sharma, A. and Mahajan, A. (2017). Bio-Efficacy of Early Post and Post Emergent Application of Tembotrione on Nutrient Removal by Crop and Weeds in Spring Maize (*Zea mays* L.) Under Irrigated Sub-Tropical Shiwalik Foothill Conditions of J and K, India. *International Journal of Current Microbiology and Applied Sciences* 6(6): 663-670.

Alharbi, A. (2015). Effect of mulch on soil properties under organic farming conditions in center of Saudi Arabia. *Journal of American Science* 11(1): 108-115.

Altieri, M. A. (2018). *Agroecology: the science of sustainable agriculture*. CRC Press. 448pp.

Altieri, M. A., Lana, M. A., Bittencourt, H. V., Kieling, A. S., Comin, J. J. and Lovato, P. E. (2011). Enhancing crop productivity via weed suppression in organic no-till cropping systems in Santa Catarina, Brazil. *Journal of Sustainable Agriculture* 35(8): 855-869.

Amare, T., Sileshi, F. and Hamza, I. (2015). Effect of weed interference period on yield of transplanted tomato (*Lycopersicon Esculentum* M.) in Guder West Shewa-Oromia, Ethiopia. *ISABB Journal of Food and Agricultural Sciences* 5 (3): 14-20.

Armengot, L., José-María, L., Chamorro, L. and Sans, F. X. (2013). Weed harrowing in organically grown cereal crops avoids yield losses without reducing weed diversity. *Agronomy for Sustainable Development* 33(2): 405-411.

Awodoyin, R. O. and Ogunyemi, S. (2005). Use of sicklepod, *Senna obtusifolia* (L.) Irwin and Barneby, as mulch interplant in cayenne pepper, *Capsicum frutescens* L., production. *Emirates Journal Agricultural Science* 17(1): 10-22.

Ayres, E., Dromph, K. M., Cook, R., Ostle, N. and Bardgett, R. D. (2007). The influence of below-ground herbivory and defoliation of a legume on nitrogen transfer to neighbouring plants. *Functional Ecology* 21(2): 256-263.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Avilés-Vázquez, K., Samulon, A. and Perfecto, I. (2007). Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems* 22(2): 86–108.

Bàrberi, P. (2002). Weed management in organic agriculture: are we addressing the right issues? *Weed Research* 42: 177–193.

Birkhofer, K. L. A. U. S., Entling, M. H. and Lubin, Y. A. E. L. (Eds.) (2013). *Trait composition, spatial relationships, trophic interactions. Spider Research in the 21st Century: Trends and Perspectives.* Siri Scientific Press, Rochdale, United Kingdom. 200-229pp.

Birkhofer, K., Arvidsson, F., Ehlers, D., Mader, V. L., Bengtsson, J. and Smith, H. G. (2016). Organic farming affects the biological control of hemipteran pests and yields in spring barley independent of landscape complexity. *Landscape Ecology* 31(3): 567-579.

Bouwman, L., Goldewijk, K. K., Van Der Hoek, K. W., Beusen, A. H., Van Vuuren, D. P., Willems, J., Rufino, M. C. and Stehfest, E. (2013). Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *Proceedings of the National Academy of Sciences* 110(52): 20882-20887.

Carr, P. M., Mäder, P., Creamer, N. G. and Beeby, J. S. (2012). Overview and comparison of conservation tillage practices and organic farming in Europe and North America. *Renewable Agriculture and Food Systems* 27(1): 2-6.

Carrera, A., Echenique, V., Zhang, W., Helguera, M., Manthey, F., Schrager, A., Picca, A., Cervigni, G. and Dubcovsky, J. (2007). A deletion at the Lpx-B1 locus is associated with low lipoxygenase activity and improved pasta color in durum wheat. *Journal of Cereal Science* 45: 67-77.

Chauhan, B. S. (2013). Growth response of itch grass (*Rottboellia cochinchinensis*) to water stress. *Weed Science* 61(1): 98-103.

Chianu, J. N. and Akintola, J.O. (2003). Labour needs for weeding: Implications for the adoption of improved fallow management systems in the derived savannas of south-western Nigeria. *Nigerian Journal of Weed Science* 16: 1-7.

Crews, T. E., Blesh, J., Culman, S. W., Hayes, R. C., Jensen, E. S., Mack, M. C., Peoples, M. B. and Schipanski, M. E. (2016). Going where no grains have gone before: From early to mid-succession. *Agriculture, Ecosystems and Environment* 223: 223-238.

Danne, A., Thomson, L. J., Sharley, D. J., Penfold, C. M. and Hoffmann, A. A. (2010). Effects of native grass cover crops on beneficial and pest invertebrates in Australian vineyards. *Environmental Entomology* 39(3): 970-978.

Darnhofer, I., Fairweather, J. and Moller, H. (2010). Assessing a farm's sustainability: insights from resilience thinking. *International Journal of Agricultural Sustainability* 8(3): 186-198.

Dhaliwal, G. S., Vikas, J. and Dhawan, A. K. (2010). Insect pest problems and crop losses: changing trends. *Indian Journal of Ecology* 37(1): 1-7.

Dube, E., Chiduza, C., Muchaonyerwa, P., Fanadzo, M. and Mthoko, T.S. (2012). Winter cover crops and fertiliser effects on the weed seed bank in a low-input maize-based conservation agriculture system. *South African Journal of Plant and Soil* 29(3-4): 195-197.

Eckert, E. and Bell, A. (2005). Invisible force: Farmers' mental models and how they influence learning and actions. *Journal of Extension* 43(3): 1-10.

Edelfeldt, S., Lundkvist, A., Forkman, J. and Verwijst, T. (2016). Establishment and early growth of willow at different levels of weed competition and nitrogen fertilization. *Bioenergy Research* 9(3): 763-772.

FAO (1999). Organic Agriculture. Food and Agriculture Organization of the United Nations, Rome. [http//www.fao.org/unfao/bodies/COAG/COAG15/X0075E.htm] site visited on 22/04/2011.

FAO/WHO. Codex Alimentarius Commission (2001). *Guidelines for the production of, processing, labeling and marketing of organically produced foods.* CAC/GL 32 - 1999 - Rev 1 - 2001 Rome.

Frøseth, R. B. (2016). Nitrogen dynamics in an organic green manure cereal rotation and mineralization of clover leaves at low temperature. PhD Thesis Norwegian University of Life Sciences, Oslo, Norway, 110pp.

Galieni, A., Stagnari, F., Speca, S., D'Egidio, S., Pagnani, G. and Pisante, M. (2017). Management of crop residues to improve quality traits of tomato (*Solanum lycopersicum* L.) fruits. *Italian Journal of Agronomy* 12(1).

Gellings, C. W. and Parmenter, K. E. (2016). *Energy efficiency in fertilizer production and use.* Eolss Publishers Co. Ltd., Oxford. 135pp.

Genger, R. K., Rouse, D. I. and Charkowski, A. O. (2018). Straw mulch increases potato yield and suppresses weeds in an organic production system. *Biological Agriculture and Horticulture* 34(1): 53-69.

Hooks, C. R. and Johnson, M. W. (2006). Population densities of herbivorous lepidopterans in diverse cruciferous cropping habitats: Effects of mixed cropping and using a living mulch. *BioControl* 51(4): 485-506.

Horrigan, L., Lawrence, R. S. and Walker, P. (2002). How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental Health Perspectives* 110(5): 445-456.

Hossain, M. A. and Ishimine, Y. (2007). Effects of farmyard manure on growth and yield of turmeric (*Curcuma longa* L.) cultivated in dark-red soil, red soil and gray soil in Okinawa, Japan. *Plant Production Science* 10(1): 146-150.

Johnston, A. E. (1991). *Potential changes in soil fertility from arable farming systems including organic systems*. Proceedings of the Fertilizer Society of London 306: 1-38.

Kader, M. A., Senge, M., Mojid, M. A. and Ito, K. (2017). Recent advances in mulching materials and methods for modifying soil environment. *Soil and Tillage Research* 168: 155-166.

Kaur, S., Kaur, R. and Chauhan, B. S. (2018). Understanding crop-weed-fertilizer-water interactions and their implications for weed management in agricultural systems. *Crop Protection* 103: 65-72.

Király, I., Palkovics, A. and Mihálka, V. (2018). Yield and fruit quality of strawberry cultivars under different mulching systems. *Agricultural Management/Lucrari Stiintifice Seria I, Management Agricol* 20(1): 59-64.

Kruidhof, H. M., Bastiaans, L. and Kropff, M. J. (2008). Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. *Weed Research* 48: 492–502.

Kumar, A., Rana, S. S., Negi, S. C. and Kumar, S. (2015). Assessment of yield and nutrient losses due to weeds in maize based cropping systems. *Himachal Journal of Agricultural Research* 41(1): 42-48.

Kunz, C., Sturm, D. J., Varnholt, D., Walker, F. and Gerhards, R. (2016). Allelopathic effects and weed suppressive ability of cover crops. *Plant, Soil and Environment* 62(2): 60-66.

Lal Bhardwaj, R. (2013). Effect of mulching on crop production under rainfed condition-a review. *Agricultural Reviews* 34(3).

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

Lange, M., Habekost, M., Eisenhauer, N., Roscher, C., Bessler, H., Engels, C., Oelmann, Y., Scheu, S., Wilcke, W., Schulze, E. D. and Gleixner, G. (2014). Biotic and abiotic properties mediating plant diversity effects on soil microbial communities in an experimental grassland. *PloS One* 9(5): 96182.

Lim, C. A. A., Awan, T. H., Cruz, P. C. S. and Chauhan, B. S. (2015). Influence of environmental factors, cultural practices, and herbicide application on seed germination and emergence ecology of *Ischaemum rugosum* Salisb. *PloS one* 10(9).

Linde, C. C., Smith, L. M. and Peakall, R. (2016). Weeds, as ancillary hosts, pose disproportionate risk for virulent pathogen transfer to crops. *BMC Evolutionary Biology* 16(1): 101.

Lowry, C. J. and Smith, R. G. (2018). Weed Control Through Crop Plant Manipulations. *Non-Chemical Weed Control*: 73-96.

Lundquist, E. J., Jackson, L. E., Scow, K. M. and Hsu, C. (1999). Changes in microbial biomass and community composition, soil carbon and nitrogen pools after incorporation of rye into three California agricultural soils. *Soil Biology and Biochemistry* 31: 221-236.

Martinsen, V., Shitumbanuma, V., Mulder, J., Ritz, C. and Cornelissen, G. (2017). Effects of hand-hoe tilled conservation farming on soil quality and carbon stocks under on-farm conditions in Zambia. *Agriculture, Ecosystems and Environment* 241: 168-178.

Mbuthia, L. W., Acosta-Martínez, V., DeBruyn, J., Schaeffer, S., Tyler, D., Odoi, E., Mpheshea, M., Walker, F. and Eash, N. (2015). Long term tillage, cover crop, and fertilization effects on microbial community structure, activity: Implications for soil quality. *Soil Biology and Biochemistry* 89: 24-34.

Mele, P. M. and Carter, M. R. (1999). Impact of crop management factors in conservation tillage farming on earthworm density, age structure and species abundance in south-eastern Australia. *Soil Tillage Research* 50: 1-10.

Mirsky, S. B., Ryan, M. R., Teasdale, J. R., Curran, W. S., Reberg-Horton, C. S., Spargo, J. T., Wells, M. S., Keene, C. L. and Moyer, J. W. (2013). Overcoming weed management challenges in cover crop based organic rotational no-till soybean production in the eastern United States. *Weed Technology* 27(1): 193-203.

Mochiah, M. B. and Baidoo, P. K. (2012). Effects of mulching materials on agronomic characteristics, pests of pepper (*Capsicum annuum* L.) and their natural enemies population. *Agriculture and Biology Journal of North America* 3(6): 253-261.

Montgomery, D. R. (2007). Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences* 104(33): 13268-13272.

Muhammed, U. F. B., Sindhu, P. V., Gopal, K. S. and Thomas, C. G. (2015). Influence of mulches on rhizosphere microflora, yield and weed competition in okra [*Abelmoschus esculentus* (L.) Moench]. *Journal of Tropical Agriculture* 53(1): 70-74.

Mwango, S. B., Msanya, B. M., Mtakwa, P. W., Kimaro, D. N., Deckers, J. and Poesen, J. (2016). Effectiveness of mulching under miraba in controlling soil erosion, fertility restoration and crop yield in the Usambara Mountains, Tanzania. *Land Degradation and Development* 27(4): 1266-1275.

Ngereza, A. J. and Pawelzik, E. (2016). Constraints and opportunities of organic fruit production in Tanzania. International Journal of Agricultural Policy and Research. [http://hdl.handle.net/20.500.12018/2808] site visited on 11/2/2018.

Ngowi, A. V. F., Mbise, T. J., Ijani, A. S. M, Ajayi, O. C. and London, L. (2007). Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects. *Crop Protection* 26(11): 1617-1624.

Oerke, E. C. (2006). Crop losses to pests. *The Journal of Agricultural Science* 144(1): 31-43.

Pimentel, D., McLaughlin, L., Zepp, A., Lakitan, B., Kraus, T., Kleinman, P., Vancini, F., Roach, W. J., Graap, E., Keeton, W. S. and Selig, G. (1991). Environmental and economic effects of reducing pesticide use. *BioScience* 41(6): 402-409.

Poeplau, C. and Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops–A meta-analysis. *Agriculture, Ecosystems and Environment* 200: 33-41.

Pretty, J. and Waibel, H. (2005). *Paying the price: the full cost of pesticides*. The Pesticide Detox. Earthscan, London. 254pp.

Prosdocimi, M., Jordán, A., Tarolli, P., Keesstra, S., Novara, A. and Cerdà, A. (2016). The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. *Science of the Total Environment* 547: 323-330.

Quintanilla-Tornel, M. A., Wang, K. H., Tavares, J. and Hooks, C. R. (2016). Effects of mulching on above and below ground pests and beneficials in a green onion agroecosystem. *Agriculture, Ecosystems and Environment* 224: 75-85.

Raviv, M. (2010). Is organic horticulture sustainable? *Chronica Horticulturae* 50: 7–14

Reddy, K. N., Zablotowicz, R. M., Locke, M. A. and Koger, C. H. (2003). Cover crop, tillage and herbicide effects on weeds, soil properties, microbial populations and soybean yield. *Weed Science* 51: 987-994.

Reganold, J. P. and Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature Plants* 2(2): 15221.

Reynolds, S. H., Ritz, K., Crotty, F. V., Stoate, C., West, H. and Neal, A. L. (2017). Effects of cover crops on phosphatase activity in a clay arable soil in the UK. *Annals of Applied Biology*. [http://eprints.nottingham.ac.uk/id/eprint/48781] site visited on 22/7/2018.

Rembialkowska, E. (2000). Wholesomeness and sensory quality of the potatoes and selected vegetables from the organic farms. Zdrowotna i sensoryczna jakość ziemniaków oraz wybranych warzyw z pospodarstw ekologicznych. Fundacja Rozwój SGGW. Warsaw. [http://agris.fao.org/agris-search/search.do?recordID=US201300062120] site visited on 10/08/2018.

Robertson, G. P., Bruulsema, T. W., Gehl, R. J., Kanter, D., Mauzerall, D. L., Rotz, C. A. and Williams, C.O. (2012). Nitrogen-climate interactions in US agriculture. *Biogeochemistry* 114: 41–70.

Rubatzky, V. E. and Yamaguchi, M. (2012). *World vegetables: principles, production, and nutritive values*. Springer Science and Business Media. 687pp.

Saeed, R., Razaq, M. and Hardy, I. C. (2015). The importance of alternative host plants as reservoirs of the cotton leaf hopper, Amrasca devastans, and its natural enemies. *Journal of Pest Science* 88(3): 517-531.

Sainju, U. M., Singh, B. P. and Whitehead, W. F. (2002). Long term effects of tillage, cover crops and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Soil Tillage Research* 63: 167-179.

Saria, A. G., Semu, E., Høgh-Jensen, H. and Sibuga, K. P. (2018). Soil fertility dynamics of ultisol as influenced by greengram and mucuna green manures. *Journal of Plant Sciences and Agricultural Research* 2(2): 14.

Saria, A. G. (2014). Weed management and insects dynamics in selected organically produced vegetables in Usambara mountain valleys, Tanzania. M.Sc. (Crop Science) Dissertation Sokoine University of Agriculture, Morogoro, Tanzania, 63pp.

Sarwar, M. A., Ibrahim, M., Tahir, M., Ahmad, K., Khan Z. I. and Valeem, E. E. (2010). Appraisal of pressmud and inorganic fertilizers on soil properties, yield and sugarcane quality. *Pakistan Journal of Botany* 42: 1361-1367.

Sinkeviciene, A., Jodaugiene, D., Pupaliene, R. and Urboniene, M. (2009). The influence of organic mulches on soil properties and crop yield. *Agronomy Research* 7(1): 485-491.

Sharma, P., Abrol, V. and Sharma, R. K. (2011). Impact of tillage and mulch management on economics, energy requirement and crop performance in maize–wheat rotation in rainfed subhumid inceptisols, India. *European Journal of Agronomy* 34(1): 46-51.

Shreck, A., Getz, C. and Feenstra, G. (2006). Social sustainability, farm labor, and organic agriculture: Findings from an exploratory analysis. *Agriculture and Human Values* 23(4): 439-449.

Skidmore, A., Wilson, N., Williams, M. and Bessin, R. (2017). The impact of tillage regime and row cover use on insect pests and yield in organic cucurbit production. *Renewable Agriculture and Food Systems* :1-11.

Smith-Spangler, C., Brandeau, M. L., Hunter, G. E., Bavinger, J. C., Pearson, M., Eschbach, P. J., Sundaram, V., Liu, H., Schirmer, P., Stave, C. and Olkin, I.

(2012). Are organic foods safer or healthier than conventional alternatives?: A systematic review. *Annals of Internal Medicine* 157(5): 348-366.

Stracke, B. A., Rüfer, C. E., Weibel, F. P., Bub, A. and Watzl, B. (2009). Three-year comparison of the polyphenol contents and antioxidant capacities in organically and conventionally produced apples (*Malus domestica* Bork. Cultivar Golden Delicious'). *Journal of Agricultural and Food Chemistry* 57(11): 4598-4605.

Sujatha, S., Suchitra, V., Swami, D. V., Subbaramamma, P., Krishna, K. U. and Saravanan, L. (2018). Influence of mulching materials on fruit quality of strawberry (*Fragaria ananassa* Duch.) cv. CAMAROSA grown under shade net conditions of coastal Andhra Pradesh. *International Journal of Agricultural Sciences* 14(1): 128-132.

Sun, B., Zhang, L., Yang, L., Zhang, F., Norse, D. and Zhu, Z. (2012). Agricultural non-point source pollution in China: causes and mitigation measures. *Ambio* 41(4): 370-379.

Swanton, C. J., Nkoa, R. and Blackshaw, R. E. (2015). Experimental methods for crop–weed competition studies. *Weed Science* 63(SP1): 2-11.

Thankamani, C. K., Kandiannan, K., Hamza, S. and Saji, K. V. (2016). Effect of mulches on weed suppression and yield of ginger (*Zingiber officinale* Roscoe). *Scientia Horticulturae* 207: 125-130.

Thies, C., Haenke, S., Scherber, C., Bengtsson, J., Bommarco, R., Clement, L. W., Ceryngier, P., Dennis, C., Emmerson, M., Gagic, V. and Hawro, V. (2011). The relationship between agricultural intensification and biological control: experimental tests across Europe. *Ecological Applications* 21(6): 2187-2196.

Thompson, S. M., Tan, Y. P., Shivas, R. G., Neate, S. M., Morin, L., Bissett, A. and Aitken, E. A. B. (2015). Green and brown bridges between weeds and crops reveal novel Diaporthe species in Australia. *Persoonia: Molecular Phylogeny and Evolution of Fungi* 35: 39-49.

Tian, J., Wang, J., Dippold, M., Gao, Y., Blagodatskaya, E. and Kuzyakov, Y. (2016). Biochar affects soil organic matter cycling and microbial functions but does not alter microbial community structure in a paddy soil. *Science of the Total Environment* 556: 89-97.

UN (2008). *Organic Agriculture and Food Security in Africa.* United Nations, New York and Geneva: 61.

United Nations UN (2006). Overview of the Current State of Organic Agriculture in Kenya, Uganda and the United Republic of Tanzania and the Opportunities for Regional Harmonization. United Nations Conference on Trade and Development (UNCTAD): 65pp.

Unger, P. W. and Vigil, M. F. (1998). Cover crop effects on soil water relationship. *Journal of Soil Water Conservation* 53: 200-207.

Uzo, J. O. and Currah, L. (2018). Cultural systems and agronomic practices in tropical climates. *Onions and Allied Crops Volume II: Agronomy Biotic Interactions*.

Waller, B. E., Hoy, C. W., Henderson, J. L., Stinner, B. and Welty, C. (1998). Matching innovations with potential users, a case study of potato IPM practices. *Agriculture, Ecosystems and Environment* 70(2-3): 203-215.

Willer, H. and Lernoud, J. (2016). *The world of organic agriculture. Statistics and emerging trends 2016*. Research Institute of Organic Agriculture FiBL and IFOAM Organics International: 1-336.

Williams, B. J. (2006). Aztec soil knowledge: Classes, management, and ecology. In: *Footprints in the Soil: People and Ideas in Soil History*. (*Edited by Warkentin,B. P.*), Elsevie, Amsterdam/Oxford. pp. 17-41.

Yates, S. R., McConnell, I. L., Hapeman, C. J., Papiernik, S. K., Gao, S. and Trabue, S. L. (2011). Managing agricultural emissions to the atmosphere: state of the science, fate and mitigation, and identifying research gaps. *Journal of Environmental Quality* 40: 1347-1358.

Zachrisson, B., Herrera-Vásquez, J. Á. and Bernal, J. (2017). Hosts plants of Bemisia tabaci (Gennadius) (Hemíptera: Aleyrodidae), in adjacent areas of the tomato crop, in the east region of Panama. *IDESIA* 35(1): 119-122.

Zhang, H., Tang, J. and Liang, S. (2017). Effects of snow cover plus straw mulching on microorganisms in paddy soil during winter. *Applied Soil Ecology* 119: 339-344.

Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P. and Shen, Y. (2015). Managing nitrogen for sustainable development. *Nature* 528 (7580): 51.

Zotarelli, L., Zatorre, N. P., Boddey, R. M., Urquiaga, S., Jantalia, C. P., Franchini, J. C. and Alves, B. J. (2012). Influence of no-tillage and frequency of a green manure legume in crop rotations for balancing N outputs and preserving soil organic C stocks. *Field Crops Research* 132: 185-195.

CHAPTER TWO

2.0 SOIL FERTILITY DYNAMICS OF ULTISOL AS INFLUENCED BY GREENGRAM AND MUCUNA GREEN MANURES[1]

Saria, A. G.[1, 4*], Semu, E.[2], Henning, J. H.[3] and Sibuga, K. P.[1]

[1]Department of Crop Science and Horticulture, Sokoine University of Agriculture (SUA), Morogoro, Tanzania.

[2]Department of Soil and Geological Sciences, Sokoine University of Agriculture (SUA), Morogoro, Tanzania.

[3]Department of Food Technology, Technical University of Denmark, Copenhagen, Denmark.

[4]Tanzania Official Seed Certification Institute, Tanzania

*Corresponding author: adolfsaria@gmail.com

Abstract

Synchronisation between supply of plant available nutrients to crops' needs and uptake is a major challenge in Sub-Saharan Africa. Experiments were set to evaluate release patterns and availability of nutrients by leguminous green manures in soil. Mucuna and greengram materials were buried 10 cm deep in mesh bags. Replicated bags removed weekly and analysed to determine decomposition rates and quantities of nutrients released into soil. Mucuna decomposition was faster compared with greengram, from third to twelve week of incubation. This implies that greengram has relatively more resistant materials to decomposition compared with mucuna. Maximum effect on soil nutrient content occurred in sixth and seventh weeks after application of green manures. Total organic C in soils treated with cover crops increased by a factor of 2.3 to 3.2. Total N

---

[1]Published in Journal of Plant Sciences and Agricultural Research 2(2): 14.

increased significantly from 1.28% to 2.64% at sixth week in soil with greengram and 2.83% at seventh week in soil with mucuna. Available P content of soil increased from 0.03 to 0.39 and 0.37 mg kg^{-1} in soil treated with greengram and mucuna. Optimum microbial population was attained from fifth to seventh week after manure application, with 2.3 x 10^8 in soil with greengram and 3.08 x 10^8 with mucuna, significantly improved compared with original population.

Key words: green manure, soil fertility, incubation period, cover crop.

2.1 Introduction

Poor soil fertility has been one among the major problems in agriculture in Sub-Saharan Africa, leading to poor crop productivity (Camara and Heinemann 2006). Agriculture in many African countries is subjected to poor nutrient replenishment in soils, leading to soil degradation and hence poor productivity (Kimetu *et al.,* 2008; Abate *et al.,* 2017; Shepherd 2007). However, the use of inorganic fertilisers alone cannot be a long term solution for soil fertility management among poor African farmers, and thus integrated soil fertility management has been proposed (Sanginga and Woomer 2009). The synchronisation between sufficient supply of plant available nutrients like phosphorus (P), potassium (K) and nitrogen (N) to the crops needs and uptake is a major challenge (Edmeades 2003; Sharma et *al.,* 2008; Mafongoya *et al.,* 2006). However, the use of leguminous plants as green manure can be a good alternative for replenishing soil fertility and diversify farm productivity in intensive production because legumes generally are nutrient rich (Diacono *et al.,* 2011; Mafongoya *et al.,* 2006).

Therefore, agriculture intensification in poor fertility soils can be supported through natural means of improving and sustaining the soil fertility (Vanlauwe *et al.,* 2014). Cover crops, which are used for pests control in organic agriculture, can be a good source of nutrients as green manure (Mulvaney *et al.,* 2008; Sarwar *et al.,* 2010) and also increase soil organic matter content which can support soil microbial activity (Lundquist *et al.,* 1999). The use of cover crops as green manure and for weed control was adopted as strategy for replenishing soil nitrogen that had been taken up by crops and to provide organic matter for maintaining soil's fertility and improving its properties (Mulvaney *et al.,* 2008; Ganry *et al.,* 2001). Marandu *et al.* (2011) observed an increase of about 12.4 mg mineral N kg^{-1} soil when maize was grown in rotation with greengram.

There is evidence on the ability of Mucuna species green manure to influence soils' physical and biological and chemical properties (Djigal *et al.,* 2012; Elfstrand *et al.,* 2007). However, lack of synchrony between mineralization of organic N from green manure and plant N requirements of a subsequent crop is a major challenge (Palm *et al.,* 1997; Mafongoya *et al.,* 1998). Understanding the nutrient release patterns of the green manure applied is thus a prerequisite to optimize an efficient use of the green manure and to sustain a high value vegetable crop (Baijukya *et al.*, 2006; Möller 2009).

The objective of the current study consequently was to determine relative decomposition patterns, nutrient release rates and microorganism proliferation as influenced by two leguminous green manure crops, mucuna (*Mucuna pruriens*) and greengram (*Vigna radiata (L.)*), that were incorporated into the soil under field conditions in Morogoro, Tanzania, using the mesh bag approach.

2.2 Materials and Methods

2.2.1 Experimental site

The field decomposition study was carried out at Sokoine University of Agriculture (SUA) Crop Museum in Morogoro region (06^{o} 50’ 34.4” S and 6^{o} 82’ S, 37^{o} 38’ 50.3”) lying at an average elevation of 534 m.a.s.l. The location has bimodal rainfall of 800-1000 mm annually with the short rains in November to January and the longest from March to May. Rainfall patterns for the twelve weeks at the experimental area during the experiment are presented in Figure 2.1.

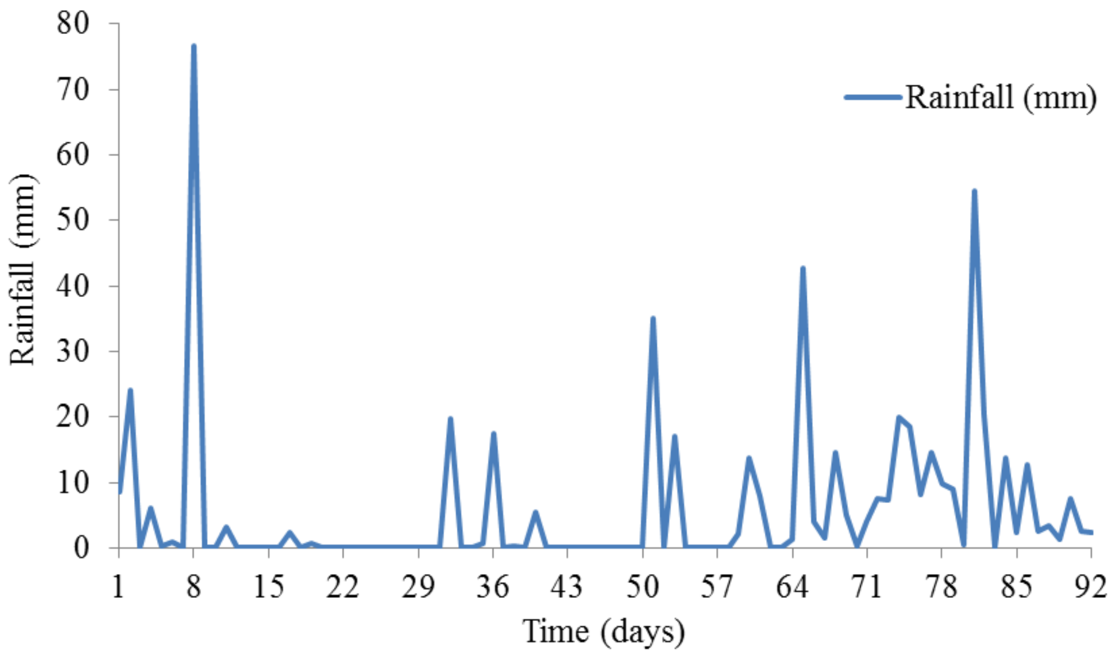

Figure 2.1: Rainfall patterns at the experimental site during the twelve weeks of the experiment

For the previous three seasons the field was used for cultivating various annual crops. The initial soil analysis of the experimental site within SUA crop museum was done for a composite soil sampled diagonally across the site within the 0-20 cm depth. The area is characterized by kaolinitic clay soils which are well drained. The physiographic features of the area are characteristically an undulating convex land and the slope is about 4% (Kisetu and Mtankimwa 2013). The sample was air dried and ground to pass through a 2 mm sieve.

2.2.2 Experimental layout and sampling

Mucuna (*Mucuna pruriens*) and greengram (*Vigna radiata (L.)*) were grown adjacent to the experimental site to the 50% flowering stage. The crops were harvested just above the soil surface, chopped and 500 g fresh weight filled into polyethylene plastic mesh bags (20 x 20 cm) of 2 mm mesh size. The litter-bags were buried 5-10 cm deep into the soil in four replicates. For twelve consecutive weeks, with exact intervals of 7 days, four replicated mesh bags were sampled for decomposition analysis. The 5 cm soil located directly below the mesh bags was collected. The plant and soil samples were air dried in a screen house for 72 hours and then oven dried for 24 hours at 70^0C to constant weight. The samples were ground ready for analysis to determine their decomposition patterns.

2.2.3 Plant analysis

Total nitrogen was determined by using a sample of 0.2 g of green manure which was transferred to a 500 ml Kjeldahl tube and two grams of mixed salts catalyst (K_2SO_4 + $CuSO_4$ + selenium powder, in the ratio of 10: 10: 1 by weight) was added. Ten ml of H_2SO_4 were added. The mixture digested for one hour at 360^oC. After cooling, 50 ml of water were added, followed by 25 ml of H_3BO_3 and 50 mls of 40% NaOH. The mixture was distilled and about 200 ml of distillate collected. The distillate was titrated using 0.05N H_2SO_4 (Horneck and Miller 1998).

2.2.4 Phosphorus content

Extractable P was determined using the Bray 1 method (Kovar *et al.,* 2009). A sample of three grams was taken in to the extraction bottle, 20 ml of extraction solution and shaken thoroughly. Then the mixture was filtered through filter paper. Five milliliters aliquot of the sample mixture was transferred to 50 ml volumetric flask and 10 ml of water added. Two millilitres of phosphate reagent was added and the volume was made to 50 ml, the colour was allowed to develop in 15 minutes. Then phosphorus content in solution was determined in a spectrophotometer at 882 nm.

2.2.5 Soil analysis

2.2.5.1 Organic soil carbon

Organic carbon analysis of the green manure was done using the Walkely-Black method (Yeomans and Bremner1988). Duplicate samples of 1 g were weighed in an Erlenmeyer flask, 10 ml of 1N $K_2Cr_2O_7$ was added followed immediately by 20 ml concentrated H_2SO_4 and hand shaken for about a minute to oxidize the soil's organic carbon. Then the mixture was allowed to stand on asbestos plates for 30 minutes. About 100 ml of water were added followed by 10 ml orthophosphoric acid and 10 drops of diphenylamine indicator. The solution was titrated with $FeSO_4$ to determine the organic carbon.

2.2.5.2 Total soil nitrogen and Phosphorus

These elements were also determined using the same methods used for the analysis of the plant materials.

2.2.5.3 Ca and Mg content

The exchangeable Ca and Mg were determined from the same solution used to determine P by atomic absorption spectrophotometer (Cheng 1951).

2.2.5.4 Cation Exchange Capacity (CEC)

The soil remained after exchangeable bases extraction filtration was washed using 100 ml of ethanol and then placed into plastic bottles. 50 mls of 4% KCL were added and shaken for 30 minutes, distilled and the distillate collected over Boric acid. Then the distillate was titrated with 0.1N H_2SO_4 and the titre value was used to calculate the CEC (Rhoades 1982).

2.2.5.5 Total microbial count

Microbial count was done by determining moisture content of the sample. Ten grams sample was placed in 90 ml water and shaken vigorously to uniform suspension to detach microbial cells from soil particles in to the suspension. One ml of the suspension was transferred to 9 ml water, and similarly the dilution was continued up to a dilution of 10^7. Then the 10^3 to 10^7 dilutions were plated into petri dishes with nutrient agar and spread evenly. The plates were incubated 21^0C for four days and then plates with 30-300 colonies were selected for microbial population counting and calculation of microbial populations. The microbial population per gram of soil was calculated using the formula:

$$\text{Microbial population} = \frac{\text{colony count x dilution counted}}{\text{Weight of soil}}$$

2.2.6 Data analysis

Data were subjected to analysis of variance using GENSTAT statistical program (Genstat release 6.1 Lawes Agricultural Trust). Treatment means were ranked using Duncan's Multiple Range Test at P≤0.05.

2.3 Results

2.3.1 Decomposition patterns of the green manures

The decomposition patterns of the green manures were assessed using decreases of organic carbon (C), total nitrogen (N), phosphorus (P) content and associated changes in nutrient content and total microbial populations in the mesh bags and in the soil just below the mesh bags. Initially the weight of the green manure incubated in the soil decreased with time immediately from the first week throughout the incubation period (Fig. 2.2) following a first-order negative exponential curve (mucuna: R^2=0.98 and greengram R^2= 0.98) as commonly found in other studies (Melillo *et al.*, 1989; Palm and Sanchez 1990; Campbell *et al.*, 1995).

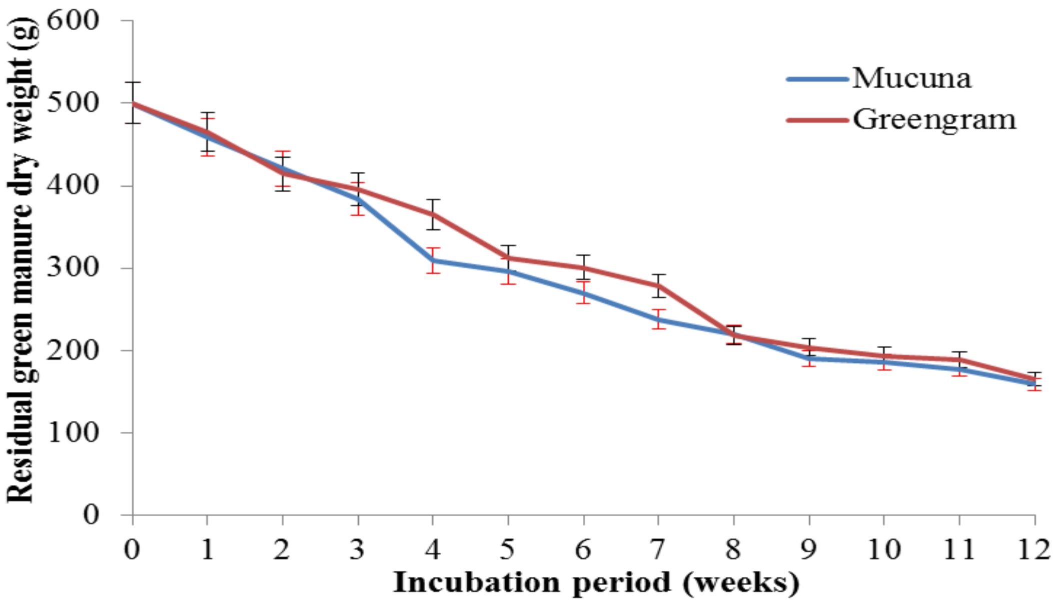

Figure 2.2: Mean decrease in dry weight per mesh bag of the green manure materials upon incubation over time

The proportion of organic C content in the plant materials was about 40% for mucuna and 35% for greengram. However, the half-life ($t^{1/2}$) of the two materials was similar as both attained their half-life at the fifth week of incubation as it is shown in Figure 2.2. Due to the negative exponentially, the decomposition pattern of the two green manures were fast to about the seventh week of incubation which concur with other studies done by Omollo and Abayo 2011 and Whitbread *et al.,* 2004. This pattern of decomposition led to the rapid decrease of the proportion of organic C in the mesh bags in first six to seven weeks of incubation (Fig. 2.3). Some of the C is respired but others are eventually added and incorporated in the soil below the mesh bag as its accumulation is shown in Figure 2.4.

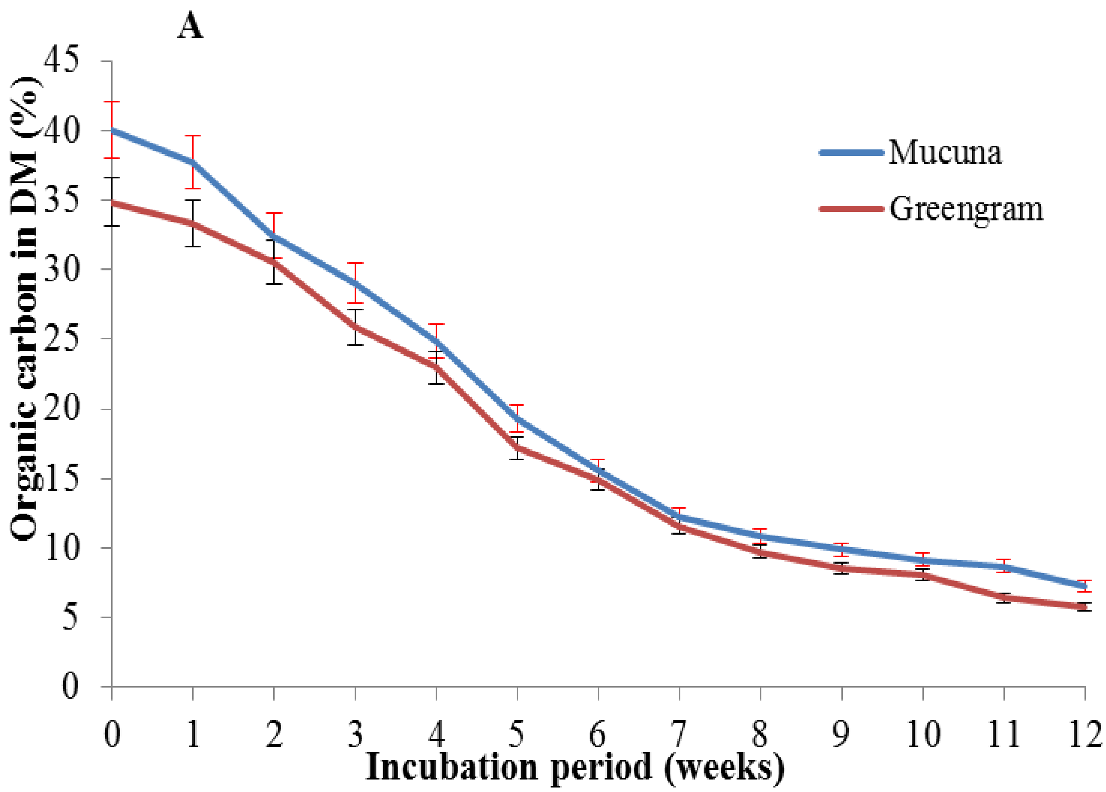

Figure 2.3: Mean organic carbon content in dry matter of residue plant materials

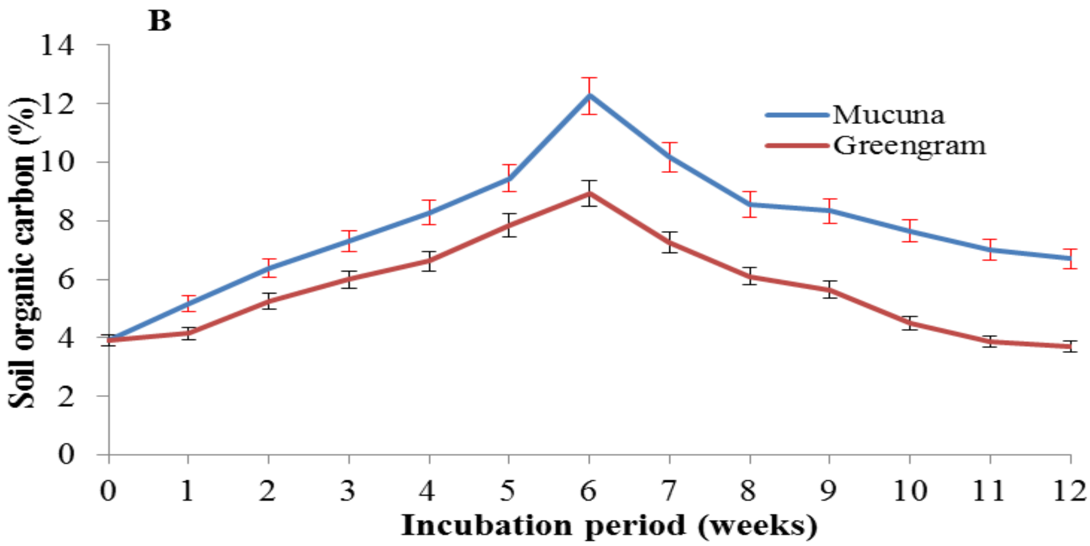

Figure 2.4: Mean amount of organic carbon accumulation in soil just below the mesh bags

2.3.2 Decrease in nitrogen in the residual plant materials and nitrogen gains in soil

For both green manure materials, the trend in the proportion of N in the mesh bag mirrored the trend in the proportion of carbon (Fig. 2.5). The net release of N from the mesh bag was evident in the soils below the mesh bag (Fig. 2.6) until week 7, after which release rates decreased substantially as the microbial biomass started to decrease (Fig. 2.13), precipitation increases (Fig. 2.1) and the content in the soil stabilized (Fig. 2.6).

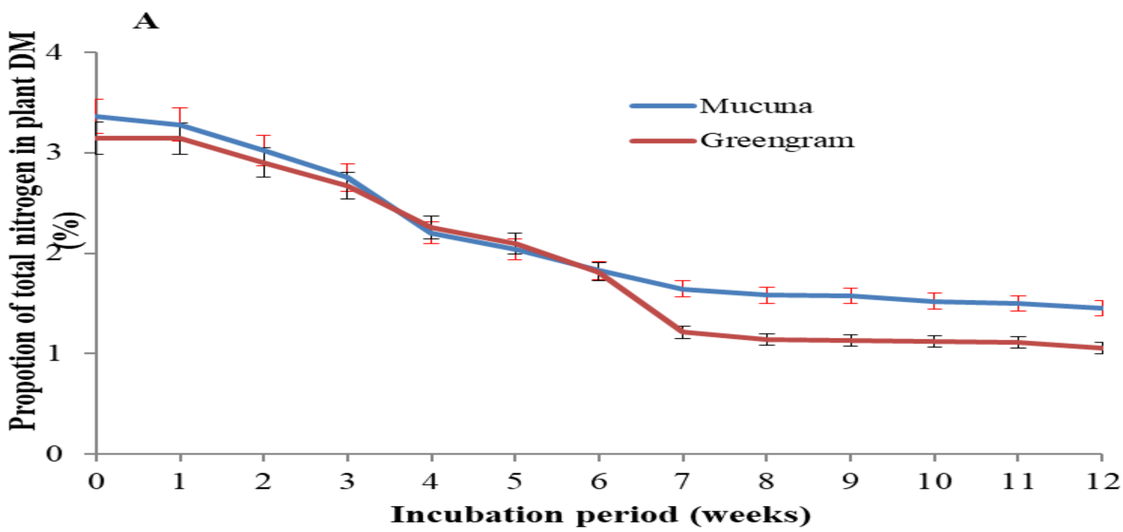

Figure 2.5: Mean proportion of total nitrogen in plant material dry matter upon incubation

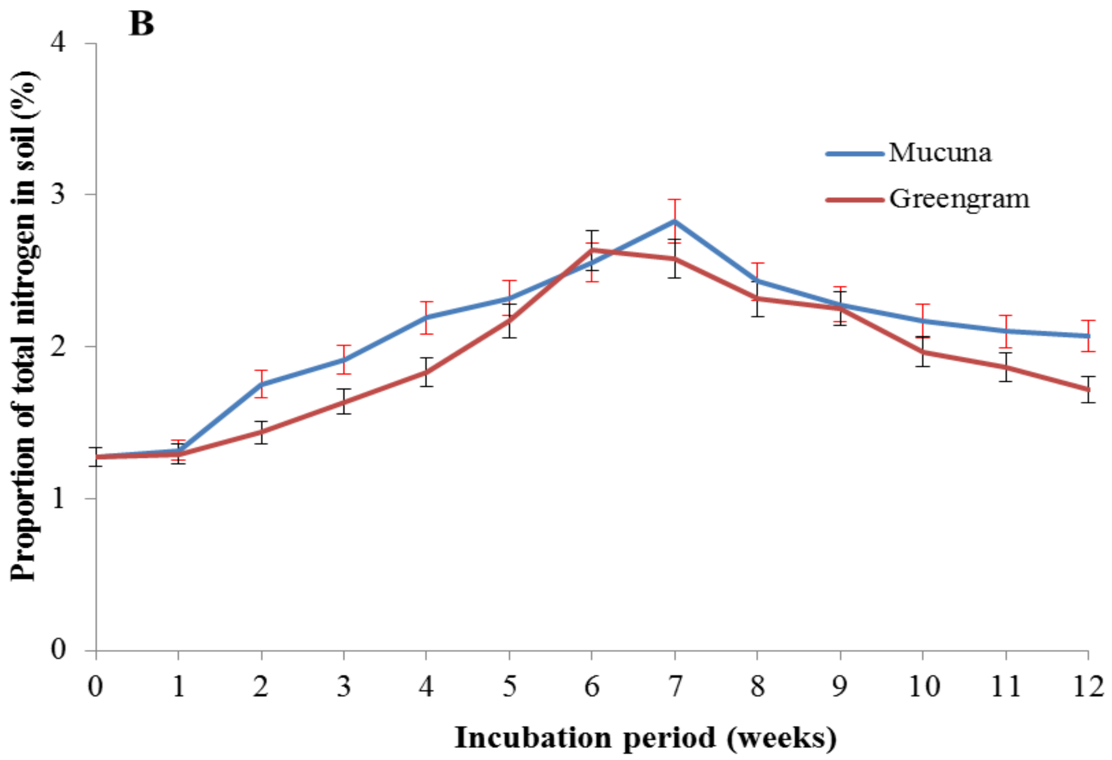

Figure 2.6: Mean amount of nitrogen accumulation in soil just below the mesh bags upon incubation

2.3.3 Phosphorus decrease in decomposed residual plant materials and P gains in soil

The P content of the degrading green manures followed a linear decline (Fig. 2.7) with R^2=0.94 for mucuna and R^2=0.95 for greengram. The degradation of P from both types of plant materials did not differ significantly. In both green manures, the P release was fast up to the ninth week and then became stagnant. However, the quantity of P in the decomposing mucuna materials was higher for the first five weeks as compared with that in greengram and then it dropped below that of greengram at the tenth to twelfth weeks of incubation.

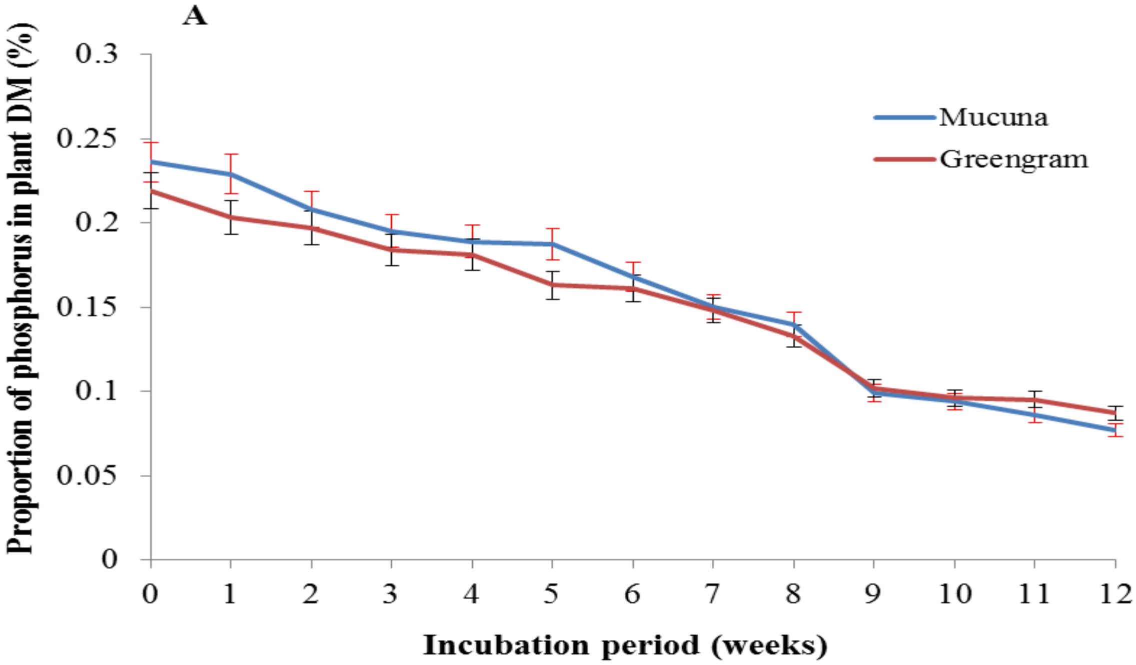

Figure 2.7: Decrease pattern of phosphorus in the plant materials

Interestingly, the amount extractable inorganic P (Bray 1) accumulation in the soil was faster and higher in the soil under mucuna compared with greengram (Fig. 2.8). At the fourth week, soil incubated with mucuna had attained 0.35% of P compared with 0.1% of greengram (Fig. 2.8). At the sixth week, the extractable P had reached the same level but green gram had a slower start.

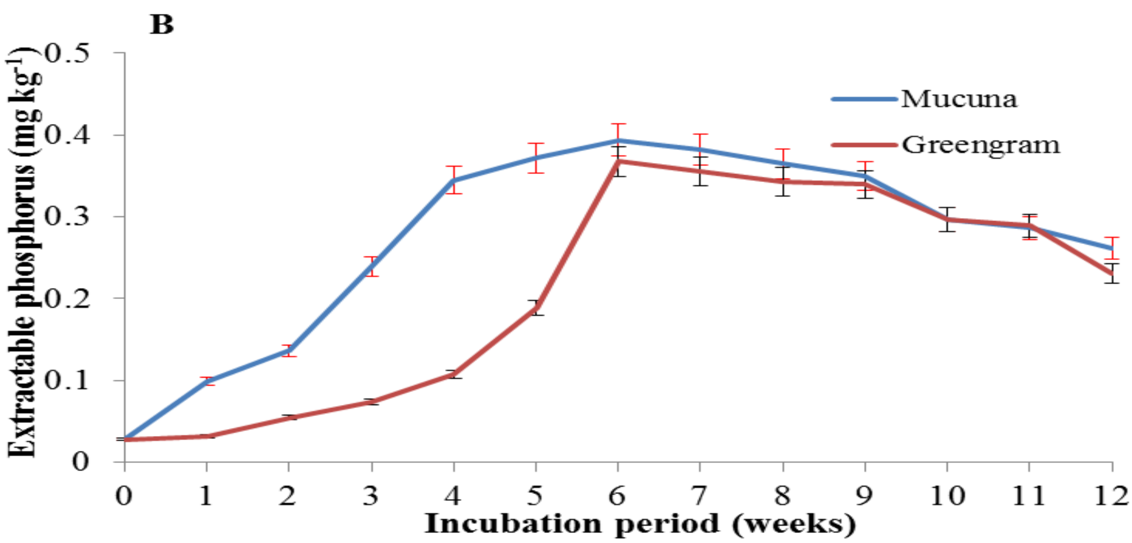

Figure 2.8: Patterns of phosphorus gain in the soil upon incubation

2.3.4 Decrease in calcium in plant materials and calcium gains in soil

The trend of Ca release by the green manures and gain by the soil is presented in Figure 2.9. Calcium release from the plant materials proceeded steadily, with the rate decreasing somewhat in the last three weeks. Throughout the incubation period the residual green manures did not differ in their Ca contents and the release into the soil below it. The faster rate of decomposition and nutrient release by green manure was also observed by Cobo *et al.* (2002), where mucuna had high release of Ca up to the twentieth week after incorporation in the soil, as revealed by higher accumulation in the soil. This was also observed in the present study where the plant materials continued to release Ca for all the twelve weeks.

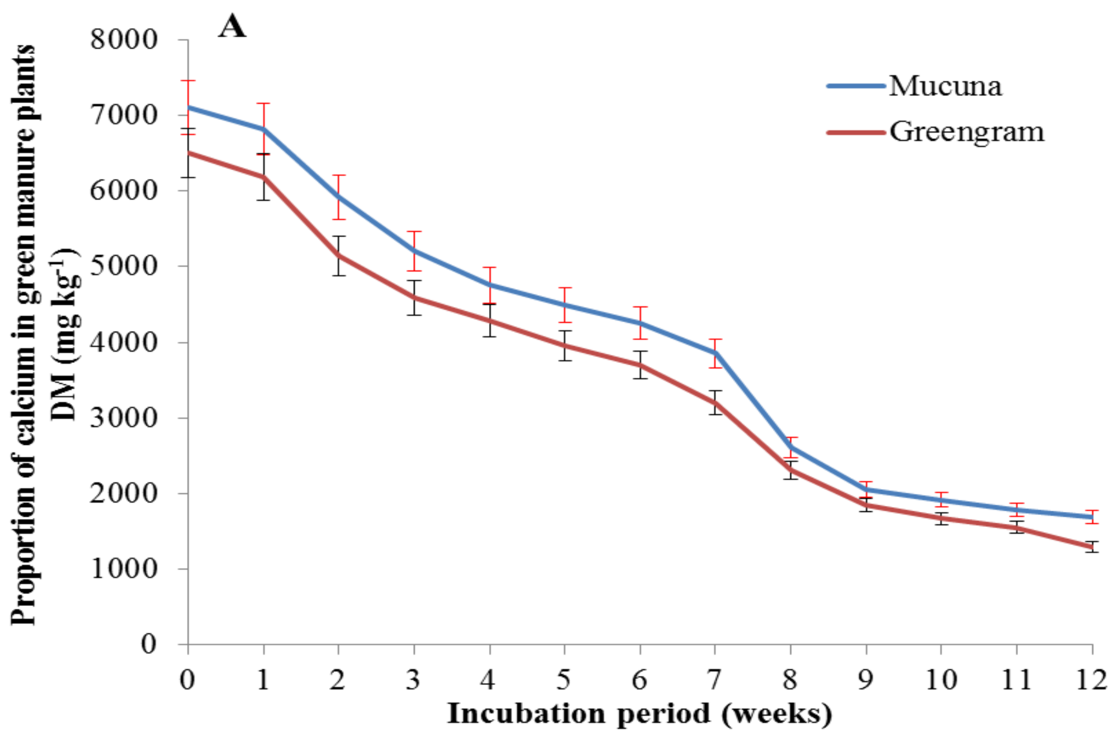

Figure 2.9: Decrease patterns of calcium in the plant materials

In the soil, the Ca gain trend was similar between the two green manures as it is shown in Figure 2.10. However, soils incubated with mucuna attained highest total Ca at the sixth week, which was one week later as compared with greengram which attained its peak at the fifth week. The decrease of Ca observed in the present study beyond the fifth and sixth weeks was due to its high immobilisation in the soil. Cobo *et al.* (2002) observed a similar trend of Ca release from decomposing green manure; however, no consistent trend was found on the Ca accumulation patterns due to its high immobilisation. Other authors reported high ability of Ca immobilisation in the decomposing materials in different ways and through its accumulation in fungi found in the decomposing materials (Lehmann *et al.*, 1995; Alvarez *et al.*, 2008).

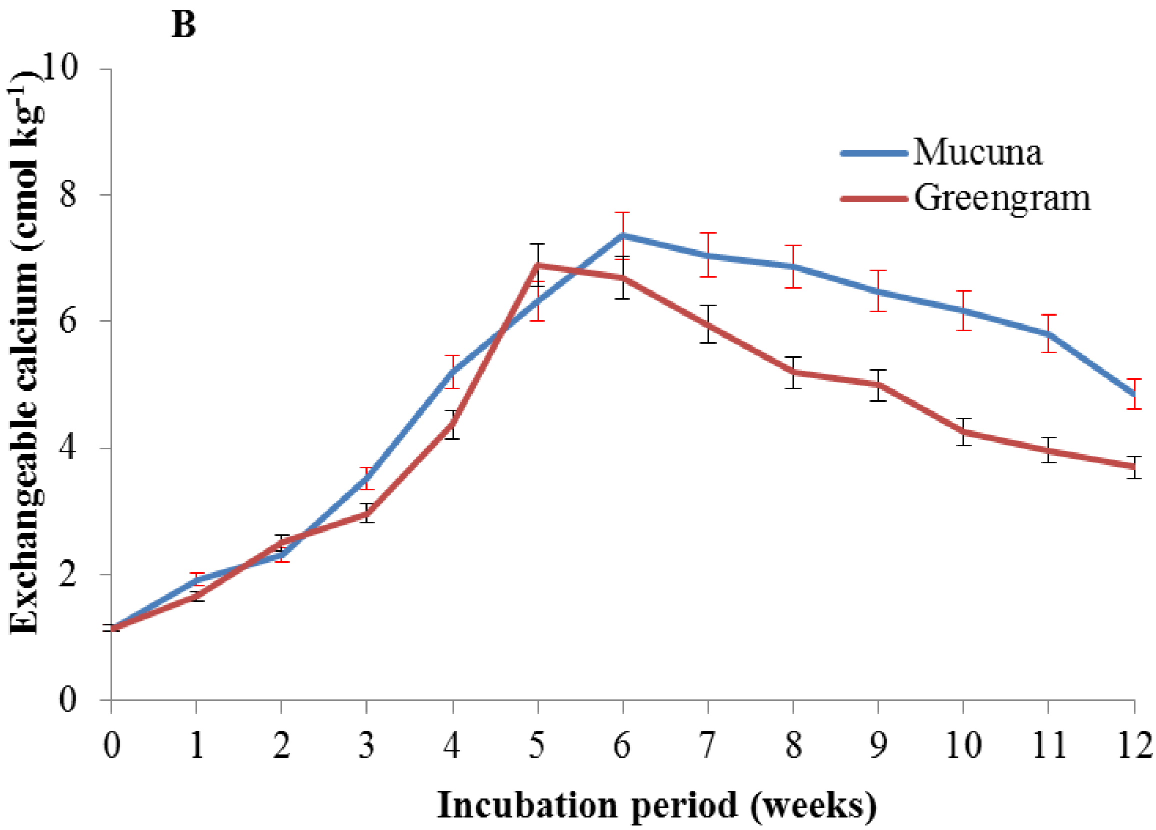

Figure 2.10: Calcium gains patterns in soil upon incubation

2.3.5 Decrease in magnesium in plant materials and magnesium gains in soil

The release of Mg from the two green manures and its gain in the soil throughout the incubation period is shown in Figure 2.11 and 2.12. Mucuna released slightly higher amount of Mg as compared with the greengram.

Soil incubated with mucuna had the highest amount of Mg at the sixth week after incubation, while that with greengram reached its highest level at the seventh week. Thereafter, there was a slight decrease in soil Mg.

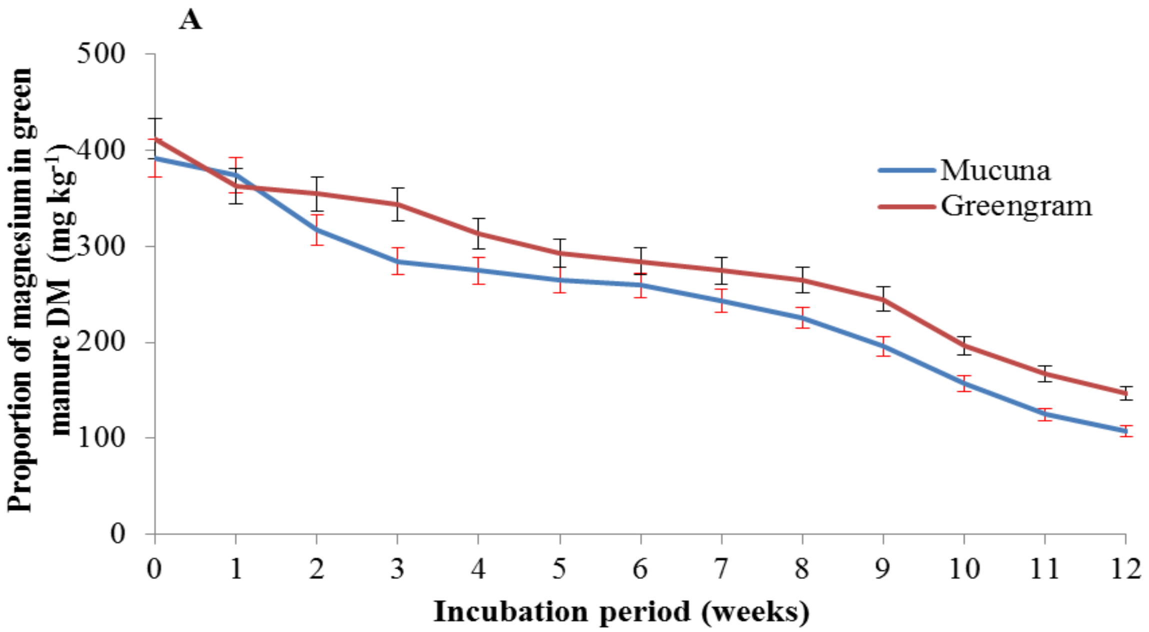

Figure 2.11: Decrease patterns of magnesium in the plant materials

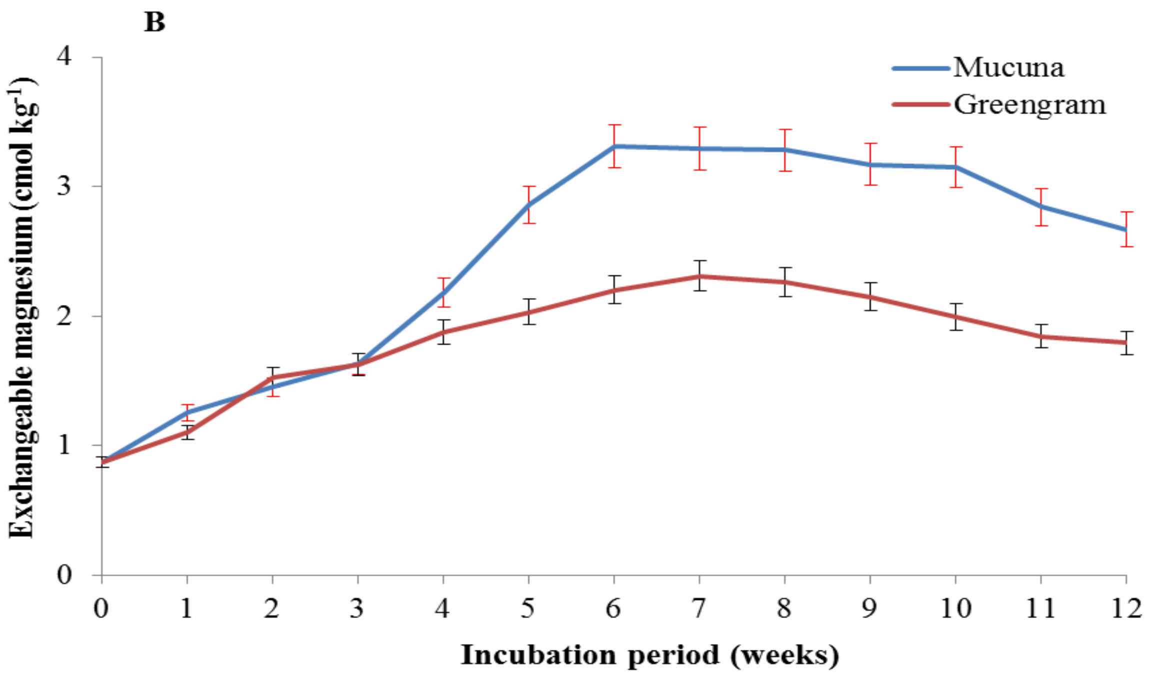

Figure 2.12: Magnesium gains patterns in soil upon incubation

2.3.6 Microbial populations in the soils under decomposing green manure materials

The total microbial population increased for six weeks following the introduction of the two green manures, with a subsequent decrease as shown Figure 2.13. The initial population in the soil was about 1.628 x 10^5, which increased up to 2.3 x 10^8 in soil with greengram and up to 3.08 x 10^8 in the soil with mucuna. Transformed into Log_{10}, these values translated to 5.21, 8.05 and 8.50, respectively (Fig. 2.13).

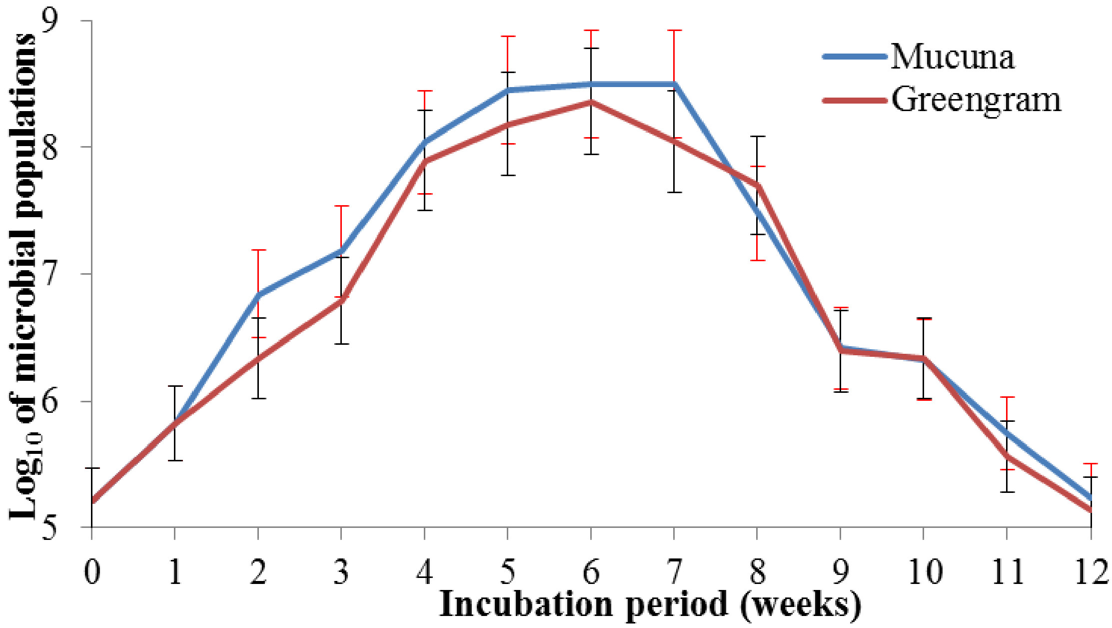

Figure 2.13: Microbial populations in the soil under decomposing plant materials

2.3.7 CEC changes in soil supplemented with mucuna and greengram

The soil treated with mucuna and greengram green manure attained higher CEC in the seventh week, as presented in Figure 2.14. The CEC in the soil treated by mucuna was 31.5 while that with greengram was 30.6 cmol kg^{-1} respectively at seventh week after they were incorporated in the soil, as compared with the original soil whose CEC was 10.8 cmol kg^{-1}.

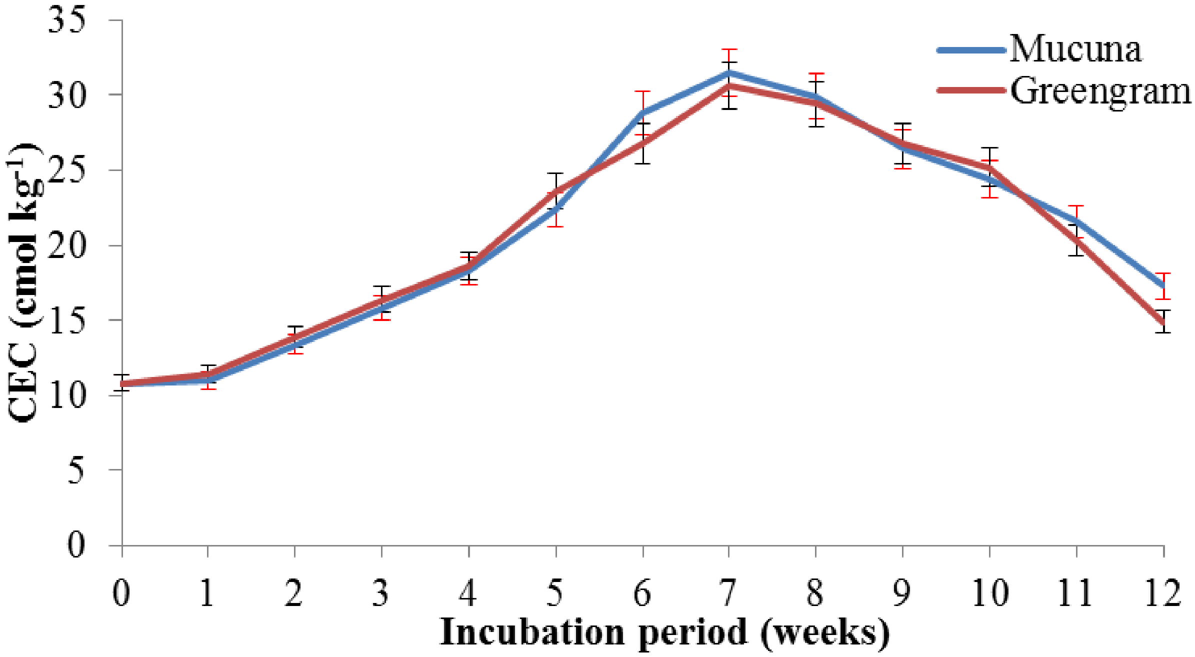

Figure 2.14: Changes in soil CEC upon plant materials incubation

2.4 Discussion

2.4.1 Organic carbon patterns and C:N ratio

The organic C compounds released from the plant materials could be seen accumulating in the soil immediately below the decomposing material in the first six weeks. The accumulation did not continue throughout but reached its optimum at the 6th week and subsequently decreased (Fig. 2.4). This dynamic is attributed to the early build-up of the soil microbial population (Fig. 2.13) that use the organic compounds as substrate and to the fact that extensive leaching has taken place due to excess of precipitation during the last 5-6 weeks of the experiment (Fig. 2.1).

In accordance with the negative exponential degradation pattern, amounts and rates of C being released from the mesh bags decreased substantially after the seventh week and simultaneously the release rates from the mesh bags most likely also decreased due to the stabilisation of the litter, for example the carbon content approaching stability (Fig. 2.3) as the C:N ratio of the residual litter approached 8-9 at week 5 after incubation after which the microbial activity may have been slowed down (Manzoni *et al.*, 2008).

For both manure substrates, the C:N ratio decreased from approximately twelve initially to five at week twelve after burying the litter bags, following a simple linear pattern. This demonstrates the potency of the green manures in the sense that it decomposes very rapidly (Fig. 2.2) and at the twelfth week had reached a structure that resembled soil. The relative low C:N ratio will also lead to a net release of N almost instantly. The apparent linearity agrees with theory (Ågren and Bossata 1998; Manzoni *et al.,* 2008) whereby these substances, as green manures with an initially low C:N ratio of approximately twelve, must be viewed towards the late period of the exponential process.

The relatively low C:N ratios is the exact reason for terming these substrates “green manure”. The low C:N ratios indicate that the degradation of the organic materials will not cause a net immobilisation (Ågren and Bosatta 1998) but be able to net release inorganic N into the soil matrix that can benefit crop growth. The rapid decomposition under the current conditions is contrary to the relatively low mineralisation rates under north European conditions as explained by Baggs *et al.* (2000).

2.4.2 Total Nitrogen patterns

The experimental site had been used for cropping the previous cropping seasons and yet it had a fairly good total N content (1.28%). The inclusion of the green manures, however, was a high injection of N to the soil such that a high flux of inorganic N must be anticipated. Other studies (Baggs *et al.*, 2000; Edmeades 2003; Thorup-Kristensen *et al.*,

2003) also observed significant increase of N in different soils treated with different green manures in long term application, explaining the difference in N contribution to the soil by these different green manures.

The higher soil N under mucuna could be due to the fact that mucuna had higher leaf:stem ratio which accounted for the higher total N (Fig. 2.5). These results agree with Cobo *et al.* (2002) who observed mucuna to have released higher amount of N as compared with the other green manures. In addition to that, in a similar decomposition study, Chikowo (2004) showed prolonged N immobilisation under field conditions. After the seventh and eighth weeks, the amount of N in soil started to decrease due to the fact that most of the N released was nitrified and then lost or leached as nitrate upon watering, where it was leached beyond the sampling zone.

2.4.3 Extractable P and Mg patterns

Despite the delay in enriching the soil in extractable P (Bray-1), for greengram it still reached the same high level as mucuna and it is still justified to call them green manures when it comes to supplying plant available P to the crops, which concur with the observation done by Randhawa *et al.* (2005). The chemical composition of the source material did not differ (Fig. 2.7) leading to the speculation that differences may be caused by the morphological differences between the two species, particularly the leaf stem ratio (Albrecht *et al.,* 1987). This has been seen to influence the release rate in other studies (Cobo *et al.,* 2002) and possible interactions between the leaf-stem due to high soluble C contents in the stem (Quemada and Cabrera 1995).

The fast decrease of P in the residual of the decomposing plant materials may be due to its soluble nature in the plant cell. Studies by Frossard *et al.* (1995) and Giacomini *et al.*, (2003) observed that soluble P in plant tissues is also available in the form of diesters (nucleic acids, phospholipids, and phosphoproteins), which can easily be released through microbial decomposition activities. This led to the release of most of the P from the two green manures in the first eight weeks of incubation. The difference in P content compared with N content in the litter is due to the fact that P, to a higher degree, is organically bound (Hassan, 2013: Randhawa *et al.*, 2005) whereas a higher proportion of the N content initially is soluble (Hättenschwiler and Vitousek 2000).

Mg release from plant materials was almost similar in both green manures. In both plant materials the trend of decomposition was similar, with a somewhat steady rate of decomposition throughout. The difference between the two types of green manures was in the gains of Mg in the soil, whereby the soil incubated with mucuna gained more Mg as compared to that incubated with greengram. Other studies have also observed that soil Mg usually accumulates and became higher mainly in the top soil then decreased with depth (Brar *et al.*, 2002).

2.4.4 Microbial population

The increase in soil microbial population was a result of increase in energy and nutrient sources for microorganisms due to the addition of green manures. Bakken *et al.* (2006) and Lavelle *et al.* (1999) observed that organic material provided by green manure promotes the activity of soil organisms, as a source of energy and nutrients. Cover crops and mulch increases the populations of macro-organisms and micro-organisms and their activities in the soil, because they increase the total inputs of organic materials to the soil

(Reddy *et al.,* 2003). Increase in total microbial population density in the soil is ascribed to the ability of the two green manures to provide conducive environments like increased soil moisture content, ensuring moderate changes in soil temperatures, providing food sources at the soil surface and retention of soil burrows that favour growth and multiplication of macro and micro-organisms.

A study by Elfstrand *et al.* (2007) on the responses by soil microbial communities to green manuring detected an increase in soil microbial biomass when green manures were added to the soil. Lundquist *et al.* (1999) also reported an increase of 24 to 52% of active bacteria into the soil due to the application of rye green manure. Some studies have revealed the ability of mucuna green manure to increase soil organic matter and improve soil moisture regimes (Barthes *et al.,* 2004). Other studies have shown that the increase in microbial population depended on the availability of the organic matter supplied by the soil amendment materials and that the population increase is rather short lived following plant incorporation (Lundquist *et al.,* 1999).

2.4.5 Cation Exchange Capacity (CEC)

The improvement of CEC was mainly due to the ability of the two green manures to release bases like Ca and Mg, as well as other cations upon decomposition. This was also observed by Kimetu *et al.* (2008) who explained the importance of green manure in the improvement of soil CEC. The soil CEC protects cations from leaching out of the plant root zone and makes them available to plant roots (Orcutt 2000).

The decrease in CEC beyond the seventh week was due to the oxidation of NH_4^+ to give NO_3^- which is highly soluble and in turn is leached beyond the sampling zone. Chikowo *et* *al.* (2004) observed the accumulation of NO_3^- beyond 40 cm depth of soil just three weeks after the beginning of the rainy season. On the other hand, NH_4^+ which is lost from the soil as ammonia gas through the process of volatilization contributes to the decrease in CEC beyond the seventh week. This was also observed by Zhenghu and Honglang (2000) who found a negative correlation between ammonium volatilization and soil CEC.

2.5 Conclusions and Perspectives

Using mucuna and greengram as green manure can be of great potential in increasing soil fertility which can contribute to improving crop production. However, in order to achieve this, the optimal period when the plant can benefit from the nutrients released should be well synchronized with the optimal release of the nutrients from the decomposing green manures. The sixth to eighth weeks after incorporation seem to maximize nutrients release form the green manure, and planting of main crops should target to take advantage of this maximum release period of the green manure. This investigation provides justifiable insights for improving soil fertility and demonstrates the suitability of mucuna and greengram green manures as suitable in the overall scenario of integrated soil fertility management strategy to enhance soil nutrient dynamics and plant nutrition under these tropical soil conditions.

REFERENCES

Abate, E., Hussein, S., Laing, M. and Mengistu, F. (2017). Soil acidity under multiple land-uses: assessment of perceived causes and indicators, and nutrient dynamics in small-holders' mixed-farming system of northwest Ethiopia. *Acta Agriculturae Scandinavica, Section B—Soil and Plant Science* 67(2): 134-147.

Agren, G. I., Ågren, G. I. and Bosatta, E. (1998). *Theoretical ecosystem ecology: understanding element cycles*. Cambridge University Press., Cambridge. 241pp.

Albrecht, K. A., Wedin, W. F. and Buxton, D. R. (1987). Cell-Wall Composition and Digestibility of Alfalfa Stems and Leaves 1. *Crop Science* 27(4): 735-741.

Alvarez, E., Marcos, M. L. F., Torrado, V. and Sanjurjo, M. J. F. (2008). Dynamics of macronutrients during the first stages of litter decomposition from forest species in a temperate area (Galicia, NW Spain). *Nutrient Cycling in Agroecosystems* 80(3): 243-256.

Baggs, E. M., Watson, C. A. and Rees, R. M. (2000). The fate of nitrogen from incorporated cover crop and green manure residues. *Nutrient Cycling in Agroecosystems* 56(2): 153-163.

Baijukya, F. P., De Ridder, N. and Giller, K. E. (2006). Nitrogen release from decomposing residues of leguminous cover crops and their effect on maize yield on depleted soils of Bukoba District, Tanzania. *Plant and Soil* 279(1-2): 77-93.

Bakken, A. K., Breland, T. A., Haraldsen, T. K., Aamlid, T. S. and Sveistrup, T. E. (2006). Soil fertility in three cropping systems after conversion from conventional to organic farming. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science* 56(2): 81-90.

Barthès, B., Azontonde, A., Blanchart, E., Girardin, C., Villenave, C., Lesaint, S., Oliver, R. and Feller, C. (2004). Effect of a legume cover crop (Mucuna pruriens var. utilis) on soil carbon in an Ultisol under maize cultivation in southern Benin. *Soil Use and Management* 20(2): 231-239.

Brar, M. S., Khurana, M. P. S. and Kansal, B. D. (2002). Effect of irrigation by untreated sewage effluents on the micro and potentially toxic elements in soils and plants. In *17. World Congress of Soil Science, Bangkok (Thailand) 14-21 Aug 2002*.

Camara, O. and Heineman, E. (2006). Overview of the fertilizer situation in Africa: Backround paper of the African Fertilizer Summit. June 9-13, 2006, Abuja, Nigeria. *Nepad: Pretoria*.

Campbell, C. A., Jame, Y. W., Akinremi, O. O. and Cabrera, M. L. (1995). Adapting the potentially mineralizable N concept for the prediction of fertilizer N requirements. *Fertilizer Research* 42(1-3): 61-75.

Cheng, K. L. and Bray, R. H. (1951). Determination of calcium and magnesium in soil and plant material. *Soil Science* 72(6): 449-458.

Chikowo, R., Mapfumo, P., Nyamugafata, P. and Giller, K. E. (2004). Maize productivity and mineral N dynamics following different soil fertility management practices on a depleted sandy soil in Zimbabwe. *Agriculture, Ecosystems and Environment* 102(2): 119-131.

Cobo, J. G., Barrios, E., Kass, D. C. L. and Thomas, R. J. (2002). Decomposition and nutrient release by green manures in a tropical hillside agroecosystem. *Plant and Soil* 240 (2): 331-342.

Diacono, M. and Montemurro, F. (2011). Long-term effects of organic amendments on soil fertility. *Sustainable Agriculture* 2: 761-786.

Djigal, D., Saj, S., Rabary, B., Blanchart, E. and Villenave, C. (2012). Mulch type affects soil biological functioning and crop yield of conservation agriculture systems in a long-term experiment in Madagascar. *Soil and Tillage Research* 118: 11-21.

Edmeades, D. C. (2003). The long-term effects of manures and fertilisers on soil productivity and quality: a review. *Nutrient Cycling in Agroecosystems* 66(2): 165-180.

Elfstrand, S., Hedlund, K. and Mårtensson, A. (2007). Soil enzyme activities, microbial community composition and function after 47 years of continuous green manuring. *Applied Soil Ecology* 35(3): 610-621.

Frossard, E., Brossard, M., Hedley, M. J. and Metherell, A. (1995). Reactions controlling the cycling of P in soils. In: *Phosphorus in the global environment*. (Edited by Tiessen, H.), Wiley, J. and Sons Ltd., Chichester. 107–137 pp.

Ganry, F., Feller, C., Harmand, J. M. and Guibert, H. (2001). Management of soil organic matter in semiarid Africa for annual cropping systems. In *Managing Organic Matter in Tropical Soils: Scope and Limitations*: 105-118. Springer, Dordrecht.

Giacomini, S. J., Aita, C., Vendruscolo, E. R. O., Cubilla, M., Nicoloso, R. S. and Fries, M. R. (2003). Dry matter, C/N ratio and nitrogen, phosphorus and potassium accumulation in mixed soil cover crops in Southern Brazil. *Revista Brasileira de Ciencia do Solo* 27(2): 325-334.

Hassan, W. (2013). C and N mineralization and dissolved organic matter potentials of two contrasting plant residues: effects of residue type, moisture, and temperature. *Acta Agriculturae Scandinavica, Section B-Soil and Plant Science* 63(7): 642-652.

Hättenschwiler, S. and Vitousek, P. M. (2000). The role of polyphenols in terrestrial ecosystem nutrient cycling. *Trends in ecology and evolution* 15(6): 238-243.

Horneck D. A. and Miller, R. O. (1998). Determination of total nitrogen in plant tissue. In *Handbook of Reference Methods for Plant Analysis*: 89-92. Soil and Plant Analysis Council Inc., CRC Press, Boca Raton, FL.

Kimetu, J. M., Lehmann, J., Ngoze, S. O., Mugendi, D. N., Kinyangi, J. M., Riha, S. and Pell, A. N. (2008). Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. *Ecosystems* 11 (5): 726.

Kisetu, E. and Mtakimwa, Z. S. (2013). Incorporating pigeon pea compost with Minjingu fertilizer brands to determine their effects on maize production in Morogoro, Tanzania. *World Journal of Agriculture Science* 1(9): 294-298.

Kovar, J. L., Bortolon, L. and Karlen, D. L. (2009). *Distribution of Phosphorus and Potassium Following Surface Banding of Fertilizer in Conservation*. The Proceedings of the International Plant Nutrition Colloquium XVI

Lavelle, P., Brussaard, L. and Hendrix, P. (1999). *Earthworm management in tropical agroecosystems*. CABI publishing.

Lehmann, J., Schroth, G. and Zech, W. (1995). Decomposition and nutrient release from leaves, twigs and roots of three alley-cropped tree legumes in central Togo. *Agroforestry Systems* 29(1): 21-36.

Lundquist, E. J., Jackson, L. E., Scow, K. M. and Hsu, C. (1999). Changes in microbial biomass and community composition, and soil carbon and nitrogen pools after incorporation of rye into three California agricultural soils. *Soil Biology and Biochemistry* 31(2): 221-236.

Mafongoya, P. L., Bationo, A., Kihara, J. and Waswa, B. S. (2006). Appropriate technologies to replenish soil fertility in southern Africa. *Nutrient Cycling in Agroecosystems* 76(2-3): 137-151.

Mafongoya, P. L., Giller, K. E. and Palm, C. A. (1998). Decomposition and nitrogen release patterns of tree prunings and litter. In *Directions in Tropical Agroforestry Research*: 77-97. Springer, Dordrecht.

Manzoni, S., Jackson, R. B., Trofymow, J. A. and Porporato, A. (2008). The global stoichiometry of litter nitrogen mineralization. *Science* 321(5889): 684-686.

Marandu, A. E. T., Mrema, J. P., Semu, E. and Nyaki, A. S. (2011). Potential of Cowpea, Pigeonpea and Greengram to Contribute Nitrogen to Maize in Rotation on Ferralsol in Tanga–Tanzania. In *Innovations as Key to the Green Revolution in Africa*: 317-323. Springer, Dordrecht.

Melillo, J. M., Aber, J. D., Linkins, A. E., Ricca, A., Fry, B. and Nadelhoffer, K. J. (1989). Carbon and nitrogen dynamics along the decay continuum: plant litter to soil organic matter. *Plant and Soil* 115(2): 189-198.

Möller, K. (2009). Influence of different manuring systems with and without biogas digestion on soil organic matter and nitrogen inputs, flows and budgets in organic cropping systems. *Nutrient Cycling in Agroecosystems* 84(2): 179-202.

Mulvaney, R. L. (2008). Advances in methodology for research on nitrogen transformations in soils. *Nitrogen in Agricultural Systems* (nitrogeninagric): 437-504.

Omollo, J. O. and Abayo, G. O. (2011). Effect of phosphorus sources and rates on sugarcane yield and quality in Kibos, Nyando Sugar Zone. In *Innovations as Key to the Green Revolution in Africa*: 533-537. Springer, Dordrecht.

Orcutt, D. M. (2000). *The physiology of plants under stress: soil and biotic factors* (Vol. 2). John Wiley and Sons.

Palm, C. A., Myers, R. J. and Nandwa, S. M. (1997). Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. *Replenishing Soil Fertility in Africa* (replenishingsoi): 193-217.

Palm, C. A. and Sanchez, P. A. (1990). Decomposition and nutrient release patterns of the leaves of three tropical legumes. *Biotropica*: 330-338.

Quemada, M. and Cabrera, M. L. (1995). Carbon and nitrogen mineralized from leaves and stems of four cover crops. *Soil Science Society of America Journal* 59(2): 471-477.

Randhawa, P. S., Condron, L. M., Di, H. J., Sinaj, S. and McLenaghen, R. D. (2005). Effect of green manure addition on soil organic phosphorus mineralisation. *Nutrient Cycling in Agroecosystems* 73(2-3): 181-189.

Reddy, K. N., Zablotowicz, R. M., Locke, M. A. and Koger, C. H. (2003). Cover crop, tillage, and herbicide effects on weeds, soil properties, microbial populations, and soybean yield. *Weed Science* 51(6): 987-994.

Rhoades, J. D. (1982). Cation Exchange Capacity 1. *Methods of soil analysis. Part 2. Chemical and microbiological properties* (methodsofsoilan2): 149-157.

Sanginga, N. and Woomer, P. L. (Eds.). (2009). *Integrated soil fertility management in Africa: principles, practices, and developmental process*. CIAT.

Sarwar, M. A., Ibrahim, M., Tahir, M., Ahmad, K., Khan, Z. I. and Valeem, E. E. (2010). Appraisal of pressmud and inorganic fertilizers on soil properties, yield and sugarcane quality. *Pakistan Journal of Botany* 42(2): 1361-1367.

Sharma, K. L., Neelaveni, K., Katyal, J. C., Srinivasa Raju, A., Srinivas, K., Kusuma Grace, J. and Madhavi, M. (2008). Effect of combined use of organic and inorganic sources of nutrients on sunflower yield, soil fertility, and overall soil quality in rainfed Alfisol. *Communications in Soil Science and Plant Analysis* 39(11-12): 1791-1831.

Shepherd, K. D. (2007). *Saving Africa's Soils: Science and technology for improved soil management in Africa*. World Agroforestry Centre.

Thorup-Kristensen, K., Magid, J. and Jensen, L. S. (2003). Catch crops and green manures as biological tools in nitrogen management in temperate zones. *Advances in Agronomy* 79(79): 227-302.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M. and Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability* 8(0): 15-22.

Whitbread, A. M., Jiri, O. and Maasdorp, B. (2004). The effect of managing improved fallows of Mucuna pruriens on maize production and soil carbon and nitrogen dynamics in sub-humid Zimbabwe. *Nutrient Cycling in Agroecosystems* 69(1): 59-71.

Yeomans, J. C. and Bremner, J. M. (1988). A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis* 19(13): 1467-1476.

Zhenghu, D. and Honglang, X. (2000). Effects of soil properties on ammonia volatilization. *Soil Science and Plant Nutrition* 46(4): 845-852.

CHAPTER THREE

3.0 PRODUCTIVITY AND MINERAL QUALITY OF ORGANIC SWEET PEPPER UNDER LIVE AND DEAD MULCH FOR MANAGEMENT OF WEEDS AND WEED SEEDBANK

Saria, A. G.[1, 4*], Sibuga, K. P.[1], Høgh-Jensen, H.[3] and Semu, E.[2]

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

[2]Department of Soil and Geological Sciences, Sokoine University of Agriculture, Morogoro, Tanzania

[3]National Food Institute, Technical University of Denmark, Denmark

[4]Tanzania Official Seed Certification Institute, Tanzania

*****Corresponding Author email: **adolfsaria@gmail.com**

Abstract

A study was conducted to investigate the ability of cover crops and other weed control methodologies in weed management and to determine their effect on weed diversity, biomass and frequency dynamics. Also cover crops were assessed for ability to increase crop nutrients uptake to optimise sweet pepper mineral qualities. Experimental plots were managed with greengram cover crop, mucuna cover crop, mixed grass dead mulch, weeding and unweeded plots as control in four replicates. Data on crop growth, production, crop mineral contents, weed density, diversity, biomass and weed seedbank were collected and analysed each season, for three seasons. Soil weed seed bank data were determined from depths 0–10, 11-20 and 21-30 cm from each treatment. Plots planted with greengram or mucuna cover crops reduced weed species to 13 and 12, respectively, in the third season, from 17 initial species identified at the beginning of the experiment. Mucuna reduced weed biomass from 33.1 g/m^2 to 9.1 g/m^2 and weed seed bank density from 17922 to 9418 per metre square. *Cyperus rotundus*, *Cynodon dactylon* and *Elangia cordifolia* were the most dominant weeds in both treatments. Plots planted with mucuna cover crops resulted in high number of sweet pepper fruits per plant (25), improved sweet pepper growth by increasing stem branches from 7 to 22 and leaves from 52 to 157. Sweet pepper planted with cover crops had highest total N and P, with mucuna having 2.81% of N and 1.63% of P, while those planted with greengram had 2.48% N and 1.09% P compared to the control plots with 1.01% N and 0.41% P. Cover crops improved sweet pepper crop growth by increasing height up to 61.8 cm from 31.8 cm and branches from 10.8 to 24.4, productivity from 0.8 to 9.1 t ha^{-1} and had highest amount of N (2.81%) and P (1.64%) due to their ability in controlling weeds, providing conducive micro-environment and improve soil fertility.

Key words: cover crops, weed seed bank, weed diversity, mineral nutrients.

3.1 Introduction

Weeds and soil fertility control are crucial for organic vegetable farming. Most weed species rely on seed for regeneration and persistence. Weed seeds can stay viable in the weed seed bank below the soil for at least four years and many remain viable for up to twenty years if conditions are favourable (Liebman *et al.*, 2001; Saatkamp *et al.*, 2014). Understanding weed seed bank dynamics is essential for identifying the optimal weed management practices and systems for specific field and crop (Norsworthy *et al.*, 2012). Weed management through tillage which disturbs the soil in turn affects weed seed depth in the soil and therefore plays a significant role in weed seed bank dynamics in terms of species compositions and populations. The weed seed species and density composition in the soil vary greatly and are closely associated with the cultural practices and cropping history of a specific field and time. Crop rotation and weed control practices also impact the weed seed bank in the soil (Gibson *et al.*, 2016).

Failure to effectively control weeds also increases soil seed banks over time, which can lead to costly infestations in crops grown later within the field (Mirsky *et al.*, 2010). Furthermore, the uncontrolled weeds can act as alternative hosts for economically important insect pests and diseases. Kruidhof *et al.* (2008) suggested that, the negative effects of weeds on crops can be limited not only by reducing weed density, but also by minimizing the resource consumption, growth and competitive ability of each surviving weed. Liebman *et al.* (2001) proposed that weeds should be shifted towards less aggressive composition which is easy to manage. Convenience and profitability considerations lead farmers to seek weed management systems which use a desirable blend of labour, input costs and management skills (Pardo *et al.*, 2010). Therefore, this study was conducted to investigate the ability of cover crops and other weed control methodologies in weed management and to determine their effect on weed diversity, biomass and frequency dynamics. Also, their ability on increasing crop nutrient uptake to optimise sweet pepper mineral quality was assessed.

3.2 Weed management in organic agriculture

In organic agriculture alternative means of weed management are considered other than herbicides use which also have high residual effects on human and environmental health (Hiltbrunner *et al.*, 2007). Organic agriculture system relies on practices which are ecological friendly such as hand hoe weeding which damage weeds mechanically or by biological agents as cover crops (Garratt *et al.*, 2018). Hand hoe weeding is the major means of weeds management in organic fields which grows vegetables (Cloutier *et al.*, 2007). However, studies have shown that hand hoe weeding can only control up to 50% of the weeds in the field (Cheema and Khaliq, 2000). Limitations with hand hoe weeding include limited weed control in crop rows at early vulnerable crop stages and weather-dependent effectiveness (Kurstjens, 2007). Hand hoe weeding increases overall labour days compared to other weed management systems (Muoni *et al.*, 2013). Tillage and hand hoe weeding promotes weeds germination as they expose deposited seeds from the soil weed seed bank from lower to upper soil layers. The seeds in upper soil layer obtain optimum condition for germination like moisture, aeration, temperature and light which prompts weed seeds germination (Chung and Paek, 2003).

Live or dead mulch are other major practices used in organic agriculture for weeds management. Live and dead mulch can be among the major means of suppressing weeds and manipulating their environmental conditions to prevent them from re-establishing and increase their seed bank which is very important for eradicating especially noxious weed species (Vranjic *et al.*, 2000). The use of cover crops has advantages of reducing the ability of weeds to germinate (Kunz *et al.*, 2016) or shift weed species composition in a way which is less competitive to crops (Liebman and Davis, 2000). Anthofer and Kroschel (2007) revealed the ability of *Mucuna pruriens* cover crop to reduce both frequency and average density of eight persistent weeds when applied by slashing and mulch in maize fields.

3.2.1 Cover crops effect on soil fertility

In most of sub Saharan countries poor agriculture productivity has been generally associated with poor soil fertility and low inputs application, resulting to depletion of nitrogen, phosphorus, potassium and other trace elements in most of the soils (Cordell *et al.,* 2009). This has been caused by the inability of small scale farmers to acquire soil inputs for agriculture production associated with high input costs and poor infrastructure (Dorward and Chirwa, 2011). Furthermore, in this regard, recent efforts have been focussed more towards the production of foods which are nutrient rich and of high quality in environments which are sustainable to ensure bio-safety. Organic agriculture system of farm production attracts the growing demand for biological based organic fertilizers as a replacement of conventional chemical fertilizers (Bhardwaj *et al.,* 2014). In organic farming, the use of inorganic fertilisers is not accepted leaving the farmers with few options for soil fertility supplementation and management.

Application of cover crops and animal manures which are recommended for maintaining soil fertility and crop productivity in organic agriculture, is faced with a challenge of inadequate knowledge on the amounts required for them to be effective in replenishing soil productivity (Vanlauwe *et al.,* 2015). Farmers have therefore been left with the option of using varieties subjected to low input practices. Studies have proved that, legume cover crops are reliable means of improving crop yields (Poeplau and Don, 2015). Cover crops do play an important role in soil fertility management through their short term effects on nutrient supply and coupled with a longer term contribution to soil organic matter (Wittwer *et al.,* 2017).

3.2.2 Influence of cover crops on crop productivity

Crop productivity largely depends on nutrients availability in the soil and the agronomic practices applied to the crop. Studies have pointed the ability of cover crops to increase crop productivity through soil fertility improvements. Kimetu and Lehmann (2010) reported the ability of cover crops to improve soil organic matter when used as green manure leading to the increase in crop productivity. Also cover crops have shown the ability of increasing soil N and its availability to plants from the soil while providing available P to plants (Agegnehu *et al.,* 2015). Furthermore, cover crops have been reported to increase soil micro nutrients which are essential to plants growth (Chukwuka and Omotayo, 2008). Application of cover crops have shown to have advantage to crop root by improving root growth and also improve crop vigour (Rosolem *et al.,* 2002). Therefore, green manures can have great advantage on crop growth and productivity. However, the quality of the organic resource applied determines its effects on nutrients availability in the soil and to the plant. Vandecasteele *et al.* (2016) reported a reduction in readily available P when biochar was applied to improve composting process of green manures, and furthermore biochar as a means to increase C content of the compost was only effective during compost storage.

Saria *et al.* (2018) indicated long term nutritional advantage of cover crops to the targeted crops due to slow rate of nutrient release to the soil making nutrients available for plants uptake up to eight weeks. Ghoname and Shafeek (2005) indicated the advantages of slow release fertilizers on increasing the production of sweet pepper in terms of fruit yield from 36.7 up to 86.6 ton ha^{-1} and vigour by having more leaves and stem branches compared to fast release fertilisers. Roy *et al.* (2011) associated the improvement on the proper growth, development and yield maximization of sweet pepper when optimal fertilisers were applied to the crop in all crop growth stages. A study by Xu *et al.* (2001) revealed an increase in total number of flowers, fruits and yield with the gradual release and increase of nitrogen supply to the plants. Furthermore, the study showed early ripening fruits with gradual increase in nitrogen supply. Therefore, cover crops which release nutrients slowly to the soil can be of great advantage to the sweet pepper crops by improving its quality and quantity.

3.2.3 Influence of soil fertility management practices on fruits mineral nutrient content

Soil fertility management practices can have effect on the mineral content of the harvested produces of different crops (Riedell *et al.,* 2009). Organic farming practices promote an increase of soil organic matter and a gradual release of plant nutrients, allowing plants to derive a more balanced nutrition (Altieri and Nicholls, 2003). Thus, while the amount of N immediately available to the crop may be lower when organic fertilizers are applied, the overall mineral nutrients content of the crop appears to be improved. The study done by Wang and Klassen (2006) explained the effects of different soil amendments on concentration of various nutrients element of Okra, among other elements they observed an increase of 24% N on Okra fruits when valvet beans were used as manure, while sun hemp enhanced okra root N concentration by 70%.

A study done by Roe *et al.* (1997) reported a significant increase of P, K, Ca and Mg in sweet peppers and cucumbers grown on soil supplemented with compost. Furthermore, Colla *et al.* (2002) reported that organically grown tomatoes were soil fertility was managed by cover crops and composted manure were significantly higher in P and Ca and conventionally grown tomatoes were higher in N and Na. Toor *et al.* (2006) associated high concentration of Mg in tomato fruits produced on soil treated with grass-clover mulch with higher rate of mineralisation of Mg from the mulch resulted to greater Mg uptake by the plants. While, Pradhan et al., (2007) demonstrated the effect of soil fertility treatments on chemical content and flavour quality of cabbage.

In organic agriculture, there is still a need to search for alternative agronomic practices which can combine weed control and soil fertility for improving sweet pepper productivity. Therefore, this study evaluated the effects of live and dead mulching materials on weed occurrence, seed bank and diversity and their potential on improving sweet pepper physical and chemical attributes.

3.3 Materials and Methods

3.3.1 Experimental location

The experiment was conducted at Sokoine University of Agriculture (SUA) research farm (6^{o} 85’ 22” South, 37^{o} 65’ 76” East) and Towero village (6^{0} 51’ S, 37^{0} 41’ E) in Morogoro region, Tanzania. SUA lies at 600 m.a.s.l. characterized by bimodal rainfall of which the short rains are from November to December with an average of 600 mm and the long rains in March to June with an average of 1000 mm. The Towero village lies at 2868 m.a.s.l. with short rainfall in November to December with an average of 950 mm and long rains from March to June with an average of 1922 mm.

3.3.2 Land preparation

The experimental area was ploughed by deep tilling and harrowed using hand hoes. Then the experimental plots were raised after deep tilling and harrowing.

3.3.3 Layout

A randomized complete block design (RCBD) with a plot size of 3 m x 3 m replicated four times was used to test five different treatments. Treatments were implemented as follows;

3.3.4 Treatments

3.3.4.1 Cover crops

Results from studies on cover crop decomposition and nutrients release (Saria *et al.*, 2018) which showed that, slashed cover crops started to decompose and release nutrients in the fourth weeks after slashing were used to plan for this study. The results were used to determine the appropriate time for main crop introduction to the field. Two cover crops mucuna and greengram were used for weed control. The cover crops were planted in their respective plots after land preparation. Mucuna was planted at a spacing of 75 cm between rows and 30 cm within row, while greengram was planted at a spacing of 10 cm between rows and 10 cm within rows. After three months mucuna cover crop which attained 50% flowering were slashed and left on top of the soil as dead mulch. The greengram cover crop was slashed 55 days after planting at the stage of 50% flowering and also left on top of the soil as dead mulch.

3.3.4.2 Mixed grass mulch

Unseeded mixture of different dead grasses was also used for weed control. A mixture of unseeded grasses was collected and used as dry mulch on plots managed by dead mulch. A layer of 15 cm of mixed grasses was applied on top of the soil as mulch three days after sweet pepper seedlings transplanting. Mixed grass mulch treatment was supplemented by 250 g of animal manure.

3.3.4.3 Hand hoe weeding

Weeding was done using hand hoe in plots managed by weeding. Hand hoe weeding was done three times, the first weeding was done at second week after sweet pepper transplanting, second weeding was done at the fourth week and the third weeding was done at the six week after sweet pepper seedlings transplanting.

3.3.4.4 Control

In a control treatment weeds were allowed to grow undisturbed throughout the experimental period.

3.3.5 Seedling transplanting

Four weeks old sweet pepper seedlings were transplanted at a spacing of 70 cm between rows and 30 cm within rows. Plots were having five rows with eleven plants each providing a population of 55 plants per plot equivalent to 47,600 plants per hectare.

3.3.6 Data collection

3.3.6.1 Weed infestation

Weeds were recorded twice, at second and fourth week after sweet pepper seedling transplanting. Weed data were collected in a quadrat of $1m^2$ established at the centre of each plot covering two sweet pepper central rows leaving guard rows on either side of the plot and 15cm from each end of the plot. The number of weeds was determined by counting the number of broadleaf weeds, grass weeds and sedge weeds separately. Data from each treatment was used to calculate weed density and frequency as follows.

$$D_i = (\Sigma\, Y_i) / \text{n}$$

Where: D_i = density of species i; ΣY_i =number of individual plants of species i contained in the sampling unit; n =surface area of the sampling unit.

$$F_i = (\sum Y_i \text{ x } 100) / \text{n}$$

Where: F_i =frequency value for species i; ΣY_i =number of sampling units (which was two per plot) with species i present; and n =total number of sampling units surveyed.

Weed count data were subjected to square-root transformation for obtaining normal distribution of the recorded data before proceeding with analysis of variance (ANOVA).

3.3.6.2 Weed biomass

The weed biomass (g/m^2) was determined by cutting weed shoots at the root collar near the ground level in earlier established quadrats at the twelfth week after transplanting. The collected weed shoots were oven dried at 70^oC for 72 hours and then weighed to obtain the total weed dry weight (Demjanová *et al.*, 2009).

3.3.6.3 Weed diversity index

The diversity index was calculated using Shannon's diversity index (H') as described by Magurran in 2004 (Rosenberg, 2005).

3.3.6.4 Weed seed bank

Weed seed bank was determined by floatation method which is used to quantify the total number of probable seeds per hectare (Tsuyuzaki, 1994). Three samples from each plot were collected from different depths, which were 0-10 cm, 11-20 cm and 21-30 cm. The samples were analysed through flotation and weed seed were extraction as described by Konstantinović *et al.* (2011). Soil samples were passed through two sieves, a nine mesh with larger openings to retain coarser materials like plant residues and then a 32 mesh to retain weed seeds, soil particles and plant material that were not retained by the previous sieve.

One litre aliquot of soil was mixed with 300 ml of 5.5 M K_2C0_3 solution and stirred for ten minutes. Then the sample was centrifuged at more than 4000 rpm for about five minutes. Buried seeds and lighter organic matter floated to the top of the solution while soil particles and heavy materials settled at the bottom. The solution was filtered through a filter paper, seeds and organic materials collected on the filter paper were rinsed thoroughly with distilled water and blotted dry. The extracted seeds were transferred to Petri dishes, air-dried for two weeks at room temperature and with the aid of a magnifying glass and a microscope inert materials were separated then weed seeds sorted, counted and identified. Probable number of weed seeds in the soil per hectare in each soil layer was calculated as described by Monqueiro and Christoffoleti (2003).

3.3.6.5 Crop growth

Different crop growth data were collected from a total of 27 plants obtained in the inner three rows leaving a guard row from either side in a plot of 55 plants. At the vegetative stage 45 days after transplanting, plant height, number of branches, number of leaves per plant and days to 50% flowering were determined.

3.3.6.5.1 Days to 50% flowering

This is the time taken for half of the plant population at the inner rows excluding guard rows which are used for data collection. In each plot the 50% flowering was recorded when at least 14 plants from the 27 plants have flowered. This was done by counting the number of flowered plants within the plot.

3.3.6.5.2 Plant Height

Plant height was measured from the five plants which were selected for destructive sampling out of the 27 plants of the central rows excluding guard rows by measuring tape from the plant root collar at the ground level the tip of the apical leaf.

3.3.6.5.3 Number of branches per plant

Total number of branches per plant was determined by counting both primary and secondary branches of the five plants selected for destructive sampling out 27 plants allocated for data collection. Plant branches were recorded 45 days after sweet pepper seedling transplanting.

3.3.6.5.4 Number of leaves per plant

The total number of leaves per plant was determined from the same five plants used for determining number of branches. Number of leaves per plant was obtained by counting all fully opened leaves on plant leaving the bud primordial at the shoot apex.

3.3.6.6 Plant biomass

Sweet pepper plant biomass (g/m^2) was determined by cutting five plants from the centre of the plot. The plants were cut at the root collar near the ground level 45 days after transplanting. The collected sweet pepper shoots were oven dried at 70°C for 72 hours and then weighed to obtain the total sweet pepper plant dry weight (Demjanová *et al.*, 2009).

3.3.6.7 Yield and yield components

The remained 22 plants after destructive sampling from the middle rows of the plot were selected and tagged in each plot for yield data collection. This excluded plot guide rows and five plants used as destructive sampling for biomass determination.

3.3.6.7.1 Number and weight of fruits per plant

In each harvest, harvested fruits per each plant were counted, weighed and recorded to ascertain the average total number and weight of fruits per plant.

3.3.6.7.2 Fruit length and width

Twenty fruits were randomly selected from each plot at the second harvest, length and width of each fruit were measured using a Vernier caliper. The mean lengths and width (cm) were then recorded from each plot (IPGRI, 1995)

3.3.6.8 Crop mineral content

Ten sweet pepper fruits randomly selected from the total harvested fruits for determination of fruits mineral contents. Also 45 days after transplanting, a quadrant of $1m^2$ was determined at the centre of two central rows of each plot with a total of eight sweet pepper plants. From the eight plants, destructive sampling was done by randomly cutting five plants at root collar for determination of different minerals content in sweet pepper plant vegetative parts. For the vegetative parts from the root collar including shoots and leaves of the crop N, P and K were determined and Mn, Zn, Cu, Mg and Fe were determined for the sweet pepper fruits from each treatment. The mineral contents were determined as follows;

3.3.6.8.1 Total nitrogen

Plant materials were left to desiccate for 7 days, then transferred in an oven at 70^oC for 72 hours to complete the drying process. Then after, the materials were grinded and a sample weight of 0.2 g was transferred to a 500 ml Kjeldahl tube and two grams of mixed salts catalyst (K_2SO_4 + $CuSO_4$ + selenium powder, in the ratio of 10: 10: 1 by weight) was added. Ten ml of H_2SO_4 were added. The mixture digested for one hour at 360 ^0C. After cooling, 50 ml of water were added, followed by 25 ml of H_3BO_3 and 50 mls of 40% NaOH. The mixture was distilled and about 200 ml of distillate collected. The distillate was titrated using 0.05 N H_2SO_4 (Horneck and Miller, 1998).

3.3.6.8.2 Phosphorus content

Extractable P was determined using the Bray 1 method (Kovar *et al.,* 2009). A sample of three grams dried sweet pepper shoot was placed in to an extraction bottle and mixed with 20 ml of extraction solution and shaken thoroughly. Then the mixture was filtered through filter paper. Five milliliters aliquot of the sample mixture was transferred to 50 ml volumetric flask and 10 ml of water added. Two milliliters of phosphate reagent was added and the volume was made to 50 ml, the colour was allowed to develop in 15 minutes. The extractable P content in solution was determined in a spectrophotometer at 882 nm.

3.3.6.8.3 Mg content

Exchangeable Mg was determined using the Bray 1 method (Kovar *et al.,* 2009). A sample of three grams of dried sweet pepper fruits was added in to the extraction bottle, 20 ml of sodium bicarbonate extraction solution and shaken thoroughly. Then the mixture was filtered through a filter paper. Five millilitres aliquot of the sample mixture was transferred to 50 ml volumetric flask and 10 ml of water added. Two millilitres of phosphate reagent were added and the volume was made to 50 ml, the colour was allowed to develop in 15 minutes. The exchangeable Mg was determined using atomic absorption spectrophotometer as explained by Cheng and Bray (1951).

3.3.6.8.4 Mn, Zn, Fe and Cu

Mn, Zn, Fe and Cu were determined from the same solution used to determine Mg using an atomic absorption spectrophotometer as described by Mcgrath and Cunliffe (1985).

3.3.7 Statistical analysis

Weed count data were subjected to square-root transformation before proceeding with analysis of variance (ANOVA). Weeds, crop growth and production data were subjected to analysis of variance using (ANOVA) using GENSTAT statistical program (Genstat release 6.1 Lawes Agricultural Trust). Treatment means were ranked using Duncan's Multiple Range Test at $P \leq 0.05$. The scores of preference ranking were treated as quantities measured on a continuous scale. Data were analyzed using SPSS (2002) statistical packages.

3.4 Results

3.4.1 Weed density and frequency

At the experimental sites weed seeds which occurred in the weed seed bank were species consisting of broad-leaved and grass species. Weed seed bank densities and relative abundance of 17 species originally observed in the experimental area. The most frequent weed species were *Cyperus esculantus, Cynodon dactylon* and *Commelina bangalensis* in all three years of the experiment (Table 3.1). The densities and frequency of each species in the soil remained unchanged for the first two experimental years and then varied from year to year in the last two years of the experiment. Results show that, a total of 17 species was recorded in 2015 and 2016, in all sites while 13 and 12 species were recorded in 2017 and 2018, respectively.

Table 3.1: Weed species found in the experimental field, their details of density and frequency before and after treatments application

Weed species	Common name	Group	2015		2017		2018	
			Density (m^{-2})	Frequency	Density (m^{-2})	Frequency	Density (m^{-2})	Frequency
Cyperus rotundus	Nut sedge	S	118.8d	100a	110.48a	98c	105.73a	94c
Cynodon dactylon	Bermuda grass	G	62.19bd	100a	52.86b	89c	50.99b	79c
Mimosa pudica	Touch me not	B	9.39a	64b	7.32c	64c	6.76c	62c
Commelina bangelensis	Wandering Jew	B	11.09a	59b	7.32c	58bc	6.54c	44bc
Sida acuta	Wire weed	B	11.01a	57b	9.80c	57bc	9.58c	53bc
Oxygonium sinuatum	Star stalk	B	41.26b	100a	7.43c	100d	30.95bc	100c
Corchorus oliotorius	Jute mallow	B	5.17a	41b	3.26c	33ab	2.79c	37abc
Conyza sumatrensis	Fleabane	B	23.86ab	100a	21.24c	50b	27.53bc	15a
Euphorbia hirta	Asthma plant	B	21.05ab	88ab	10.31c	57bc	7.58c	22a
Panicum maximum	Guinea grass	G	6.81a	63b	4.77c	17a	0c	0a
Kyllinga erecta	Spike sedge	S	4.67a	41b	3.74c	13a	0c	0a
Elangia cordifolia	Elangia	B	87.11d	58b	51.40b	52b	47.04bc	39abc
Launaea cornuta	Wild lettuce	B	15.27ab	70ab	84.97a	66c	12.06c	60c
Cassia obtusifolia	Sickle senna	B	21.97ab	30bc	14.71c	29ab	13.62c	29ab
Spermacoce sinensis	False buttonweed	B	4.33a	4d	1.73c	5a	0c	0a
Tridax procumbensi	Tridax	B	3.0a	33bc	1.62c	3a	0c	0a
Trichodema zeylyanican	Trichodema	B	5.5a	3d	2.75c	3a	0c	0a
Means			26.62	59.47	23.28	46.71	18.89	37.29
SE			2.6	4.2	5.6	6.1	4.3	3.9
CV (%)			9.8	11.6	13.4	17.1	10.5	12.3

NOTE: Figures followed with same letter(s) are not significantly different at P≤0.05 by Duncan's Multiple Range

KEY: G = grass, B = broad leaf, S = sedge

Average weed density and frequency (Table 3.1) for both sites (SUA and Towero) were reduced in the three years of the experiment compared with the third season. The two cover crops mucuna and greengram managed to reduce weed density after being applied in the field for three consecutive seasons. Weed counts were generally lowest when plots were treated with cover crops and mulch compared with bare plots (Fig. 3.1). In plots were weeds were managed by mulch mixed grass, mucuna or greengram, average weeds were reduced significantly in both sites. At Sokoine University site weeds were reduced in the four experimental years from 34, 16 and 21 in the first year of the trials to 19, 9 and 14 in plots with mixed grass mulch, mucuna and greengram respectively in the fourth year (Fig. 3.1). While weeds were reduced from 31, 13 and 18 to 16, 5 and 11, respectively, at Towero village (Fig. 3.2).

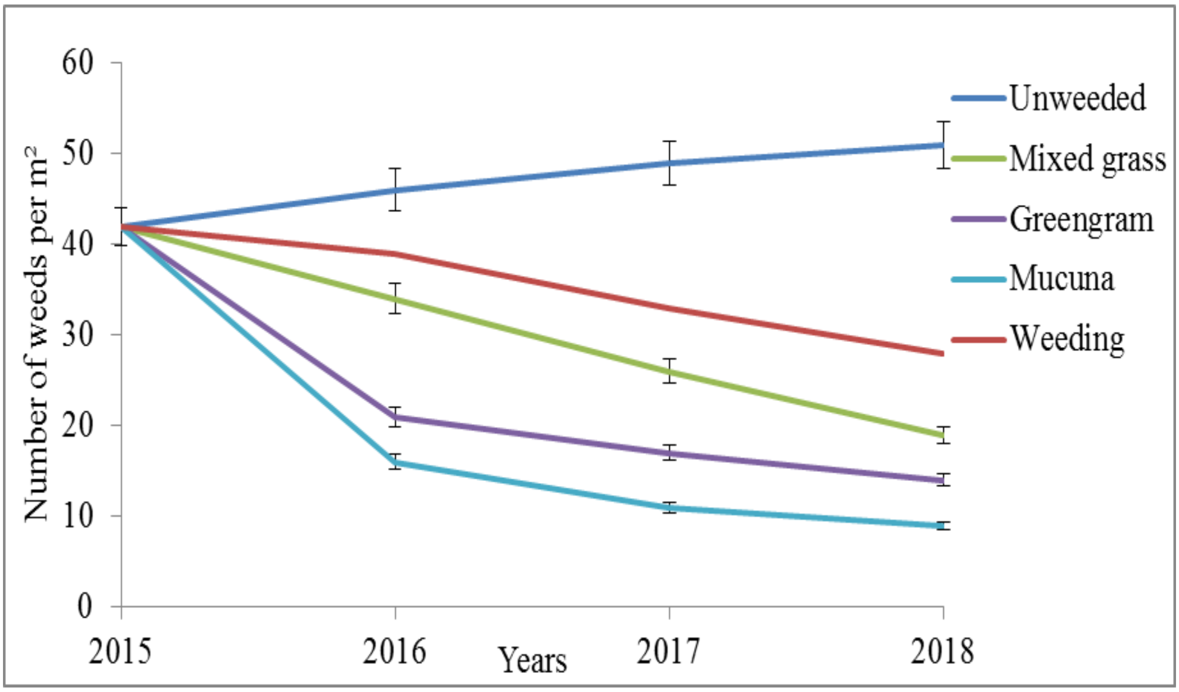

Figure 3.1: Average weed count at SUA

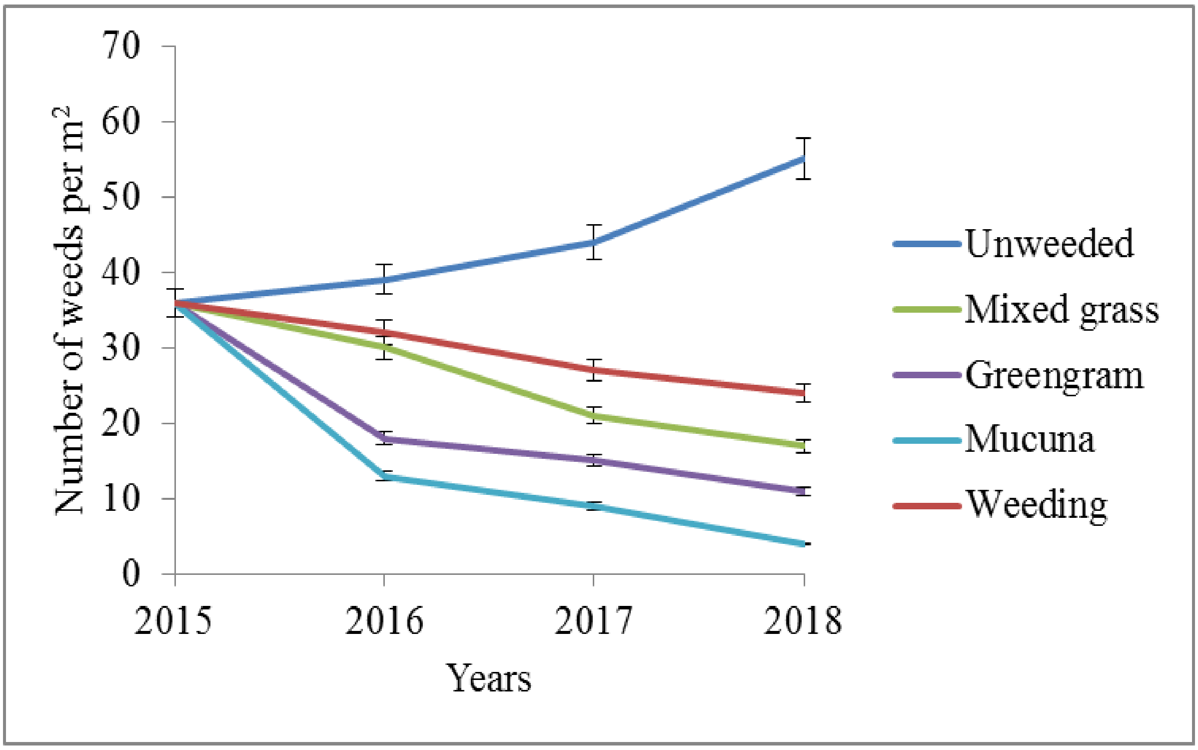

Figure 3.2: Average weed count at Towero

3.4.2 Weed seed bank diversity index

Weed seed bank diversity was higher in samples obtained from upper and middle soil layers in both sites. At SUA (Table 3.2), mucuna cover crop decreased the Shannon index of the weed seed bank diversity from the original 1.22 to 1.02 at the top layer of the soil after it was grown on the same field for three seasons consecutively. Furthermore, the diversity within layers also decreased with soil depth, in the deeper layer of the soil (21 to 30 cm) the diversity decreasing from 1.39 which was the highest obtained in weeded plots to 0.74 which was the lowest recorded in plots planted with mucuna.

Table 3.2: Total seed bank density and Shannon's diversity index value in three soil depths at SUA

Year	Soil depth (cm)	Control D	Control *H'*	Weeding D	Weeding *H'*	Mulch D	Mulch *H'*	Greengram D	Greengram *H'*	Mucuna D	Mucuna *H'*
2015	0-10	19601	1.22	20735	1.89	16489	1.93	16192	1.61	15892	1.45
	11-20	21862	1.38	17608	1.18	16153	1.27	15843	1.39	15211	1.26
	21-30	13506	0.91	14928	1.36	15181	1.05	14123	1.14	11985	1.85
2018	0-10	26804	2.83	2198	2.11	14648	1.64	12837	1.33	10896	1.02
	11-20	23452	1.56	18103	1.46	11508	1.35	10438	1.22	7203	0.87
	21-30	15768	1.01	15279	1.39	10964	1.16	89642	1.18	5946	0.74

KEY: D = Denity and *H'* = Shannon's diversity index

At Towero, the trend of weed diversity was similar to that of SUA with plots planted with cover crops having less weed diversity compared to other treatments (Table 3.3). The control plots where weeds were left undisturbed were richer in weeds diversity reaching an index of up to 1.66. On other hand, plots treated with mucuna cover crops were poor in weeds diversity managing to reduce weeds diversity to a lower index of 1.02 at the upper layer of soil by the third year of applying mucuna cover crop on the field.

Table 3.3: Total seed bank density and Shannon's diversity index value in three soil depths at SUA

Year	Soil depth (cm)	Control		Weeding		Mulch		Greengram		Mucuna	
		D	*H'*	D	*H'*	D	*H'*	D	*H'*	D	*H'*
2015	0-10	17154	1.11	17120	1.62	16933	1.93	17095	1.51	16386	1.33
	11-20	19302	1.19	13583	1.22	15781	1.34	15460	1.40	14994	1.24
	21-30	9836	0.86	11076	1.18	12372	1.10	12091	1.18	12133	1.43
2018	0-10	16970	1.66	16287	1.89	14097	1.52	11297	1.33	7682	1.02
	11-20	19354	1.25	13645	1.36	10831	1.38	8643	1.14	4874	0.71
	21-30	14982	1.11	14986	1.33	99648	1.14	8914	1.20	5861	0.83

KEY: D = Density and *H'* = Shannon's diversity index

3.4.3 Weed Seed Bank Density

At SUA, mucuna and greengram cover crops reduced total seed density from 17922 seeds per metre square obtained from the control plot, to about 9418 seeds per metre square in plots planted with mucuna cover crop prior to sweet pepper transplanting. Furthermore, plots planted with greengraam reduced seed density to 12501 seeds per meter square (Fig. 3.3). However, in plots where weeds management was done using hand hoe weeding, the rate of seed bank reduction was lower (16295) compared with plot managed using cover crops.

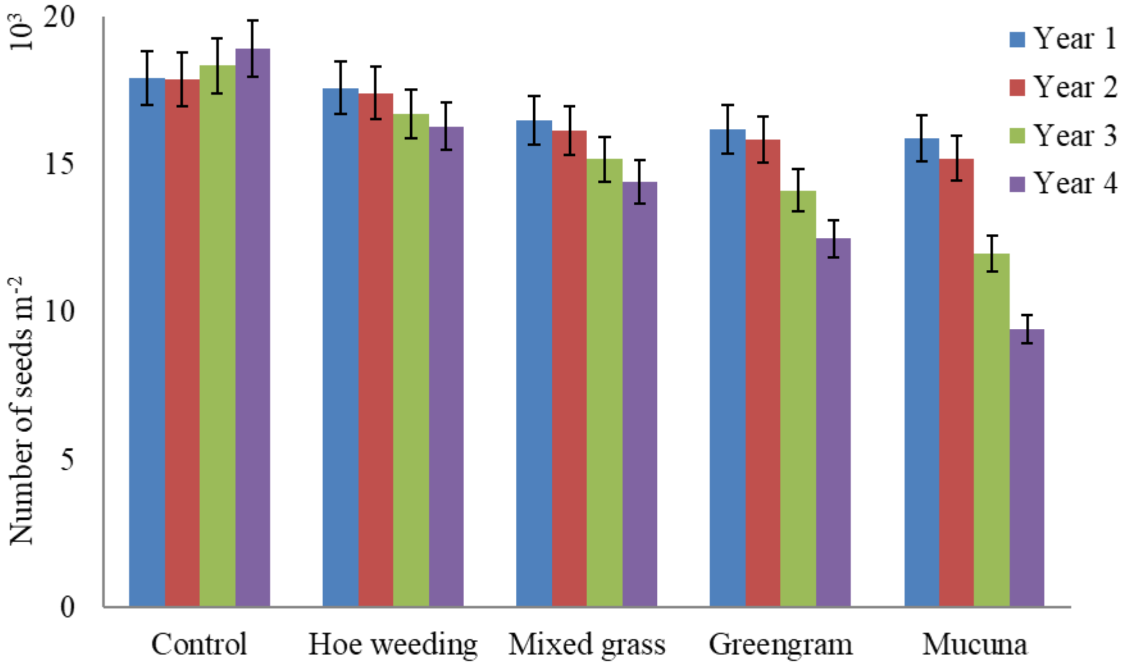

Figure 3.3: Total weed seed bank m^{-2} under different weed management treatments at SUA

At Towero, the trend of weed seed bank reduction was similar with that of SUA. Plots planted with mucuna cover crops reduced weed seed bank density to 4874 per metre square compared with a density of 17154 seeds per metre square obtained from the control plots (Fig. 3.4). Plots managed using greengram cover crops reduced weed seed bank density to about 7682 seeds per metre square.

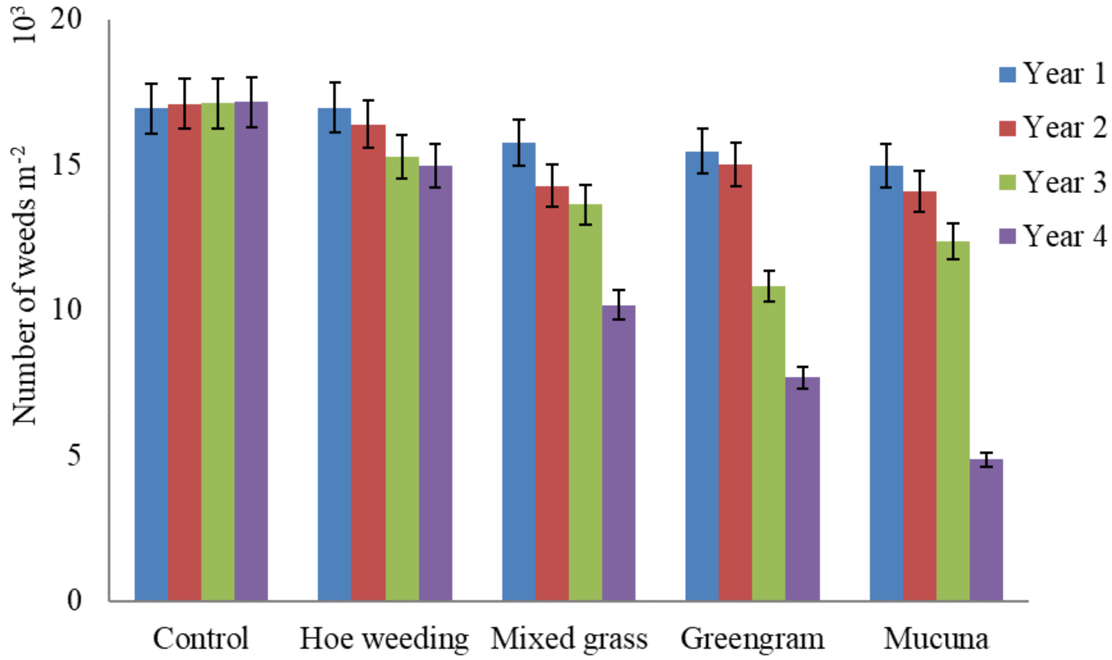

Figure 3.4: Total weed seed bank m^{-2} under different weed management treatments at Towero

Number of weed seeds deposited in the soil were reduced significantly ($P \leq 0.05$) in plots treated with cover crops prior to sweet pepper transplanting in both sites SUA (Table 3.4) and Towero (Table 3.5). At SUA the cover crops were the best treatments in weed seed bank management, the cover crop managed to reduce total weed seeds from 18847 seeds/m^2 recorded in the control plots in first season to 9418 seeds/m^2 which was recorded in plots treated with mucuna and 12501 seeds/m^2 recorded in plots treated with greengram. At Towero, mucuna plots were recorded to have reduced total weed seeds in the soil to 7682 seeds/m^2 from 16770 seeds/m^2 recorded in control plots, while plots managed by greengram cover crop reduced total weed seeds to 11297 seeds/m^2.

Table 3.4: Total seed bank m^{-2} for different weed types under different weed management practices at SUA

Year	Control		Weeding		Mixed grass		Greengram		Mucuna	
	Grass	Broadleaves	Grass	Broadleaves	Grass	Broadleaves	Grass	Broadleaves	Grass	Broadleaves
1	16098a	2749b	14860a	3504a	14268a	2221ab	13809a	2383a	13562a	2330a
2	14567c	2807b	13910b	3516a	13753a	2406a	13563a	2280a	13274a	1937a
3	15539b	3124a	12590c	4121b	12837b	2344a	12571b	1552b	10919a	1066b
4	16777a	3320a	12258c	4037b	10883c	2087b	11353c	1148c	8492c	926b
Mean	15745.3	3000.0	13404.5	3794.5	12935.3	2264.5	12824.0	1840.8	11561.8	1564.8
SE	446.3	115.2	218.6	108.4	288.1	212.1	196.8	128.4	156.3	251.0
CV (%)	15.9	8.6	10.5	6.2	8.0	14.3	19.9	6.4	17.2	16.4

NOTE: Figures followed with same letter are not significantly different at P≤0.05 by Duncan's Multiple Range

Table 3.5: Total seed bank m^{-2} for different weed types under different weed management practices at Towero

Year	Control		Weeding		Mixed grass		Greengram		Mucuna	
	Grass	Broadleaves	Grass	Broadleaves	Grass	Broadleaves	Grass	Broadleaves	Grass	Broadleaves
1	13997a	3157a	13586a	3264a	13835a	3098a	13804a	3291a	13200a	3186a
2	12955b	2704b	13201a	3086a	13231a	2892a	12977b	2280a	12317b	2831b
3	12870b	3092c	11837b	2835b	12313b	2516b	11485c	1393ab	8704c	1058c
4	13524a	3246c	11227b	2673b	11940b	2157b	10218d	1079b	6950d	732c
Mean	13336.5	3049.8	12462.8	2964.5	12829.8	2665.8	12121.0	2010.8	10292.8	1951.8
SE	308.2	216.2	213.2	164.0	232.8	212.1	205.4	135.9	256.4	212.9
CV (%)	12.1	16.4	12.6	16.8	11.9	14.3	15.1	8.6	14.9	14.7

NOTE: Figures followed with same letter are not significantly different at P≤0.05 by Duncan's Multiple Range

3.4.4 Weed Biomass

Weed biomass between treatments for the three seasons (Tables 3.6-3.8) differed significantly ($P \leq 0.05$) and the highest biomass was recorded from the control plots with 33.1 g/m^2 in the first experimental season (Table 3.6) which was reduced to 20.7 g/m^2 in the third season (Table 3.8). The treatment with the lowest weed biomass compared with all remaining treatments were plots with mucuna cover crop prior to sweet pepper transplanting, which had 14.6 g/m^2 after the first season reduced to 9.1 g/m^2 after the last season.

Results at Towero village indicate that plots treated with cover crops performed better compared with other treatments by reducing weeds population and biomass. In plots planted with cover crops prior to transplanting of sweet pepper seedlings total number of weeds was reduced from 50.2 to 8.5, while total weed dry weight decreased with time from 30.7 g/m^2 to 9.1 g/m^2. At this site the weeds number and dry weight between treatments were significantly different ($P \leq 0.05$).

Table 3.6: Weed counts, total biomass and sweet pepper yield in different weed management treatments in 2016 season

Treatment	SUA					Towero				
	Number of weeds m^2			Weed total dry weight (g/m^2)	Crop yield (t h^{-1})	Number of weeds m^2			Weed total dry weight (g/m^2)	Crop yield (t h^{-1})
	Grasses	Broadleaf	Total count			Grasses	Broadleaf	Total count		
Control	25.5b	24.9b	50.4bc	33.1d	2.9a	31.2a	17.5a	48.7a	30.7a	1.1a
Weeding	23.8b	19.3b	43.1bc	27.8c	3.8b	22.4a	13.1b	35.5b	28.2b	3.2b
Mixed grass	22.6b	11.1c	33.7b	22.2b	5.4c	18.6a	11.1c	29.7b	20.3b	4.7b
Greengram	13.4a	7.9a	21.3a	17.5a	6.9d	11.3b	7.9a	19.2b	14.4c	6.5bc
Mucuna	10.2a	5.4a	15.6a	14.6a	8.7e	8.2b	4.9a	13.1a	11.2c	8.3c
Mean	19.1	13.7	32.8	23.0	5.54	18.3	10.9	29.2	21.0	4.8
SE	0.37	0.49	0.51	0.44	0.24	0.36	0.56	0.63	0.37	0.44
CV (%)	15.48	21.64	18.12	17.0	14.5	11.31	26.48	13.06	15.31	16.7

NOTE: Figures followed with same letter(s) are not significantly different at P≤0.05 by Duncan's Multiple Range

Table 3.7: Weed counts, total biomass and sweet pepper yield in different weed management treatments in 2017 season

Treatment	SUA					Towero				
	Number of Weeds m^2			Weed total dry weight (g/m^2)	Crop yield (t h^{-1})	Number of weeds m^2			Weed total dry weight (g/m^2)	Crop yield (t h^{-1})
	Grasses	Broadleaf	Total count			Grasses	Broadleaf	Total count		
Control	27.4a	27.7a	55.1a	29.4a	2.2a	33.8a	15.8a	49.6a	28.5a	0.9e
Weeding	18.6b	16.4b	35.0b	21.4b	3.5b	18.3b	11.2ab	29.5b	26.2a	3.2d
Mixed grass	16.7b	8.3c	25.0b	19.0b	5.6c	15.3b	9.6b	24.9b	20.3c	4.9c
Greengram	9.2c	4.8c	14.0b	15.2b	7.2d	8.1c	6.9b	15.0c	15.1c	6.8b
Mucuna	7.4c	4.4c	11.8b	11.2c	9.1e	7.4c	5.2b	12.6c	10.6d	8.5a
Mean	15.9	12.3	28.2	19.2	5.5	16.6	9.7	26.3	20.1	4.9
SE	0.61	0.36	0.24	0.35	0.39	0.23	0.32	0.63	0.37	0.41
CV (%)	19.07	15.58	6.98	14.87	16.6	14.10	22.33	13.06	15.31	10.9

NOTE: Figures followed with same letter are not significantly different at P≤0.05 by Duncan's Multiple Range

Table 3.8: Weed counts, total biomass and sweet pepper yield in different weed management treatments in 2018 season

Treatment	SUA					Towero				
	Number of weeds m^2			Weed total dry weight (g/m^2)	Crop yield (t h^{-1})	Number of weeds m^2			Weed total dry weight (g/m^2)	Crop yield (t h^{-1})
	Grasses	Broadleaf	Total count			Grasses	Broadleaf	Total count		
Control	12.5b	26.0d	38.5c	20.7bc	3.0a	15.6b	31.0d	46.6c	22.1bc	0.8a
Weeding	12.1b	11.7c	23.8b	17.2bc	4.1a	13.9b	16.4c	30.3b	19.8bc	3.6b
Mixed grass	11.7b	8.1b	19.8b	18.6bc	6.7b	12.7b	9.2b	21.9b	18.5bc	5.4c
Greengram	11.4b	6.0b	17.4b	14.3b	7.8b	10.3b	6.1b	16.4b	14.4b	7.2cd
Mucuna	6.2a	1.9a	8.1a	9.1a	9.1c	8.4a	2.1a	10.5a	9.6a	8.9d
Mean	10.8	10.7	21.5	16.0	6.1	12.2	13.0	25.1	16.9	5.2
SE	0.36	0.32	0.38	0.25	0.33	0.18	0.35	0.29	0.22	0.21
CV (%)	11.18	15.01	19.06	13.28	16.4	19.07	13.77	11.23	8.98	8.6

NOTE: Figures followed with same letter(s) are not significantly different at P≤0.05 by Duncan's Multiple Range

3.4.5 Plant growth and development

At SUA experimental site, mucuna and greengram cover crops improved plant growth significantly ($P \leq 0.05$) compared to other treatments (Table 3.9 to 3.11). Plots planted with mucuna cover crop prior to sweet pepper transplanting increased plant vigour in terms of height of the sweet pepper plants in all season reaching up to a highest height of 61.6 cm in first season compared with 31.8 cm recorded from plants grown in the control plots (Table 3.9). The tallest plants grown in plots planted with greengram cover crop were recorded in the second season with a plant height of 57.1 cm (Table 3.10). Plants grown in plots treated with mucuna cover crop had more number of branches up to 24.4 (Table 3.9) compared to a maximum of 10.8 branches recorded in plants grown in control plots (Table 3.11). The highest number of leaves which was 160.1 was recorded in plants grown in plots treated with mucuna cover crops prior to sweet pepper significantly higher compared with that of plants grown in control plots which was 66.3 (Table 3.9). Plant biomass was highest in plots treated with mucuna in all seasons compared with other treatments with the highest biomass in the third season with a total of 97.1 g and the lowest plant biomass recorded from control plots plants with a total biomass of 26.4 g (Table 3.11).

At Towero, results plots planted with mucuna cover crop prior to sweet pepper transplanting increased plant height of the sweet pepper up to 60.8 cm while greengram cover crop increased sweet pepper height up to 60.8 cm compared to the control plots with sweet pepper plants of 28.6 cm in height. Furthermore, crops grown in plots planted with mucuna cover crop prior to sweet pepper transplanting had more average number of stem branches of 22 and leaves 157 compared with other treatments. Plots with cover crops were late to achieve 50% flowering, with plots planted with mucuna cover crop prior to sweet pepper transplanting flowering after 57 and 54 days at SUA and Towero respectively, late than all other treatments. Plots treated by greengram cover crops flowered 52 days after transplanting at SUA and 54 days at Towero. These were significantly late compared with unweeded plots which were earliest in flowering just 33 and 35 days after seedlings transplanting at both SUA and Towero sites respectively (Table 3.9 and 3.10).

Table 3.9: Effect of different weed management practices on sweet pepper growth in 2016 season

Treatment	SUA						Towero					
	Plant height (cm)	Number of		Dry weight (g)		50% Flowering (days)	Plant height (cm)	Number of		Dry weight (g)		50% Flowering (days)
		Leaves/plant	Branches/plant	Leaves	Stems			Leaves/plant	Branches/plant	Leaves	Stems	
Control	31.8a	66.3a	7.1c	17.9b	13.4a	38a	28.6a	57.6a	6.8a	15.1a	11.2a	41a
Weeding	42.4a	84.6a	11.7bc	22.7b	24.1b	36a	40.9a	90.9b	9.9ab	16.9a	20.3b	45a
Mixed grass	48.9ab	112.6b	13.8bc	31.8c	28.3b	48b	48.2b	117.6b	12.7b	24.8b	29.4c	51b
Greengram	54.7b	146.2c	16.3b	36.5c	39.9c	48b	55.4b	159.5c	15.8b	33.5c	33.5c	53bc
Mucuna	61.6b	160.1c	24.4a	43.6a	51.8d	51b	60.8c	167.4c	18.3b	34.7c	40.6d	57c
Mean	47.9	114.0	14.7	30.5	31.5	44.2	46.8	118.6	12.7	25	27	49.4
SE	0.61	1.62	0.36	0.24	0.27	0.33	0.42	0.98	1.28	0.56	0.35	2.4
CV (%)	8.3	11.0	14.3	16.1	12.8	18.1	6.1	9.7	8.4	14.8	6.9	4.7

NOTE: Means in a column followed by same letter(s) are not significantly different at P≤0.05 according to Duncan's New Multiple Range Test.

Table 3.10: Effect of different weed management practices on sweet pepper growth in 2017 season

Treatment	SUA						Towero					
	Plant height (cm)	Number of		Dry weight (g)		50% Flowering (days)	Plant height (cm)	Number of		Dry weight (g)		50% Flowering (days)
		Leaves/plant	Branches/plant	Leaves	Stems			Leaves/plant	Branches/plant	Leaves	Stems	
Control	35.1a	64.2c	9.7a	18.5a	13.7a	36a	27.1c	54.6d	10.1a	13.8a	9.5d	33c
Weeding	44.6b	96.3b	13.1b	24.8b	27.8b	39a	38.4b	84.3c	11.4a	15.6a	19.6c	44b
Mixed grass	46.4b	117.6b	13.4b	25.7b	27.6b	46b	41.5b	119.2b	12.7ab	24.2b	29.8b	50a
Greengram	57.1c	151.4a	18.4c	39.7c	43.8c	51c	48.3a	140.9a	15.7b	34.1c	34.1b	53a
Mucuna	57.7c	149.6a	21.2c	42.2c	39.7c	49bc	50.8a	142.1a	20.2c	37.4c	44.8a	54a
Mean	48.2	115.8	15.2	30.2	30.5	44.2	41.2	108.2	14.0	25.0	137.8	46.8
SE	0.38	2.46	0.56	0.43	0.32	0.31	0.94	1.93	1.03	0.59	0.48	0.97
CV (%)	17.6	10.5	12.3	18.6	15.9	19.1	13.1	8.9	16.1	10.1	18.3	10.9

NOTE: Means in a column followed by same letter(s) are not significantly different at P≤0.05 according to Duncan's New Multiple Range Test.

Table 3.11: Effect of different weed management practices on sweet pepper growth in 2018 season

Treatment	SUA						Towero					
	Plant height (cm)	Number of		Dry weight (g)		50% Flowering (days)	Plant height (cm)	Number of		Dry weight (g)		50% Flowering (days)
		Leaves/plant	Branches/plant	Leaves	Stems			Leaves/plant	Branches/plant	Leaves	Stems	
Control	33.6a	59.2a	10.8a	16.5a	9.9a	33a	24.2a	52.7a	8.7d	15.8a	11.2a	35a
Weeding	44.3b	78.4b	9.9a	21.6b	23.8b	41b	33.4b	71.1b	9.3c	16.2a	20.7b	43b
Mixed grass	48.6b	71.9b	11.4a	26.1b	21.6b	49c	39.9c	82.2b	11.7a	23.8ab	27.4b	48b
Greengram	53.9bc	142.4c	15.8b	36.2c	37.8c	52c	43.3cd	124.1c	12.3a	32.4b	35.9c	54bc
Mucuna	56.8c	156.8c	21.6c	44.7d	52.4d	54c	46.5d	136.9c	17.5b	41.9c	50.7d	57c
Mean	47.4	101.7	13.9	29.0	29.1	45.8	37.5	93.4	11.9	26.0	29.2	47.4
SE	0.45	2.31	0.37	1.93	0.35	0.21	1.42	0.72	0.16	0.51	6.5	0.4
CV $_{(\%)}$	14.6	13.2	13.3	11.6	10.4	17.9	6.3	12.0	8.1	4.2	6.1	12.7

NOTE: Means in a column followed by same letter(s) are not significantly different at $P \leq 0.05$ according to Duncan's New Multiple Range Test.

3.4.6 Fruit yields and physical qualities

Plots planted with mucuna cover crop prior to sweet pepper transplanting produced highest fruit yield compared with other treatments (Tables 3.12-3.14). Plots planted with mucuna gave the highest number of fruits with 25 and 20 fruits per plant at SUA and Towero, respectively, with a total fruit yield per hectare of 9.1 and 8.9 t ha^{-1}. Furthermore, plots planted with mucuna had physical fruits quality in terms of fruit diameter (7.2 and 5.9 cm) and length (9.9 and 9.8 cm) in both sites SUA and Towero. Generally, the two cover crops were significantly ($P \leq 0.05$) superior compared with the other treatments in all three seasons in terms of total fruit yield and physical qualities of the sweet pepper fruits.

Table 3.12: Effect of different weed management practices on physical and yield parameters of sweet pepper in 2016 season

Treatment	SUA					Towero				
	Fruit length (cm)	Fruit diameter (cm)	No. of fruits/plant	Fruits weight/plant (kg)	Yield (t ha^{-1})	Fruit length (cm)	Fruit diameter (cm)	No. of fruits/plant	Fruit weight/plant (kg)	Yield (t ha^{-1})
Control	6.7a	4.8a	8.6a	1.2a	2.9a	6.8a	4.2a	5.1a	0.9a	1.1a
Weeding	7.2ab	5.2a	12.9b	2.1b	3.8b	7.3b	4.6b	9.8b	1.8b	3.2b
Mixed grass	9.4b	5.8ab	16.7c	2.9c	5.4c	8.3c	5.3c	13.6bc	2.4b	4.7b
Greengram	8.8b	5.4a	20.7d	3.8d	6.9d	8.6c	5.7d	16.9c	3.1c	6.5bc
Mucuna	10.1b	6.1b	24.1e	4.2d	8.7e	9.3d	5.9d	20.4c	3.9d	8.3c
Mean	8.4	5.5	16.6	2.8	5.5	8.1	5.1	13.2	2.4	4.76
SE	0.57	0.71	0.33	0.21	0.24	0.21	0.1	0.38	0.27	0.44
CV $_{(\%)}$	10.1	9.1	11.4	19.6	14.5	6.8	8.9	12.2	11.8	16.7

NOTE: Means in a column followed by same letter(s) are not significantly different at P≤0.05 according to Duncan's New Multiple Range Test.

Table 3.13: Effect of different weed management practices on physical and yield parameters of sweet pepper in 2017 season

Treatment	SUA					Towero				
	Fruit length (cm)	Fruit diameter (cm)	No. of fruits/plant	Fruits weight/plant (kg)	Yield (t ha^{-1})	Fruit length (cm)	Fruit diameter (cm)	No. of fruits/plant	Fruit weight/plant (kg)	Yield (t ha^{-1})
Control	6.4d	4.1d	4.8d	0.5d	0.9e	6.1a	5.1a	8.1a	1.4a	2.2a
Weeding	7.5c	4.6c	10.0c	1.9c	3.2d	7.3a	5.4a	12.6a	2.6a	3.5b
Mixed grass	8.4b	5.3b	13.8c	2.6b	4.9c	9.7bc	5.5a	14.3a	2.3a	5.6c
Greengram	8.8b	5.8a	17.1b	3.4a	6.8b	8.9b	5.9ab	22.7b	4.3b	7.2d
Mucuna	9.5a	5.9a	22.1a	4.0a	8.5a	10.4c	6.4b	24.5b	4.5b	9.1e
Mucuna	8.1	5.1	13.6	2.5	4.9	8.5	5.7	16.4	3.0	5.5
SE	0.13	0.24	1.07	0.68	0.41	0.29	0.36	2.11	0.48	0.39
CV $_{(\%)}$	9.7	16.1	14.5	19.2	10.9	15.0	12.3	9.7	13.6	16.6

NOTE: Means in a column followed by same letter(s) are not significantly different at P≤0.05 according to Duncan's New Multiple Range Test.

Table 3.14: Effect of different weed management practices on physical and yield parameters of sweet pepper in 2018 season

Treatment	SUA					Towero				
	Fruit length (cm)	**Fruit diameter (cm)**	**No. of fruits/plant**	**Fruits weight/plant (kg)**	**Yield (t ha^{-1})**	**Fruit length (cm)**	**Fruit diameter (cm)**	**No. of fruits/plant**	**Fruit weight/plant (kg)**	**Yield (t ha^{-1})**
Control	6.7a	4.4a	7.1a	1.1a	3.0a	6.2a	3.9a	5.1a	0.6a	0.8a
Weeding	7.4a	4.5a	9.8a	2.3a	4.1a	7.6b	4.9b	10.1b	2.0b	3.6b
Mixed grass	8.9b	5.6b	15.9b	3.1ab	6.7b	8.7c	5.4c	14.2b	2.8c	5.4c
Greengram	9.2b	5.9b	20.1c	4.3b	7.8b	9.0c	5.8c	18.4bc	3.7d	7.2cd
Mucuna	9.9b	7.2c	25.4d	4.8b	9.1c	9.8d	5.9c	19.5c	4.1d	8.9d
Mean	8.4	5.5	15.7	3.1	6.1	8.3	5.2	13.5	2.6	5.2
SE	0.28	0.34	0.41	1.14	0.33	0.17	0.16	0.11	0.6	0.21
CV $_{(\%)}$	11.3	15.6	9.9	13.4	16.4	7.3	8.9	4.0	8.9	8.6

NOTE: Means in a column followed by same letter are not significantly different at $P \leq 0.05$ according to Duncan’s New Multiple Range Test.

3.4.7 Mineral contents of sweet pepper vegetative parts and fruits

The mineral composition of sweet pepper leaves and stems is presented in Tables 3.12 and 3.13 for both sites. The two cover crops consistently increased total N content per plant in plant stem and leaves. The highest total N and P contents per plant were observed in plots treated with mucuna (2.81 and 1.64%) and greengram (2.48 and 1.09%) cover crops compared to remaining treatments. Large differences in the chemical composition of the plant stem were observed between mucuna and control plots. Potassium content accumulated up to 5.6% in plots planted with mucuna cover crop prior to sweet pepper transplanting, which was higher than in other treatments. However, in most cases there were no significant differences in N, P and K content obtained in plant parts of the sweet pepper grown under mucuna, greengram and mixed grass mulch.

Table 3.15: Effect of different weed management practices on mineral contents of sweet pepper leaves and stems

Treatment	2016 season (%)						2018 season (%)					
	SUA			Towero			SUA			Towero		
	N	P	K	N	P	K	N	P	K	N	P	K
Control	1.33a	0.62a	2.2a	1.01a	0.57a	1.9a	1.01a	0.44a	1.7a	1.06a	0.41a	1.1a
Weeding	1.75b	0.65a	3.9b	1.67b	0.66ab	3.5b	1.86b	0.71b	3.8b	1.61b	0.53ab	3.6b
Mixed grass	1.90c	0.81b	4.0b	1.93bc	0.84ab	4.1b	1.98b	0.86b	4.4b	1.89b	0.67b	4.7bc
Greengram	2.29c	0.83b	4.6bc	2.33c	0.91b	4.8bc	2.44c	0.94b	5.1bc	2.48c	0.96c	4.8bc
Mucuna	2.37d	1.11c	5.3c	2.41c	1.23c	5.1c	2.61c	1.31c	5.6c	2.81c	1.28d	5.4c
Mean	1.93	0.80	4.00	1.87	0.84	3.88	1.98	0.85	4.12	1.97	0.77	3.92
SE	0.33	0.32	0.23	0.22	0.39	0.38	0.11	0.27	0.24	0.18	0.21	0.54
CV (%)	7.0	6.7	8.3	9.3	5.6	8.9	10.2	8.6	6.4	16.1	11.2	13.6

NOTE: Means in a column followed by same letters are not significantly different at $P \leq 0.05$ according to Duncan's New Multiple Range Test.

Sweet pepper fruits produced by plots with cover crops generally significantly higher concentration of Mn, Zn, Cu, Fe and Mg in both sites SUA and Towero (Tables 3.12 and 3.13). The highest total Mn content in sweet pepper fruits was 81.0 mg g^{-1} recorded at Towero from sweet pepper plants grown in plots planted with greengram cover crop prior to sweet pepper transplanting. Other highest mineral content was observed in sweet pepper fruit produced from plots planted with mucuna were its fruits contained 95.3 mg g^{-1} of Zn at Towero, 0.61 mg g^{-1} of Cu at both SUA and Towero, and 483.0 mg g^{-1} of Fe at SUA.

Furthermore, the highest amount of total Mg was obtained in plots planted with greengram cover crop, fruits from these plots observed to contain up to 570.2 mg g^{-1} of total Mg significantly ($P \leq 0.05$) higher compared with all remaining treatment. However, the increase in Ca and Mg in sweet pepper fruits was not significantly ($P \leq 0.05$) different in between plots planted with mucuna and greengram cover crops prior to sweet pepper transplanting but was significantly improved compared with the remaining treatments. These results concurs with the study done by Pant *et al.* (2009) who observed significantly increase in chemical nutrients in plant vegetative parts through the application of vermicompost extract.

Table 3.16: Effect of different weed management practices on mineral contents of sweet pepper fruits in 2016 season

Treatment	SUA (mg g^{-1})					Towero (mg g^{-1})				
	Mn	Zn	Cu	Mg	Fe	Mn	Zn	Cu	Mg	Fe
Control	19.1a	52.6a	0.34a	232.3a	170.4a	20.7a	44.5a	0.26a	210.9a	174.4a
Weeding	40.4b	62.2ab	0.40ab	241.2a	182.9a	39.9b	58.6ab	0.37b	242.6ab	191.9a
Mixed grass	42.1b	68.8b	0.58b	252.7ab	259.8b	48.3b	71.4b	0.49c	274.1b	280.3b
Greengram	77.6d	75.8b	0.57b	570.2c	392.4c	81.0c	83.9bc	0.59d	556.4d	411.6c
Mucuna	65.6c	90.2c	0.59b	341.8b	469.7d	72.6c	95.3c	0.61d	461.2c	480.0d
Mean	48.9	69.9	0.5	327.6	295.0	52.5	70.7	0.5	349.0	307.64
SE	5.27	6.24	0.25	10.44	11.28	0.19	9.18	0.21	10.20	13.41
$CV_{(\%)}$	5.1	4.8	10.1	3.6	7.5	3.1	6.6	2.2	8.3	9.6

NOTE: Means in a column followed by same letter(s) are not significantly different at $P \leq 0.05$ according to Duncan's New Multiple Range Test.

Table 3.17: Effect of different weed management practices on mineral contents of sweet pepper fruits in 2018 season

Treatment	SUA (mg g^{-1})					Towero (mg g^{-1})				
	Mn	Zn	Cu	Mg	Fe	Mn	Zn	Cu	Mg	Fe
Control	20.7a	44.5a	0.26a	210.9a	174.4a	19.9a	43.1a	0.28a	199.9a	173.2a
Weeding	39.9b	58.6ab	0.37b	242.6ab	191.9a	42.3b	51.4ab	0.34b	247.3ab	194.6a
Mixed grass	48.3b	71.4b	0.49c	274.1b	280.3b	44.6b	69.9b	0.51c	271.1b	281.0b
Greengram	81.0c	83.9bc	0.59d	556.4d	411.6c	81.0c	78.7bc	0.59d	496.3d	401.6c
Mucuna	72.6c	95.3c	0.61d	461.2c	483.0d	72.6c	91.2c	0.60d	468.9c	480.0d
Mean	52.5	70.7	0.5	349.0	308.2	52.1	66.9	0.5	336.7	306.1
SE	8.19	4.18	0.21	6.20	3.41	2.19	11.18	0.23	30.20	13.41
$CV_{(\%)}$	3.1	6.6	2.2	8.3	9.6	3.1	6.6	2.2	8.3	9.6

NOTE: Means in a column followed by same letter(s) are not significantly different at $P \leq 0.05$ according to Duncan's New Multiple Range Test.

3.5 Discussion

3.5.1 Weed population

Weed reduction, particularly weed seed bank, diversity and density in both sites was associated with greater ability of cover crops to effectively supress weeds by hindering them from penetrating the introduced cover. The significant decrease in weed seed bank could be explained by the effectiveness of cover crops and mulch on weeds control (Moonen and Barberi, 2004). Kruidhof *et al.* (2008) explained the ability of cover crops on hindering the growth of different weeds seedlings immediately after their germination. In both sites (SUA and Towero), the cover crops managed to control weeds by reducing weed species by 29% from the original 17 species to 12 as shown in Table 3.1. This is due to the ability of cover crop in denying growing weeds optimal level of light which is a crucial requirement for them to grow.

Cover crop can affect weed establishment through its effects on the radiation and chemical environment of the weed and inhibit weed emergence by physically impeding the progress of seedlings from accessing light (Teadale and Mohler, 2000; Langeroodi *et al.*, 2018) as well as by releasing phytotoxins that inhibit seedling growth (Lou *et al.*, 2016). By doing so few weed species, which are weak competitors, eventually are eradicated. Foliage cover crops like mucuna and greengram, due to their fast establishment and growth capacity in field, are more efficient and suitable in weed control compared to mechanical weeding and mixed grass mulch.

Furthermore, as a cover crop covers the soil it helps to retain soil moisture which stimulate weed seeds to germinate. However, the germinating weed seeds fail to emerge due to lack of other factors like optimal temperature, oxygen and light, which are obstructed by the cover crop. This has led to the reduction of weed seed bank by 30.2% to 47.5% by mucuna cover crop in the two sites SUA and Towero, in all the four seasons of mucuna cover crops application as shown in Fig 3.1 and 3.2. Mickelson and Grey (2006) observed increasing mortality rate of *Avena fatua* (L.) seeds as soil moisture content increased from 6 to 24% with maximum mortality values reaching 55 and 88% after two years.

In contrast to the cover crop, hand hoe weeding and mixed grass mulch which are the common weed management practices used by organic farmers was poor in weed control in all four seasons because it covered the soil for a time not enough to fully manage weeds below economic loss compared with the cover crops. Hand hoe weeding reduced weed seed bank by 12.6% to 13.9% only for a while mixed grass mulch managed to reduce weed seed bank by 23.8% to 40.6% as shown in Table 3.4 and 3.5. The ability of cover crops to cover the soil for long time during their growth as cover crops and then when slashed to be used as dead mulch denied weeds opportunity to grow for not less than four months. Correspondingly, two to three hand hoe weeding, could not attain significant weed control as most of the weeds managed to re-occupy the plots a few days just after first weeding and before another weeding been done. This was partly caused by soil disturbance through weeding which provided an opportunity for new weeds to emerge by creating conducive environment after soil disturbance.

Hunková *et al.* (2014) observed that weed infestation decreases when the reduction of seeds exceeds their entry into the soil and consequently deplete weed seed bank. The increase of up to 5.6% in weed seed bank in control plots in which weeds were allowed to grow undisturbed throughout the season, was due to the ability of some of the weeds to reach reproductive phase and produce weed seeds which were added and stored in the soil seed bank. Controlling weeds using hand hoe by weeding twice or three times did not have good impact compared with cover crops as it did not deny some of the weed species like *Cyperus spp* to reproduce. Two to three weeding frequencies could not keep away completely some of the weeds throughout the production period. Weeds like *Cyperus spp*. complete their life cycle in a short time mostly before second weeding is applied, hence they are able to mature and produce weed seeds which are taken back to soil before second weeding.

Furthermore, depending on weather and environmental condition, occasionally two or three hand hoe weeding a common practice done by organic farmers fall short on controlling weeds to the extent of avoiding crop economic losses. Most tropical grown crops sometimes they need more than three weeding in order to control weeds until they are harvested. Therefore, in hand hoe weeding, weed seed bank of just few weeds with long life cycle can be reduced as can be controlled before they can produce new seeds. Hunková *et al.* (2014) explained that the reduction of weed infestation is caused by a number of factors, including, the decrease of dropping weed seeds on the field, weed suppression and control, increase of soil’s self-cleaning ability and controlling the use of materials like organic fertilisers, mulch and crop seeds for sowing that can transport weed seeds.

In this experiment results indicates that for organic sweet pepper farmers who manage weeds by using hand hoe they should have at least three or more weedings in order to avoid economical loss which can be associated with weeds. this is due to the fact that disturbing the soil by hand hoe weeding stimulates new weeds germination as it provides conducive environment for them to germinate. For the crops grown with mixed grass mulch or greengram cover crops, supplementary hand weeding is important for removing few weeds which manage to penetrate the mulch.

3.5.2 Weed biomass

Weed biomass generally was reduced progressively over years when cover crops were applied in sweet pepper production. In the third season weed biomass reduction was prominent reaching a significantly reduction of 9.1 g/m^2 in both plots planted with mucuna and greengram cover crops compared with that of unweeded plots which ranged from 20.7 to 33.1 g/m^2 as shown in Table 3.9. Hoe weeded and mixed grass treatment at both SUA and Towero had higher weed biomass compared with plots treated with cover crops as weeding and mixed grass mulch treatments allowed more weeds to germinate and stay in the field for about two weeks before the next weeding has been applied. As weeds have more competing ability than crops, staying in the plots for this time enabled them to accumulate more biomass compared with the weeds in plots planted with cover crops which delayed to emerge and were few in numbers. This observation is in agreement with Little and Schumann (1996) who observed weed biomass accumulation to be directly proportional to the time in which weeds remains into the field.

In comparison between fields planted with the mucuna and greengram cover crops, fields treated with greengram cover crop prior to sweet pepper transplanting had more weed biomass compared with those treated with mucuna. The effect of weed biomass increase was reflected in sweet pepper fruit production. As weed biomass increased for each specific treatment, sweet pepper yield was reduced proportionally. This is due to the fact that, the biomass accumulated by weeds was by the expense of the intended sweet pepper crop as reflected in sweet pepper lower yield it was observed in Table 3.12 to 3.14.

The more weed biomass in plots planted with greengram was due to the fact that greengram decomposed fast for about a week earlier compared with mucuna after being slashed (Saria *et al.*, 2018). The fast decomposition of greengram allowed weeds to re-germinate, grow and reoccupy the field. In addition to that germinated weeds benefited from the nutrients provided by the decomposed greengram cover crop. The decomposed greengram cover crop acted as green manure providing nutrients to the weeds within the plot, the weeds took advantage of the nutrients and benefited more than crops and grow vigorously on the expense of crops due to its highly competing advantage over most sole crops in the field (Corre-Hellou *et al.*, 2011). As a results of this effect, plots treated with greengram prior to sweet pepper planting had high weed biomass compared with plots treated with mucuna which decomposed slowly compared to greengram.

The effect of cover crop on weeds biomass was more prominent in the third season compared to the first and second season. This is due to the ability of cover crops to reduce the weeds in terms of population and species over time. Furthermore, low weed biomass may be attributed to better resource use by the cover crop introduced and then the sweet pepper main crop planted, which could have resulted in fewer resources for weed growth resulting to the lowest biomass in the third season. Land cultivation before application of cover crop also contributed to the reduction of weed biomass, this is due to the fact that cultivation stimulated weed emergence which later are denied light for photosynthesis and other growing factors. Repetition of this practice for several seasons led to a significant reduction of weed biomass in the third season.

3.5.3 Weed diversity index

Cover crops managed to reduce weed diversity in all soil layers. Mucuna reduced Shannon diversity index by 16.4% in the top soil at SUA and 38.6% at Towero, while the index was reduced by 46.8% at SUA and by 25.2% at Towero in the deeper layer as indicated in Table 3.2 and 3.3. Diversity index shows that the middle layer of the soil is richer in different species of weed seeds. This is due to the fact that some of the weed seeds species deposited on upper soil germinates and others die before reproducing newly fresh seeds making the upper soil to be dominated by few species of weed seeds and eventually reduce their diversity. While some of the seed species are reduced on in the upper soil layer, several species are deposited below this layer which has the ability to remain viable for long time and therefore increasing their diversity in the deeper soil. Hunková *et al.* (2014) also observed more weed seeds being deposited in the lower layer of soil (21-30 cm) which eventually increased weed seed bank diversity in comparison to the top soil (0-10 cm) where less amount was deposited as most of it germinate immediately after receiving conducive environment decreasing weed seed diversity.

Weeding and mixed grass mulch which are the common practices done by organic farmers did not reduce weed diversity significantly especially in the upper soil. Weeding at SUA increased weed diversity at the upper soil layer by 11.6% at SUA and 16.7% at Towero. This is due to the fact that hand hoe weeding can bring up dormant weed seeds which are deposited in the lower soil and subject them in the condusive environments for germination. The new weeds from lower soil layers then grows and reproduce new seeds which eventually are deposited on upper soil layer. Furthermore, new weeds which are brought with other means like wind or other mechanical means will be allowed to germinate in this plots before the next weeding and some of the will reproduce before next weeding adding new weed seeds to the upper soil increasing weed seed diversity. The effect of mixed grass mulch to weed seed diversity was not significant, however grass mulch managed to reduce weed diversity of the soil upper layer by 15% at SUA and 41% at Towero. This is due to the fact that, mixed grass mulch did not cover the soil long enough compared with cover crops, this gives an opportunity to weeds to re-invade the open land when mulch is not applied on it increasing the ability of weeds to germinate, grow and reproduce new seeds which are deposited on the upper soil and hence increase its diversity.

It is important to note that, the more the weed seed diversity in the upper layer means that the more different species of weeds will emerge and grow in that soil leading in to more difficulties in managing them. However, despite the frequent addition of weed seeds in the upper soil layer, most of the weed seeds which are deposited at the upper part of the soil usually germinate and some die before completing their life cycle. From this study it was observed that, the cover crops have the ability of affecting relative abundance of the weeds more than species composition which concurs with the study done by Shrestha *et al.* (2002).

3.5.4 Cover crop effectiveness

The ability of cover crops to control weed pests is associated with the amount of biomass it produced in the field, the more biomass the specific cover crop is able to produce the more the ability of it to control weeds. This was also observed by Liebman and Davis (2000) and Mirsky *et al.* (2012) who found that the ability of cover crops to effectively control weeds is directly proportional to the amount of biomass it can produce when is grown in the field. Furthermore, the greater weed suppressing effect of *Mucuna* *pruriens* above other treatments is considered to be a result of its longer life span compared with other treatments. This concurs to the study done by Anthofer and Kroschel (2007) who observed that late maturing *Mucuna pruriens* (L.) DC var. *utilis* (Wright) Burck reduced weed dry matter by 58% to 68% compared to other early maturing varieties.

The positive effect of weeds reduction by mucuna which is a high biomass producing cover crop, is explained by low number of weed species up nine both at SUA and Towero compared with twenty which was the lowest in mixed grass much at Towero, 24 in weeding at both sites, and nine in greengram recorded at SUA, and the reduction of weeds diversity which pulled down the average weed seed bank within the fields planted with mucuna cover crops by 38.6% below significantly ($P \leq 0.05$) lower than other treatments. This is due to the facts that, land cultivation which is done before cover crops planting stimulates emergence of weed seeds. The weed seedlings which emerge and start to grow fail to compete with cover crops especially for light. Eventually the growing weeds die before maturity and fail to produce seeds which consequently reduce the amount of weed seed bank in the soil. This concurs with the study done by Mirsky *et al.* (2010), who observed that cover crops managed to reduce the amount of weed seed bank significantly when applied in maize crop fields.

3.5.5 Plant growth and development

Overall, cover crops improved most of the plant growth and development parameters. Greengram and mucuna cover crops consistently enhanced sweet pepper plant growth when used to control weeds prior to sweet pepper planting due to their ability to reduce weeds competition, improve soil condition for plant growth and improve soil fertility

(Saria *et al.,* 2018). Due to their ability of providing protection from weed pests and improve soil fertility, mucuna and greengram increased significantly the number of sweet pepper branches and leaves compared to the common weeding strategy used by organic farmers. This observation is in accordance with the findings of previous studies by Ortiz-ceballos *et al.* (2007) and Wittwer *et al.* (2017) who observed a significant yield increase in maize when mucuna cover crops was used as green manure. However, between all treatments, crops grown in mucuna plots had higher above-ground total dry weights (97.1 g/m^2) compared with crops grown in all other treatments. This was an increase of about 38 to 46% compared with the two common weed management practices of weeding and mixed grass mulch which are applied by most organic farmers.

The higher number of sweet pepper branches, leaves and plant biomass in plots treated with mucuna cover crop is due to the ability of mucuna to produce more biomass which in turn improved crop growth conditions like moisture and also produce nutrients in the soil when they decompose compared with other treatments (Saria *et al.,* 2018). The increase in sweet pepper branches, leaves and biomass is reflected in fruit yield as it increases the ability of sweet pepper plant to set more fruits and feed them. The improvement of plant growth and development parameters has been attributed by the ability of the two cover crops to provide organic N to the crop when they decompose after being used as dead mulch which can be assimilated easily by plants. Piotrowska and Wilczewski (2012) explained the positive effects of green manures to soil fertility by supplying organic N which can benefit the crops grown in the same field. Furthermore, the two cover crops had the ability to reduce the amount of weeds increasing the competitive advantage of sweet pepper crops by outcompeting weeds for light, nutrients and water and make them less destructive to crops at crucial sweet pepper growth stages as observed by Cherr *et al.*

(2006). The strong correlation between plant biomass and nutrients uptake by plants explains the increased in yield reaction to crops grown in plots treated with the two cover crops prior to transplanting compared to plots treated with other treatments.

However, despite the improved sweet pepper growth in plots treated by the cover crops, sweet pepper from control plots and weeding were the ones which flowered earlier compared with other treatments including the cover crop treatments. Sweet pepper from unweeded plots flowered 19 to 22 days earlier than the two cover crops plots, while weeded plots flowered up to 21 and mixed mulch up to 11 days earlier. This may be caused by the competition between weeds and sweet pepper and temperature variation between treatments, leading to control plots which are not covered by mulch to have more temperature and weeds which increase resources competition to sweet pepper plants causing early flowering. Khah and Passam (1992) explained the influence of temperature increase in sweet pepper crops on maturity earliness, while Marcelis *et al.* (2004) indicated that limitation on plant resources will trigger early sweet pepper flowering but eventually will lead to high flower and fruits abortion.

3.5.6 Sweet pepper fruit yields and size

Improved sweet pepper fruit yields and size observed in plots treated with mucuna with an increase of up to 7.2 cm in diameter and 9.9 cm in length yielding up to 9.1 tha^{-1}. The best treatment among the two commonly used weed management strategy by farmers was mixed grass mulch producing fruits of up to 9.7 cm in length and 5.8 in diameter yielding a maximum of 6.7 tha^{-1}. Significant increase in sweet pepper yields and size in plots treated with cover crops have been resulting from better plant growth and development caused by the ability of the two cover crops to improve growth conditions like moisture and temperature, suppressing weeds and improves soil fertility when they were applied as live and then dead mulch. Tejada *et al.* (2008) and Agegnehu *et al.* (2016) observed significant yield increase in maize crops when different types of green manures were applied for soil fertility. Cover crops like mucuna and greengram has the capability to improve soil fertility by improving soil N, P, K and organic matter which are essential for plant growth, development and productivity (Fageria *et al.*, 2005; Mwango *et al.*, 2016).

Furthermore, the two leguminous cover crops may have increased the population of N_2-fixing rhizosphere bacteria and their activity in the soil improving plant available N in the soil for the benefit of the intended crop. Choudhury and Kennedy (2004) observed the ability of the cover crops to enhance the activity of N_2-fixing bacteria in the soil when applied as manure. In addition, the biomass added in the soil by the cover crops may have increased soil organic matter significantly leading to the improvement of soil physical characteristics for the benefit of the crop (Tejada *at al.*, 2008). This explains the positive association between improved fruit yields and size of sweet pepper grown in plots were the cover crops were grown before sweet pepper transplanting and then used as dead mulch at transplanting. Also Copetta *et al.* (2011) reported an improvent in fruit quality in terms of size and chemical contents in solanaceous crops treated by cover crops. This is due to the improvement of soil fertility through the ability of cover crops to supply different soil nutrients.

3.5.7 Sweet pepper mineral contents

Cover crops consistently improved plant growth, nutrients concentration and fruit size of sweet pepper plants in all seasons. This was in accordance with the findings of other study done by Astier *et al.* (2006). Nutrient analysis indicated that sweet pepper plants grown under cover crops had significantly higher amount of soluble mineral contents compared with plants grown under other treatments. This can be explained by the ability of the cover crops to provide different nutrients for plant growth and development in different stages when used as dead mulch during plant growth. Furthermore this can be attributed to the ability of cover crops to influence nutrients up take by plants by improving roots absorption ability through increasing soil nutrients on top soil as it was observed by Thorup-Kristensen, (2006). Pant *et al.* (2009) explained the association between the amount of mineral nutrients supplied by a specific fertiliser and its reflection in plants mineral nutrients content. Consequently, a longer and steady release of mineral nutrients to the soil by the cover crops leads to constant nutrients uptake by the plant throughout its growth and development stage (Cobo *et al.,* 2002).

The high amount of different nutrients obtained in the sweet pepper grown in the two cover crops may be explained by the ability of the cover crops to improve soil fertility and provide available nutrients to the sweet pepper crop. Ghoname and Shafeek (2005) associated sweet pepper nutrients increase with the role of bio-fertilisers like green manures to increase micro-organisms population and activities in the soil. Such micro-organisms convert the organic form of nutrients to mineral forms which are readily available to the plants, and increase its availability and uptake by plants enhancing chemical properties and mineral contents of the sweet pepper. Furthermore, cover crop has the capacity to significantly reduced pH to levels that favours plants nutrients uptake by increasing nutrient availability at the root surface leading to increased plant nutrients contents (Tejada *et al.,* 2008).

However, with reference to recommended dietary allowances and adequate intakes provided in Dietary Reference Intakes (DRIs) by Food and Nutrition Board of the Institute of Medicine, National Academies (Appendix 4), the amount of all five element obtained in sweet pepper fruits grown in all weed management strategies were sufficient to supply enough required elements per meal for a human being of different ages and gender except for Cu. In all treatments Cu observed to be low below the recommended intake per meal, therefore it is not possible to rely on sweet pepper produced by these strategies as a sole source of Cu for any age or gender.

3.6 Conclusion

Among the strategies applied, cover crops were the most effective weed management strategy for sweet pepper production. The following conclusions were drawn from this study;

i. Mucuna and greengram cover crops managed to control most of the weeds and reduce significantly their seed bank. Mucuna and greengram cover crop provided a relatively strong and consistent inhibition of emergence of different types of weeds.
ii. The effect of weeding which is a common practice by farmers was significantly less effective on weed management and soil fertility management compared with cover crops and mixed grass mulch strategies.
iii. Cover crops increased sweet pepper yields and improved their yield parameters like plant height and number of leaves per plant.
iv. Mucuna and greengram increased sweet pepper mineral content and fruit size in terms of length and width.

REFERENCES

Agegnehu, G., Bass, A. M., Nelson, P. N. and Bird, M. I. (2016). Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment* 543: 295-306.

Agegnehu, G., Bass, A. M., Nelson, P. N., Muirhead, B., Wright, G. and Bird, M. I. (2015). Biochar and biochar-compost as soil amendments: effects on peanut yield, soil properties and greenhouse gas emissions in tropical North Queensland, Australia. *Agriculture, Ecosystems and Environment* 213: 72-85.

Altieri, M. A. and Nicholls, C. I. (2003). Soil fertility management and insect pests: harmonizing soil and plant health in agroecosystems. *Soil and Tillage Research* 72(2): 203-211.

Anthofer, J. and Kroschel, J. (2007). Effect of Mucuna fallow on weed dry matter and composition in succeeding maize. *Biological Agriculture and Horticulture* 24(4): 397-414.

Astier, M., Maass, J. M., Etchevers-Barra, J. D., Pena, J. J. and de León González, F. (2006). Short-term green manure and tillage management effects on maize yield and soil quality in an Andisol. *Soil and Tillage Research* 88(1-2): 153-159.

Bhardwaj, D., Ansari, M. W., Sahoo, R. K. and Tuteja, N. (2014). Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories* 13(1): 66.

Cheema, Z. A. and Khaliq, A. (2000). Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi-arid region of Punjab. *Agriculture, Ecosystems and Environment* 79(2-3): 105-112.

Cheng, K. L. and Bray, R. H. (1951). Determination of calcium and magnesium in soil and plant material. *Soil Science* 72(6): 449-458.

Cherr, C. M., Scholberg, J. M. S. and McSorley, R. (2006). Green manure approaches to crop production. *Agronomy Journal* 98(2): 302-319.

Choudhury, A. T. M. A. and Kennedy, I. R. (2004). Prospects and potentials for systems of biological nitrogen fixation in sustainable rice production. *Biology and Fertility of Soils* 39(4): 219–27.

Chukwuka, K. S. and Omotayo, O. E. (2008). Effects of tithonia green manure and water hyacinth compost application on nutrient depleted soil in South-Western Nigeria. *International Journal of Soil Science* 3(2): 69–74.

Chung, N. J. and Paek, N. C. (2003). Photoblastism and ecophysiology of seed germination in weedy rice. *Agronomy Journal* 95(1): 184-190.

Cloutier, D. C., Van der Weide, R. Y., Peruzzi, A. and Leblanc, M. L. (2007). Mechanical weed management. *Non-Chemical Weed Management. Oxfordshire, UK: CAB International*: 111-134.

Cobo, J. G., Barrios, E., Kass, D. C. L., and Thomas, R. J. (2002). Decomposition and nutrient release by green manures in a tropical hillside agroecosystem. *Plant and Soil* 240(2): 331-342.

Colla, G., Mitchell, J. P., Poudel, D. D. and Temple, S. R. (2002). Changes of tomato yield and fruit elemental composition in conventional, low input, and organic systems. *Journal of Sustainable Agriculture* 20: 53-67.

Copetta, A., Bardi, L., Bertolone, E. and Berta, G. (2011). Fruit production and quality of tomato plants (*Solanum Lycopersicum* L.) are affected by green compost and arbuscular mycorrhizal fungi. *Plant Biosystems* 145(1): 106–15.

Cordell, D., Jan O. D. and Stuart, W. (2009). The story of phosphorus: global food security and food for thought. *Global Environmental Change* 19(2): 292–305.

Corre-Hellou, G., Dibet, A., Hauggaard-Nielsen, H., Crozat, Y., Gooding, M., Ambus, P., Dahlmann, C., von Fragstein, P., Pristeri, A., Monti, M. and Jensen, E. S. (2011). The competitive ability of pea–barley intercrops against weeds and the interactions with crop productivity and soil N availability. *Field Crops Research* 122(3): 264-272.

Demjanová, E., Macák, M., Dalovic, I., Majernik, F., Tyr, S. and Smatana, S. (2009). Effects of tillage systems and crop rotation on weed density, weed species composition and weed biomass in maize. *Agronomy Research* 7(2): 785-792.

Dorward, A. and Ephraim C. (2011). The Malawi agricultural input subsidy programme: 2005/06 to 2008/09. *International Journal of Agricultural Sustainability* 9(1): 232–47.

Fageria, N. K., Baligar, V. C. and Bailey, B. A. (2005). Communications in soil science and plant analysis role of cover crops in improving soil and row crop productivity role of cover crops in improving soil. *Communications in Soil Science and Plant Analysis* 36(19-20): 2733–57.

Garratt, M. P., Bommarco, R., Kleijn, D., Martin, E., Mortimer, S. R., Redlich, S., Senapathi, D., Steffan-Dewenter, I., Świtek, S., Takács, V. and van Gils, S. (2018). Enhancing soil organic matter as a route to the ecological intensification of European arable systems. *Ecosystems*: 1-12.

Ghoname, A. and Shafeek, M. R. (2005). Growth and productivity of sweet pepper (*Capsicum annum* L.) Grown in plastic house as affected by organic, mineral and bio-N-fertilisers. *Journal of Agronomy* 4(4): 369–72.

Gibson, D. J., Young, B. G., Owen, M. D., Gage, K. L., Matthews, J. L., Jordan, D. L., Shaw, D. R., Weller, S. C. and Wilson, R. G. (2016). Benchmark study on glyphosate-resistant cropping systems in the United States. Part 7: Effects of weed management strategy (grower practices versus academic recommendations) on the weed soil seedbank over 6 years. *Pest Management Science* 72(4): 692-700.

Hiltbrunner, J., Liedgens, M., Bloch, L., Stamp, P. and Streit, B. (2007). Legume cover crops as living mulches for winter wheat: components of biomass and the control of weeds. *European Journal of Agronomy* 26(1): 21-29.

Horneck, D. A. and Miller, R. O. (1998). Determination of total nitrogen in plant tissue. In: *Handbook of reference methods for plant analysis*. (Edited by Kalra, Y): CRC Press, Boca Raton, Florida, USA. 75–83 pp.

Hunková, E., Winkler, J. and Demjanová, E. (2014). The weed seed bank assessment in two soil depths under various mineral fertilising. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* 59(5): 105-112.

International Plant Genetic Resources Institute (IPGRI) (1995). Descriptors for *Capsicum*: 33-35

Khah, E. M., and Passam, H. C. (1992). Flowering, fruit set and development of the fruit and seed of sweet pepper (*Capsicum annuum* L.) cultivated under conditions of high ambient temperature. *Journal of Horticultural Science* 67(2): 251-258.

Kimetu, J. M. and Lehmann, J. (2010). Stability and stabilisation of biochar and green manure in soil with different organic carbon contents. *Australian Journal of Soil Research* 48: 577–85.

Konstantinović, B., Meseldžija, M., Korać, M. and Mandić, N. (2011). Horizontal and vertical seed distribution under different field crops. *Herbologia* 12(1): 165-171.

Kovar, J. L. and Pierzynski, G. M. (2009). Methods of phosphorus analysis for soils, sediments, residuals, and waters second edition. *Southern Cooperative Series Bulletin* 408.

Kruidhof, H. M., Bastiaans, L. and Kropff, M. J. (2008). Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. *Weed Research* 48(6): 492-502.

Kunz, C., Sturm, D. J., Varnholt, D., Walker, F. and Gerhards, R. (2016). Allelopathic effects and weed suppressive ability of cover crops. *Plant and Soil Environment* 62(2): 60-66.

Kurstjens, D. A. (2007). Precise tillage systems for enhanced non-chemical weed management. *Soil and Tillage Research* 97(2): 293-305.

Langeroodi, A. S., Radicetti, E. and Campiglia, E. (2018). How cover crop residue management and herbicide rate affect weed management and yield of tomato (*Solanum lycopersicon* L.) crop. *Renewable Agriculture and Food Systems*: 1-9.

Liebman, M. A. T. T. (2001). Weed management: a need for ecological. *Ecological Management of Agricultural Weeds* 1.

Liebman, M. and Davis, A. S. (2000). Integration of soil, crop and weed management in low-external-input farming systems. *Weed Research-Oxford* 40(1): 27-48.

Little, K. M. and Schumann, A. W. (1996). A new systematic trial design for the optimization of interspecific weed control. In *Proceedings of the 11th Australian Weeds Conference, Melbourne, Australia, 30 September-3 October 1996*. Weed Science Society of Victoria Inc..

Lou, Y., Davis, A. S. and Yannarell, A. C. (2016). Interactions between allelochemicals and the microbial community affect weed suppression following cover crop residue incorporation into soil. *Plant and Soil* 399(1-2): 357-371.

Marcelis, L. F. M., Heuvelink, E., Baan Hofman-Eijer, L. R., Den Bakker, J. and Xue, L. B. (2004). Flower and fruit abortion in sweet pepper in relation to source and sink strength. *Journal of Experimental Botany* 55(406): 2261-2268.

McGrath, S. P. and Cunliffe, C. H. (1985). A simplified method for the extraction of the metals Fe, Zn, Cu, Ni, Cd, Pb, Cr, Co and Mn from soils and sewage sludges. *Journal of the Science of Food and Agriculture* 36(9): 794-798.

Mickelson, J. A. and Grey, W. E. (2006). Effect of soil water content on wild oat (*Avena fatua*) seed mortality and seedling emergence. *Weed Science* 54(2): 255-262.

Mirsky, S. B., Ryan, M. R., Curran, W. S., Teasdale, J. R., Maul, J., Spargo, J. T., Moyer, J., Grantham, A. M., Weber, D., Way, T. R. and Camargo, G. G. (2012). Conservation tillage issues: Cover crop-based organic rotational no-till grain production in the mid-Atlantic region, USA. *Renewable Agriculture and Food Systems* 27(1): 31-40.

Mirsky, S. B., Gallandt, E. R., Mortensen, D. A., Curran, W. S. and Shumway, D. L. (2010). Reducing the germinable weed seedbank with soil disturbance and cover crops. *Weed Research* 50(4): 341-352.

Monquero, P. A. and Christoffoleti, P. J. (2003). Seed bank dynamics in areas with frequent glyphosate application. *Planta Daninha* 21(1): 63-69.

Moonen, A. C. and Barberi, P. (2004). Size and composition of the weed seedbank after 7 years of different cover-crop-maize management systems. *Weed Research* 44(3): 163-177.

Muoni, T., Rusinamhodzi, L. and Thierfelder, C. (2013). Weed control in conservation agriculture systems of Zimbabwe: Identifying economical best strategies. *Crop Protection* 53: 23-28.

Mwango, S. B., Msanya, B. M., Mtakwa, P. W., Kimaro, D. N., Deckers, J. and Poesen, J. (2016). Effectiveness of mulching under miraba in controlling soil erosion, fertility restoration and crop yield in the Usambara Mountains, Tanzania. *Land Degradation and Development* 27(4): 1266-1275.

Norsworthy, J. K., Ward, S. M., Shaw, D. R., Llewellyn, R. S., Nichols, R. L., Webster, T. M., Bradley, K. W., Frisvold, G., Powles, S. B., Burgos, N. R. and Witt, W. W. (2012). Reducing the risks of herbicide resistance: best management practices and recommendations. *Weed Science* 60(SP1): 31-62.

Ortiz-Ceballos, A. I., Fragoso, C. and Brown, G. G. (2007). Synergistic effect of a tropical earthworm *Balanteodrilus pearsei* and velvet bean *Mucuna pruriens* var. utilis on maize growth and crop production. *Applied Soil Ecology* 35(2): 356-362.

Pant, A. P., Radovich, T. J., Hue, N. V., Talcott, S. T. and Krenek, K. A. (2009). Vermicompost extracts influence growth, mineral nutrients, phytonutrients and antioxidant activity in pak choi (*Brassica rapa* cv. Bonsai, Chinensis group) grown under vermicompost and chemical fertiliser. *Journal of the Science of Food and Agriculture* 89(14): 2383-2392.

Pardo, G., Riravololona, M. and Munier-Jolain, N. M. (2010). Using a farming system model to evaluate cropping system prototypes: Are labour constraints and economic performances hampering the adoption of Integrated Weed Management? *European Journal of Agronomy* 33(1): 24-32.

Piotrowska, A. and Wilczewski, E. (2012). Effects of catch crops cultivated for green manure and mineral nitrogen fertilization on soil enzyme activities and chemical properties. *Geoderma* 189: 72-80.

Poeplau, C. and Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops–A meta-analysis. *Agriculture, Ecosystems and Environment* 200: 33-41.

Pradhan, S. K., Nerg, A. M., Sjöblom, A., Holopainen, J. K. and Heinonen-Tanski, H. (2007). Use of human urine fertilizer in cultivation of cabbage (Brassica oleracea) impacts on chemical, microbial, and flavor quality. *Journal of Agricultural and Food Chemistry* 55(21): 8657-8663.

Riedell, W. E., Pikul, J. L., Jaradat, A. A. and Schumacher, T. E. (2009). Crop rotation and nitrogen input effects on soil fertility, maize mineral nutrition, yield, and seed composition. *Agronomy Journal* 101(4): 870-879.

Roe, N. E., Stoffella, P. J. and Graetz, D. (1997). Composts from various municipal solid waste feedstocks affect vegetable crops. II. Growth, yields and fruit quality. *Journal of American Society of Horticulture Science* 122: 433-437.

Rosolem, C. A., Foloni, J. S. S. and Tiritan, C. S. (2002). Root growth and nutrient accumulation in cover crops as affected by soil compaction. *Soil and Tillage Research* 65(1): 109-115.

Rosenberg, G. H. (2005). Magurran, A. 2004. Measuring Biological Diversity. Oxford, RU: Blackwell Publishing.

Roy, S. S., Khan M. S. I. and Pall, K. K. K. K. (2011). Nitrogen and Phosphorus Efficiency on the Fruit Size and Yield of Capsicum. *Journal of Experimental Sciences* 2(1): 32–37.

Saatkamp, A., Poschlod, P. and Venable, D. L. (2014). The Functional Role of Soil Seed Banks in Natural Communities. In: Hillier SH, ed. *Seeds: the ecology of regeneration in plant communities*, 3rd Edn. Wallingford, UK: CAB International 263–295pp.

Saria, A. G., Semu, E., Høgh-Jensen, H. and Sibuga, K. P. (2018). Soil fertility dynamics of ultisol as influenced by greengram and mucuna green manures. *Journal of Plant Sciences and Agricultural Research* 2(2): 14.

Shrestha, A., Knezevic, S. Z., Roy, R. C., Ball-Coelho, B. R. and Swanton, C. J. (2002). Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. *Weed Research* 42(1): 76-87.

Teasdale, J. R. and Mohler, C. L. (2000). The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Science* 48(3): 385-392.

Tejada, M., Gonzalez, J. L., García-Martínez, A. M. and Parrado, J. (2008). Effects of different green manures on soil biological properties and maize yield. *Bioresource Technology* 99(6): 1758-1767.

Thorup-Kristensen, K. (2006). Root growth and nitrogen uptake of carrot, early cabbage, onion and lettuce following a range of green manures. *Soil Use and Management* 22(1): 29–38.

Toor, R. K., Savage, G. P. and Heeb, A. (2006). Influence of different types of fertilisers on the major antioxidant components of tomatoes. *Journal of Food Composition and Analysis* 19(1): 20-27.

Tsuyuzaki, S. (1994). Rapid seed extraction from soils by a flotation method. *Weed Research* 34(6): 433-436.

Vranjic, J.A., Woods, M.J. and Barnard, J., 2000. Soil-mediated effects on germination and seedling growth of coastal wattle (Acacia sophorae) by the environmental weed, bitou bush (Chrysanthemoides monilifera ssp. rotundata). *Austral Ecology* 25(5): 445-453.

Vandecasteele, B., Sinicco, T., D'Hose, T., Nest, T. V. and Mondini, C. (2016). Biochar amendment before or after composting affects compost quality and N losses, but not P plant uptake. *Journal of Environmental Management* 168: 200-209.

Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J. and Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa: unravelling local adaptation. *Soil* 1(1): 491-508.

Wang, Q., Li, Y. and Klassen, W. (2006). Summer cover crops and soil amendments to improve growth and nutrient uptake of okra. *HortTechnology* 16(2): 328-338.

Wittwer, R. A., Dorn, B., Jossi, W. and Van Der Heijden, M. G. (2017). Cover crops support ecological intensification of arable cropping systems. *Scientific Reports* 7: 41911.

Xu, G., Wolf, S. and Kafkafi, U. (2001). Effect of varying nitrogen form and concentration during growing season on sweet pepper flowering and fruit yield. *Journal of Plant Nutrition* 24(7): 1099-1116.

CHAPTER FOUR

4.0 FARMERS PREFERENCE AND ACCEPTABILITY OF COVER CROPS FOR WEED AND SOIL FERTILITY MANAGEMENT IN SWEET PEPPER PRODUCTION

Saria, A. G.[1, 4*], Høgh-Jensen, H.[3], Sibuga, K. P.[1] and Semu, E.[2]

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

[2]Department of Soil and Geological Sciences, Sokoine University of Agriculture, Morogoro, Tanzania

[3]National Food Institute, Technical University of Denmark, Denmark

[4]Tanzania Official Seed Certification Institute, Tanzania

*****Corresponding Author email: **adolfsaria@gmail.com**

Abstract

Twenty two organic farmers assessed different weed control and soil fertility improvement strategies in Towero village, Morogoro municipality. The objective was to assess factors that influence farmers' preference and acceptability for alternative weed control and soil fertility improvement strategies. Mucuna (*Mucuna pruriens*) and greengram (*Vigna radiata* (L.)) cover crops, mixed grass mulch, hand hoe weeding and control were the strategies used for weeds control and soil fertility improvement in sweet pepper production. Absolute ranking, matrix ranking and pairwise ranking were used to determine the strategy that will suite Towero organic farmers well because of its ability to accommodate simultaneously the attributes of both the weed control and soil fertility improvement. Of the five weed and soil management strategies considered in the study, mucuna cover crop was the most preferred by 60% followed by mixed grass mulch by 31%. Sweet pepper yield, fruit quality, weeds and soil fertility control were the main choice-specific attributes with a significant impact on the choice probability. Mucuna cover crop was ranked higher in terms of cost effectiveness (4.0), sustainability (4.6) and availability (4.0) compared with the other strategies, giving the farmers more profit of up to 140% than hand hoe weeding and 199.6% than mixed grass mulch which are commonly used by farmers for weed control. As a means to extend different technologies discovered through different studies, farmers should be given an opportunity to participate in assessing, selecting and deciding which technology is mostly suitable in their condition and environment.

Key words: organic, weeds, soil fertility, assessment, ranking, preference.

4.1 Introduction

In sub-Saharan Africa including Tanzania, vegetable crops are an essential component of sustainable development, with a significant contribution to food security and nutritional balance, but also an important source of income for resource-poor growers, especially in urban and peri-urban areas (FAO, 2012). Sweet pepper is among vegetable crops which are cultivated intensively throughout Tanzania (Djian-Caporalino *et al.*, 2007). Therefore, sweet pepper cultivation is labor and input intensive and associated with high capital investments. In Tanzania, sweet pepper is mostly cultivated in Morogoro, Tanga, Iringa, Kilimanjaro, Arusha and Mbeya regions (De Putter, 2007). Small-scale farmers produce about 90% of total national Sweet pepper production in the country while the remaining 10% is produced by medium to large farms. There are several factors and interactions that may contribute to low yields of sweet pepper such as genetic potential of the used varieties, types and levels of management, environmental factors, moisture availability, soil fertility and pests.

Weeds and poor soil fertility are among major problems facing sweet pepper production especially in organic agriculture farming systems (Lotter, 2015). Farmers in this system relies mostly in hand hoe weeding technology to control weeds which is time consuming and labour intensive, and therefore it is not very well effective and not cost-effective (Martinsen *et al.,* 2017). Weeds have more effects on sweet pepper growth especially in few days after seedling transplanting as these seedlings are week competitors in their initial days of growth (Norsworthy *et al.,* 2007). When weeds like *Cyperus spp* are allowed to infest sweet pepper crops they can cause fruit loss of up to 44% (Morales-Payan *et al.*, 1997) while *Amaranthus palmeri* (S.) Wats. can cause yield loss of about 90% when unchecked (Norsworthy *et al.,* 2007).

Mulch can be one among effective and affordable technologies which can be used to control weeds and also have a positive effect on soil fertility. Among different types of mulch, live mulch specifically cover crops mulch can be effective and of great advantage for weed control in sweet pepper production in organic farming (Ngouajio and Mennan, 2005). The ability of cover crops to suppress weeds is influenced by many factors like depriving light on weeds, while some of the cover crops have allelopathic effects on weeds (Kunz *et al.*, 2016). To achieve optimum advantage from the organic mulch, the mulch should be applied immediately after sweet pepper seedling transplanting. Furthermore, cover crops when used as mulch for weeds control can be of great potential by improving soil physical properties, prevent erosion, regulate soil temperature and water retention, supply organic matter and other soil nutrients, as well as increase the biological activity (Bhardwaj, 2013).

However, farmers have been reluctant on adopting different weed management technologies which has been developed. Therefore, it is important to understand the factors that influence farmers' decisions about managing weeds and other pests. One well-studied example is research aimed at understanding the relatively weak adoption of integrated pest management (IPM) practices despite several decades of promotion by experts (Czapar *et al.,* 1997, Hammond *et al.,* 2006). It has been observed that this has to do with the complexity of IPM in contrast to the simplicity of regular pesticide application; furthermore, some of these strategies tend to increase management costs and other logistics to farmers (Waller *et al.,* 1998). This contrast has prevented many farmers from adopting more fundamental technologies. Eckert and Bell (2005) concluded that any technology that does not consider farmer's strongly held values, beliefs and on-farm decision making needs is less likely to be adopted by farmers.

To ensure that technologies generated and released through this study are adopted and address end users' needs, farmers were involved in technology development, evaluation and assessment. Farmers' participation in the evaluation will ensure faster awareness, acceptance, and adoption of the released technologies. The objective of this farmer's assessment was to introduce and evaluate cover crop live mulch and other weed management strategies for sweet pepper weeds control under farmers' condition and understand farmers' criteria for preference of different weeds control technologies in organically grown sweet pepper.

4.2 Materials and Methods

4.2.1 Experimental layout and management

A randomized completely block design (RCBD) sweet pepper experiment with 3 x 3 m plots size and four replications was set out in farmers' field at Towero village to evaluate 5 different weed management practices. Different weed control strategies which were tested and evaluated by farmers were mucuna cover crop, greengram cover crop, mixed dry grass mulch, hand hoe weeding and unweeding (control). The experiment was done on farm and managed by Towero village organic farmers themselves under researcher observation. Farmers grew sweet pepper seedlings, transplanted, applied the treatment and managed the crop throughout the growing season.

4.2.2 Treatment application

The two cover crops mucuna and greengram were first grown as cover crops and then slashed and left on top of the soil as mulch a day before sweet pepper seedlings transplanting. Dry grass was applied on top of the soil as mulch. Mulching was done the first week after sweet pepper seedlings transplanting. Hand hoe weeding was done twice (two and six weeks after vegetable seedlings transplanting) and a control which was left unweeded allowing weeds to grow with sweet pepper throughout the experimental period.

4.2.3 Farmers selection

From the Towero village a total of 22 farmers involved in organic farming were purposely selected for the assessment of the efficacy of the different treatments applied on the sweet pepper crop. These farmers were involved in the study from the beginning. The criterion for selection was their experience and knowledge in organic agriculture focusing on weed management in organic agriculture. All the farmers had grown sweet pepper previously with adequate exposure on growing the crop and had been equiped by extension officers and different non-governmental organizations with skills on assessing vegetable growing technologies.

4.2.4 Farmers' criteria for weed and soil management strategies for sweet pepper produces

A group discussion was carried out to list the most important and common criteria for selecting the best weed management methodology and the benefits they perceive. Farmers used their own knowledge and experience to develop the list and ranking of the criteria to assess weed control technologies. This step was important for defining criteria for assessing an individual weed management strategy during evaluation of different strategies, and selecting the most preferred weed management strategy. Using the pre-determined criteria, assessment and ranking of the different weed management strategies was based on the Likert scale of 1-5, with 1 being very poor performance and 5 being excellent performance. In this scale the scores were as follows;

1 = very poor,

2 = poor,

3 = good,

4 = very good, and

5 = excellent

4.2.5 Weed and soil fertility management ranking

Weed and soil fertility ranking was done by farmers using absolute, matrix and pairwise ranking. The ranking was done sequentially starting with absolute followed by matrix and then pairwise ranking. The rankings were done as follows;

4.2.5.1 Absolute ranking

Absolute ranking was done by perception scores to explain farmers' preference for one of the strategies. Farmers were first requested to observe the sweet pepper crops grown under different weed management strategies in the field before assessing them. Then they were asked to indicate their degree of agreement or disagreement with each of the various criteria on a pre-determined five-point Likert scale. Farmers assessed the five different weed management strategies for sweet pepper production namely grengram, mixed grass mulch, mucuna, weeding and control (no weed management applied). The different strategies were compared with hand hoe weeding which is the common practice used by both organic and conventional sweet pepper producers and a control in which no weed control strategy was applied.

4.2.5.2 Matrix ranking

Matrix ranking was done by farmers by scoring each strategy for each specific criteria or benefit expected from the strategy. The scores from each criterion were summed up and then averaged to find a mean score of each strategy. The mean scores were used to rank the best strategy in descending order.

4.2.5.3 Pairwise ranking

In order to solidify farmers' selection through absolute and matrix ranking, each selected weed and soil management strategy was subjected to pairwise ranking. Farmers were requested to compare each strategy over the other one by one. Then the strategy is ranked by considering the frequency of which the specific strategy has been selected over each remaining strategy. The most selected strategy over the other strategies is ranked as number one followed by the other strategies in descending order reflecting the frequency of selection.

Furthermore, fruits from different treatments were displayed for sale in an organic shop at Morogoro municipality to ascertain consumers' preference of the sweet pepper fruits grown in plots which received different experimental treatments. Sweet pepper fruits were displayed in groups according to their weed management production strategy. Consumers voluntarily requested to do visual evaluation and rank the fruits harvested from plots with different weed management strategies. Consumers were asked to evaluate each group on the scale of 1 to 5, where 1 was very poor quality and 5 being excellent quality.

4.2.5 Data analysis

The scores of preference ranking were treated as quantities measured on a continuous scale. Data were analysed using SPSS (2002) statistical packages.

4.3 Results

4.3.1 Uses and purposes of growing sweet pepper in Towero

Farmers were asked to narrate the uses, benefit or purposes of growing sweet pepper and rank them in order of importance. Table 4.1 summarizes the uses of sweet pepper at Towero village. Growing sweet pepper for food was ranked first, while for cash and crop rotation were ranked second and third respectively.

Table 4.1: Main uses of Sweet pepper at Towero cropping season (n=22)

Uses/purpose	Selection by respondents (%)	Rank
Cash	70	1
Food	16	2
Crop rotation	8	3
Insect pests control	5	4
Soil fertility improvement – different nutrients uptake	1	5
Mean	20	
SE	0.47	
CV (%)	9.3	

4.3.2 Criteria used by farmers to select sweet pepper production strategy for weeds and soil fertility management

Farmers listed criteria they use to select the best strategy for weeds and soil fertility management in sweet pepper production. From results presented on Table 4.2, yield increase, fruit quality improvement, ability to control weed pests and ability to improve soil fertility were the most important criteria for selecting the best weed and soil fertility strategy for sweet pepper production by the farmers in Towero village. However, the material used for a specific weed management strategy being a multipurpose in its use was not an important criterion for selecting and hence was ranked last.

Table 4.2: Farmers' criteria used to select strategy for weeds and soil fertility management in sweet pepper production at Towero village (n=22)

Criteria	Selection by respondents (%)	Rank
Cost associated with the strategy	5	6
Increase sweet pepper fruit yield	40	1
Improve sweet pepper fruit quality	17	2
Availability of materials	4	7
Improve soil fertility	10	4
Improve soil moisture	9	5
Single use of the material (not used as animal feed)	1	9
Sustainability of the strategy	3	8
Ability to control weeds	11	3
Mean	11.11	
SE	1.29	
CV (%)	17.82	

4.3.3 Absolute ranking

Farmers ranked weed management strategy for growing sweet pepper according to their preference. Most farmers preferred the cover crop strategy ranking mucuna and greengram first and second respectively, these were followed by mixed grass mulch strategy, with hand hoe weeding and control being the least (Table 4.3).

Table 4.3: Absolute ranking of weed and soil fertility management for sweet pepper growth by farmers (n=22)

Weed and soil fertility management strategy	Score (%)	Rank
Grengram	25	2
Mixed grass mulch	19	3
Mucuna	38	1
Hand hoe weeding	18	4
Control	0	5
Mean	20	
SE	1.04	
CV (%)	12.0	

4.3.4 Characteristics of weeds and soil fertility management strategies for sweet pepper production as indicated by the farmers

Farmers listed the characteristics of each strategy as observed in the field through observation and experiences they have as recorded on Table 4.4.

Table 4.4: Farmers' description of each strategy for sweet pepper production in Towero village (n=22)

Grengram • Improve soil fertility • Improve soil moisture • Improve sweet pepper yields • Control most of the weeds except few grasses and sedges • Improve fruits quality • Attract of some insect pests (Aphids) • Can be source of food • Cheap and less labour intensive	**Mixed grass mulch** • Improve soil fertility • Increase soil organic matter • Improve soil moisture • Improve sweet pepper yields • Control most except few grasses and sedges • Improve fruits quality • Difficult to collect • Labour intensive and time consuming • Used as animal feed
Mucuna • Improve soil fertility • Increase soil organic matter • Improve soil moisture • Improve sweet pepper yields • Control most of the weeds as it covers almost 100% of the plot • Improve fruits quality • Improves plant vigour • Cheap and less labour intensive	**Control** • Cheap interms of labour and time • Early maturing crops due to stress • Drought susceptible • Very poor yield • Attracts large number of different pests • Decrease soil fertility
Hand hoe weeding • Labour intensive • Drought susceptible • Average yields • Poor soil fertility management • Average fruit quality	

4.3.5 Matrix ranking

Farmers conducted a matrix ranking of the strategies using pre-determined nine most important criteria used to select the strategies as described in Table 4.2. Results show that farmers ranked mucuna, mixed grass mulch and greengram as the best three strategies being fisrt, second and third respectively as shown in Table 4.5.

Table 4.5: Matrix scores and ranking of weeds and soil fertility management strategies in sweet pepper production in Towero (n=22)

No	Criteria	Weed and soil fertility management strategy				
		Mixed grass mulch	Mucuna	Greengram	Control	Hand hoe weeding
1.	Increase sweet pepper fruit yield	4.4	5.0	4.6	1.0	4.0
2.	Improve soil fertility	4.0	4.5	4.0	2.0	3.5
3.	Ability to control weeds	4.0	4.6	4.3	4.0	3.4
4.	Improve soil moisture	5.0	5.0	4.0	2.5	3.0
5.	Improve sweet pepper fruit quality	4.5	4.5	4.0	2.0	3.0
6.	Cost associated with the strategy	3.5	4.0	4.0	5.0	3.0
7.	Availability of materials	3.5	4.0	4.0	5.0	4.0
8.	Sustainability of the strategy	4.0	4.6	4.0	2.0	3.8
9.	Single use of the material	3.0	5.0	3.0	5.0	5.0
	Total	36.0	41.2	35.9	28.5	32.7
	Mean	4.0	4.58	3.99	3.12	3.63
	Rank	2	1	3	5	4

Key for scores: 1 – Poor; 2 – Satisfactory; 3 – Average; 4 – Good; 5 – Excellent

4.3.6 Pair wise ranking

Results in Table 4.6 shows a pair wise ranking done by farmers at Towero village. Mucuna and greengram strategies were best, ranked first and second.

Table 4.6: Pair wise ranking of different weed and soil fertility management strategies in Sweet pepper production evaluated at Towero village

	Weed and soil fertility management strategies					Total	Ranking
	Greengram	Mixed grass mulch	Mucuna	Hand hoe weeding	Control		
Grengram		Greengram	Mucuna	Grengram	Grengram	3	2
Mixed grass mulch			Mucuna	Mixed grass mulch	Mixed grass mulch	2	3
Mucuna				Mucuna	Mucuna	4	1
Hand hoe weeding					Hand hoe weeding	1	4
Control						0	5

4.3.7 Cost of production

Results on Table 4.7 show the cost of production and the profit or loss obtained under different weed and soil fertility management strategies as compared with the normal organic farmers' practice which is hand hoe weeding. From these results, sweet pepper production under mucuna strategy provided high profit. The mucuna strategy provided to the farmers a profit of up to 140% than hand hoe weeding, and 199.6% than mixed grass mulch which are commonly used by farmers for weed control. The high profit from mucuna strategy was followed by that from greengram cover crop with 80% over hand hoe weeding and 190.5% over mixed grass mulch.

Table 4.7: Total cost of production and the profit per hectare obtained under each weed and soil fertility management strategy at Towero village

	Soil fertility stratergies				
	Control (no treatment)	**Weeded**	**Mixed grass mulch**	**Greengram**	**Mucuna**
	Tanzanian Shillings				
`Total cost	310 000	430 000	350 000	360 000	360 000
Gross revenue	4 640 000	6 080 000	8 640 000	11 040 000	13 920 000
Net benefit	4 330 000	5 650 000	8 290 000	10 680 000	13 560 000
Net profit over current practice (hand hoe weeding)	-1 320 000	0	2 640 000	5 030 000	7 910 000

4.3.8 Overall farmers' preference

Of the 22 farmers who participated in assessment, 60% preferred the use of mucuna cover crop for weeds control and soil fertility improvement while 31% and 22% preferred mixed grass dead mulch and greengram cover crop, respectively (Figure 1). The least preferred strategy was a control (0%) in which weeds were left undisturbed, all farmers (100%) did not choose this strategy followed by dead mixed grass mulch which 25% of farmers did not preferred it.

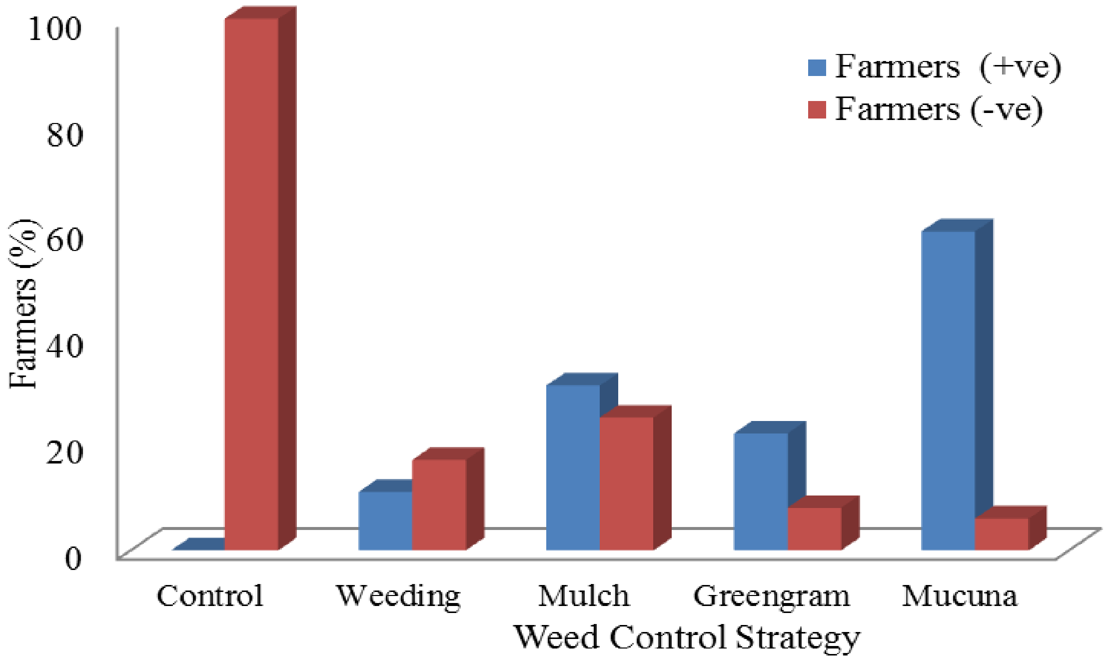

Figure 4.1. Farmers preference on different weed control strategies (n=22)

4.4 Discussion

4.4.1 Uses and purposes of growing sweet pepper in Towero

Sweet pepper crop in Tanzania is mostly used as vegetable crop for house hold consumption but also as cash crop. Farmers in Towero village have explained the importance of sweet pepper production as part of their food and income. Studies have shown the importance of sweet pepper as one among sources of nutrients and hence its significance in the maintenance of human health and prevention of diseases. They contain valuable food ingredients which can be successfully utilized to build up and repair the body (Hanif *et al.,* 2006). Furthermore, sweet peppers are valuable in maintaining alkaline reserve of the body. They are valued mainly for their high carbohydrate, vitamin and mineral contents (Marin *et al*., 2004; Pérez-López *et al.,* 2007). These studies fall in line with the objectives of Towero farmers to grow sweet pepper as one among the major vegetable crops, as the crop provide to them a stable source of income for stable house hold income and furthermore as a reliable source of nutritional food.

4.4.2 Criteria for strategy selection

To be selected by farmers, any crop production strategy should meet farmers' expectations and should be easily available, effective and with low cost (Wilke and Snapp, 2008). The major criteria for farmers to prefer a certain weed management strategy were the strategy which improve sweet pepper yield, fruit quality, control weeds, improve soil fertility and moisture, easy and reliable availability for the materials used. These are due to the fact that moisture, weed pests and soil fertility are main constrains in sweet pepper production (Maerere *et al.,* 2010). Furthermore, farmers avoided to select strategies which used materials with multiple uses. Materials with this nature are not reliable as in some seasons the materials may be used in other needs like animal feeds and hence bring competition between using it for weed control and feeding animals. For example, materials like mixed grass was ranked low compared to mucuna as these grasses had several uses rather that used as mulch. Cost for applying the strategy was among the things considered by farmers, strategies which were associated with high cost like weeding and mulching were less selected by famers.

Farmers also considered the ability of the specific strategy on organic matter addition to the soil. This was associated with moisture content retention ability, in addition to that, strategies with high biomass performed better on weeds control. This is due to the fact that, when they are applied as cover crop they are able to produce high amount of biomass which it helps in competing effectively with weed pests and reduces the pests even before they are slashed and used as mulch. The last two strategies which were hand hoe weeding and control (no treatment applied) were less preferred by farmers due to their poor ability to manage weeds and soil fertility, leading to poor yield and quality of fruits. These leads to farmers having less chance of sustaining food security for the household consumption and surplus for sale and improve household income.

4.4.3 Absolute, matrix and pairwise ranking

Matrix ranking results at Towero showed that, the three strategies tested (mucuna, greengram and mixed grass mulch) were very good in improving fruit yields and quality, improving soil fertility, managing weed pests, improving soil moisture and are sustainable. Mucuna and mixed grass scored very good to excellent (4 – 5) in most of the criteria and they were the most preferred strategies by farmers in Towero village as they were ranked first and second respectively followed by greengram. Absolute and pairwise ranking results showed that the same trend with mucuna and mixed grass mulch were the most preferred by farmers at since they ranked first and second respectively. This indicated that, the same strategies were preferred similarly by farmers in and also farmers know what they were selecting. Furthermore, this shows the ability of the two strategies on improving sweet pepper production and quality. The two materials were also preferred due to their less cost and more advantages in soil fertility through biomass addition.

4.5 Conclusions

From the study it was observed that, farmers' preference and acceptability of new technology like mulching can be significantly influenced by different factors such as material availability, cost of the technology, its effect on yield and quality of the produces. Therefore, it is concluded that;

- In general, sweet pepper farmers' selection to a certain weed and soil fertility management technology is associated with higher productivity, quality of fruits produced, material availability and cost of that technology.
- Mucuna and green gram are most preferable strategies by farmers as they ranked first and second respectively in terms of absolutely, matrix and pairwise ranking.
- Mucuna and greengram cover crop strategies are the most cost effective and profitable strategy under farmers' condition. The two cover crops increase the profit margin obtained by farmers compared to weeding and dead grass mulch strategies.
- Farmers prefer mulching materials (live or dead) which have only single use than multipurpose materials with another uses like animal feeds.

REFERENCE

Czapar, G. F., Curry M. P. and Wax, L. M. (1997). Grower acceptance of economic thresholds for weed management in Illinois. *Weed Technology* 11: 828–831.

FAO. (2012). *Growing Greener Cities in Africa. First Status Report on Urban and Peri-urban Horticulture in Africa*. Food and Agriculture Organization of the United Nations, Rome, Italy.

Hammond, C. L., Luschei, E. C., Boerboom, C. M. and Nowak, P. J. (2006). Adoption of integrated pest management tactics by Wisconsin farmers. *Weed Technology* 20: 756–767.

Lal Bhardwaj, R. (2013). Effect of mulching on crop production under rainfed condition-a review. *Agricultural Reviews* 34(3).

Lotter, D. (2015). Facing food insecurity in Africa: Why, after 30 years of work in organic agriculture, I am promoting the use of synthetic fertilizers and herbicides in small-scale staple crop production. *Agriculture and Human Values* 32(1): 111-118.

Djian-Caporalino, C., Lefebvre, V., Sage-Daubèze, A. M. and Palloix, A. (2007) *Capsicum*. In: Singh RJ (ed) Genetic resources, chromosome engineering, and crop improvement. CRC Press, Boca Raton: 185–243.

De Putter, H., Van Koesveld, M. J. and De Visser, C. L. M. (2007). *Overview of the vegetable sector in Tanzania* (No. 1). Wageningen UR.

Eckert, E. and Bell, A. (2005). Invisible force: Farmers' mental models and how they influence learning and actions. *Journal of Extension* 43(3): 1-10.

Hanif, R., Iqbal, Z., Iqbal, M., Hanif, S. and Rasheed, M. (2006). Use of vegetables as nutritional food: role in human health. *Journal of Agricultural and Biological Science* 1(1): 18-22.

Kunz, C., Sturm, D. J., Varnholt, D., Walker, F. and Gerhards, R. (2016). Allelopathic effects and weed suppressive ability of cover crops. *Plant and Soil Environment* 62(2): 60-66.

Maerere, A. P., Sibuga, K. P., Mwajombe, K. K., Kovach, J. and Erbaugh, M. (2006). Baseline survey report of tomato production in Mvomero district-Morogoro region, Tanzania. *Sokoine University of Agriculture Faculty of Agriculture Morogoro*: 1-31.

Marín, A., Ferreres, F., Tomás-Barberán, F. A. and Gil, M. I. (2004). Characterization and quantitation of antioxidant constituents of sweet pepper (*Capsicum annuum* L.). *Journal of Agricultural and Food Chemistry* 52(12): 3861-3869.

Martinsen, V., Shitumbanuma, V., Mulder, J., Ritz, C. and Cornelissen, G. (2017). Effects of hand-hoe tilled conservation farming on soil quality and carbon stocks under on-farm conditions in Zambia. *Agriculture, Ecosystems and Environment* 241: 168-178.

Ngouajio, M. and Mennan, H. (2005). Weed populations and pickling cucumber (*Cucumis sativus*) yield under summer and winter cover crop systems. *Crop Protection* 24(6): 521-526.

Norsworthy, J. K., Malik, M. S., Jha, P. and Riley, M. B. (2007). Suppression of *Digitaria sanguinalis* and *Amaranthus palmeri* using autumn-sown glucosinolate-producing cover crops in organically grown bell pepper. *Weed Research* 47(5): 425-432.

Pérez-López, A. J., López-Nicolas, J. M., Núñez-Delicado, E., Amor, F. M. D. and Carbonell-Barrachina, Á. A. (2007). Effects of agricultural practices on color, carotenoids composition, and minerals contents of sweet peppers, cv. Almuden. *Journal of Agricultural and Food Chemistry* 55(20): 8158-8164.

Waller, B. E., Hoy, C. W., Henderson, J. L., Stinner, B. and Welty, C. (1998). Matching innovations with potential users, a case study of potato IPM practices. *Agriculture, Ecosystems and Environment* 70(2-3): 203-215.

Wilke, B. J. and Snapp, S. S. (2008). Winter cover crops for local ecosystems: linking plant traits and ecosystem function. *Journal of the Science of Food and Agriculture* 88(4): 551-557.

CHAPTER FIVE

5.0 OVERALL CONCLUSIONS AND RECOMMANDATIONS

5.1 Introduction

This chapter highlights key contributions to the build of knowledge that the present study has made, furthermore it gives overall conclusions of this study done in two sites Towero village and Sokoine University of Agriculture (SUA) crop museum. In addition to that, the study also suggests areas which have been identified for further studies and provides recommendations that will help to improve the current situations to sweet pepper farmers.

This study has shown the decomposition trend of two different cover crops namely mucuna and greengram, and release of different mineral nutrients in to the soil. The study has established the period of release of mineral nutrients from the cover crops and plant assimilation of different specific nutrient by sweet pepper plants. The study has tried to synchronize between the two, nutrients release from decomposed cover crop and sweet pepper crop uptake of the specific nutrients. Findings from this will contribute to the knowledge of appropriate use of the cover crop through identifying the appropriate time of sweet pepper seedlings transplanting so that they can optimize the optimal nutrients release by cover crop and optimal time for plant uptake. Few studies on the decomposition rate of the different green manures were done in Tanzania like those done by Partey *et al.* (2011) and Kimaro *et al.* (2008).

The study further has shown the ability of the cover crops on weed management. It has been observed that, the two cover crops mucuna and greengram can suppress different types of weeds above ground and below ground in terms of weed seed bank. However, this depends much on the type of weeds available in site, as results indicate that sedge and grasses were not completely suppressed and few managed to come out. Furthermore, one year application of cover crops for weed control did not significantly reduce weed and weed seeds population. Wittwer *et al.* (2017) recommended regular use of cover crops for weed control in order to increase yield in different crops.

This study also acknowledged that application of cover crops for weed and soil management have positive implication to crop productivity, plant and fruit mineral content and fruit quality. Synchronization of nutrient release from cover crops and plant uptake by sweet pepper crop resulted into an increase in sweet pepper fruit production and plant growth vigour. It has also increase fruits mineral content which is for nutritionally benefit of consumers' health but also improved sweet pepper fruit quality in terms of size. The other weed control practices commonly used by organic farmers which is hand hoe weeding and mixed dead grass mulch produced low yield with poor quality and small size compared to the two cover crops. Furthermore, studies on green manure cover crops (Aronsson *et al.,* 2016; Finney *et al.,* 2016) indicated the ability of cover crops to improve crop productivity.

This study has also given an overview of the criteria organic farmers use on selecting the best cover crops for weed and soil fertility management. The findings will help other scientists conducting research on cover crops to know the type and areas where they can concentrate in order to provide more useful answers to the intended farmers. It has been observed that, farmers prefer multipurpose cover crops which can save as green manure and also suppress weeds. However, the intended cover crop should not be with multi-use as being a source of animal feed and also used as a mulch or source of soil fertility. In addition, the cover crop must not be of high cost and should be sustainable both in its stay in the field when used as mulch and also its availability from one season to another. This study has tried to quantify the cost of using the two cover crops mucuna and greengram comparing with other techniques, the study of Snapp *et al.* (2005) have also tried to show the cost of using different types of cover crops. Farmers will again prefer that type of cover crop or mulch which is not labour intensive in sourcing it and also during its application.

5.2 Overall Conclusions

The following conclusions were drawn frm the three studies which were done as follows;

5.2.1 Study One: Soil fertility dynamics of ultisol as influenced by greengram and mucuna applied as live cover crop green manures

i. Mucuna and greengram significantly improved soil fertility of ultisol when used as green manures. The cover crops increase organic matter content in the soil also the amount of N, P and K. The two cover crops also increase the amount of available P, Ca and Mg in the soil.

ii. Furthermore, mucuna and greengram positively improved soil microbial population.

iii. From the study, it was observed that, optimal release and availability of mineral content, organic matter and microbial population availability are at the fourth to eighth week after the cover crops are applied as green manure.

5.2.2 Study two: Effects of live and dead mulching materials on weed occurrence, seed bank and diversity and their potential for improving sweet pepper physical and chemical attributes

i. Mucuna and greengram cover crops were the best strategy for weed control. The two cover crops have significantly managed to reduce weeds occurrence, seed bank and their diversity.

ii. Mucuna and greengram cover crops increase sweet pepper yields than mixed grass mulch and weeding strategies.

iii. Sweet pepper produces harvested from field managed by mucuna and greengram were improved in their physical qualities in-terms of size and their mineral content.

5.2.3 Study three: Farmer's criteria on selection and preference of mulching technologies and their economic benefit in organic sweet pepper production.

- Sweet pepper farmers' selection to certain weeds and soil fertility management technology is associated with higher productivity, quality of fruits produced, material availability and cost of that technology.
- Mucuna and green gram are most preferable strategies by farmers as they ranked first and second respectively in terms of absolutely, matrix and pairwise ranking.
- Mucuna and greengram cover crop strategies are the most cost effective and profitable strategy under farmers' condition. The two cover crops increase the profit margin obtained by farmers compared to weeding and dead grass mulch strategies.
- Farmers prefer mulching materials (live or dead) which have only single use than multipurpose materials with another uses like animal feeds.

However, one year application of cover crops used as source of nutrients for soil fertility improvement or for weed control had poor residual effects on both weeds and soil fertility management. Among major challenges is growing them in advance for almost two to three months before transplanting sweet pepper as a major crop. Another challenge is the ability of few types of weeds like grasses and sedges which can penetrate the cover and warrant the use of hand weeding to remove them.

5.3 Recommendations

From these three studies, it is recommended that;

i. The two cover crops mucuna and greengram, should be used to improve soil fertility in sweet pepper organic farms, sweet pepper yields, fruit chemical and physical qualities.

ii. It is recommended that, the cover crops should be grown up to 50% flowering (70 and 40 days after emergence for mucuna and greengram respectively, under Morogoro condition), then slashed and be used as mulch and left on the ground for three weeks before introducing the main crop. The cut and desiccated cover crop plant materials act as mulch. This will act as a double action, first in controlling weeds by denying them an opportunity to grow when cover crops are growing and covering the soil, and then when cover crop is slashed and used as mulch protecting new weeds to invade the transplanted crop seedlings. This will also reduce weed seed bank in the soil as most of the germinated weeds will fail to grow and reproduce and hence be unable to return new seeds to the soil.

iii. It is essential that sweet pepper seedling should be transplanted three weeks after the cover crops has been slashed and left on top of soil as mulch in order to give enough time for the crop to stay with the cover crop before it is decomposed and give room for weeds to re-invade. This also will benefit the crop as it will synchronize the cover crop nutrient release during its decomposition which is at fourth to eighth week after slashing with optimal crop nutrient requirement and up take.

iv. Cover cropping should be established to continue producing the cover even if the main crop is not in the field in order to reduce weed seed bank.

v. From this study, it is also recommended that, knowing farmers' preference and criteria for assessing, preferring and accepting new agriculture technology like mucuna and greengram cover crop as dead and live mulch for weed control strategy but also (as a source of soil nutrients) is very important in order to make sure the introduced technology will be assimilated by farmers. In this study, the two cover crops mucuna and greengraam are recommended not only due to their outstanding performance but also because they were selected and preferred by farmers using their own developed criteria.

REFERENCES

Aronsson, H., Hansen, E. M., Thomsen, I. K., Liu, J., Øgaard, A. F., Känkänen, H. and Ulén, B. (2016). The ability of cover crops to reduce nitrogen and phosphorus losses from arable land in southern Scandinavia and Finland. *Journal of Soil and Water Conservation* 71(1): 41-55.

Finney, D. M., White, C. M. and Kaye, J. P. (2016). Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. *Agronomy Journal* 108(1): 39-52.

Kimaro, A. A., Timmer, V. R., Chamshama, S. A. O., Mugasha, A. G. and Kimaro, D. A. (2008). Differential response to tree fallows in rotational woodlot systems in semi-arid Tanzania: Post-fallow maize yield, nutrient uptake, and soil nutrients. *Agriculture, Ecosystems and Environment* 125(1-4): 73-83.

Partey, S. T., Quashie-Sam, S. J., Thevathasan, N. V. and Gordon, A. M. (2011). Decomposition and nutrient release patterns of the leaf biomass of the wild sunflower (*Tithonia diversifolia*): a comparative study with four leguminous agroforestry species. *Agroforestry Systems* 81(2): 123-134.

Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., Nyiraneza, J. and O'neil, K. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agronomy Journal* 97(1): 322-332.

Wittwer, R. A., Dorn, B., Jossi, W. and Van Der Heijden, M. G. (2017). Cover crops support ecological intensification of arable cropping systems. *Scientific Reports* 7: 41911.

APPENDICES

Appendix 1. Title of the Published Paper: Soil Fertility Dynamics of Ultisol as influenced by greengram and mucuna green manures

Appendix 2. Correct Citation: Saria, A. G. Semu, E., Høgh-jensen, H. and Sibuga, K. P. Soil Fertility Dynamics of Ultisol as influenced by greengram and mucuna green manyures. Journal of Plant Sciences and Agricultural Research 2 (2): 14.

Appendix 3. Link: http://www.imedpub.com/articles/ soil-fertility-dynamics-of-ultisol-as-influenced-by-greengram-and-mucuna-green-**manures.php?aid=22605**

Appendix 4. Dietary Reference Intakes (DRIs): Recommended Dietary Allowances and Adequate Intakes, Elements

Food and Nutrition Board, Institute of Medicine, National Academies

	Ca (mg/d)	Cr (μg/d)	Cu (μg/d)	F (mg/d)	I (μg/d)	Fe (mg/d)	Mg (mg/d)	Mn (mg/d)	Mo (μg/d)	P (mg/d)	Se (μg/d)	Zn (mg/d)	K (g/d)	Na(g/d)	Cl(g/d)
Infants															
0 to 6 mo	200*	0.2*	200*	0.01*	110*	0.27*	30*	0.003*	2*	100*	15*	2*	0.4*	0.12*	0.18*
6 to 12 mo	260*	5.5*	220*	0.5*	130*	**11**	75*	0.6*	3*	275*	20*	**3**	0.7*	0.37*	0.57*
Children															
1–3 y	**700**	11*	**340**	0.7*	**90**	**7**	**80**	1.2*	**17**	**460**	**20**	**3**	3.0*	1.0*	1.5*
4–8 y	**1,000**	15*	**440**	1*	**90**	**10**	**130**	1.5*	**22**	**500**	**30**	**5**	3.8*	1.2*	1.9*
Males															
9–13 y	**1,300**	25*	**700**	2*	**120**	**8**	**240**	1.9*	**34**	**1,250**	**40**	**8**	4.5*	1.5*	2.3*
14–18 y	**1,300**	35*	**890**	3*	**150**	**11**	**410**	2.2*	**43**	**1,250**	**55**	**11**	4.7*	1.5*	2.3*
19–30 y	**1,000**	35*	**900**	4*	**150**	**8**	**400**	2.3*	**45**	**700**	**55**	**11**	4.7*	1.5*	2.3*
31–50 y	**1,000**	35*	**900**	4*	**150**	**8**	**420**	2.3*	**45**	**700**	**55**	**11**	4.7*	1.5*	2.3*
51–70 y	**1,000**	30*	**900**	4*	**150**	**8**	**420**	2.3*	**45**	**700**	**55**	**11**	4.7*	1.3*	2.0*
> 70 y	**1,200**	30*	**900**	4*	**150**	**8**	**420**	2.3*	**45**	**700**	**55**	**11**	4.7*	1.2*	1.8*
Females															
9–13 y	**1,300**	21*	**700**	2*	**120**	**8**	**240**	1.6*	**34**	**1,250**	**40**	**8**	4.5*	1.5*	2.3*
14–18 y	**1,300**	24*	**890**	3*	**150**	**15**	**360**	1.6*	**43**	**1,250**	**55**	**9**	4.7*	1.5*	2.3*
19–30 y	**1,000**	25*	**900**	3*	**150**	**18**	**310**	1.8*	**45**	**700**	**55**	**8**	4.7*	1.5*	2.3*
31–50 y	**1,000**	25*	**900**	3*	**150**	**18**	**320**	1.8*	**45**	**700**	**55**	**8**	4.7*	1.5*	2.3*
51–70 y	**1,200**	20*	**900**	3*	**150**	**8**	**320**	1.8*	**45**	**700**	**55**	**8**	4.7*	1.3*	2.0*
> 70 y	**1,200**	20*	**900**	3*	**150**	**8**	**320**	1.8*	**45**	**700**	**55**	**8**	4.7*	1.2*	1.8*
Pregnancy															
14–18 y	**1,300**	29*	**1,000**	3*	**220**	**27**	**400**	2.0*	**50**	**1,250**	**60**	**12**	4.7*	1.5*	2.3*
19–30 y	**1,000**	30*	**1,000**	3*	**220**	**27**	**350**	2.0*	**50**	**700**	**60**	**11**	4.7*	1.5*	2.3*
31–50 y	**1,000**	30*	**1,000**	3*	**220**	**27**	**360**	2.0*	**50**	**700**	**60**	**11**	4.7*	1.5*	2.3*
Lactation															
14–18 y	**1,300**	44*	**1,300**	3*	**290**	**10**	**360**	2.6*	**50**	**1,250**	**70**	**13**	5.1*	1.5*	2.3*
19–30 y	**1,000**	45*	**1,300**	3*	**290**	**9**	**310**	2.6*	**50**	**700**	**70**	**12**	5.1*	1.5*	2.3*
31–50 y	**1,000**	45*	**1,300**	3*	**290**	**9**	**320**	2.6*	**50**	**700**	**70**	**12**	5.1*	1.5*	2.3*

NOTE: This table (taken from the DRI reports, see www.nap.edu) presents Recommended Dietary Allowances (RDAs) in **bold type** and Adequate Intakes (AIs) in ordinary type followed by an asterisk (*).
An RDA is the average daily dietary intake level; sufficient to meet the nutrient requirements of nearly all (97-98 percent) healthy individuals in a group. It is calculated from an Estimated Average Requirement (EAR). If sufficient scientific evidence is not available to establish an EAR, and thus calculate an RDA, an AI is usually developed. For healthy breastfed infants, an AI is the mean intake. The AI for other life stage and gender groups is believed to cover the needs of all healthy individuals in the groups, but lack of data or uncertainty in the data prevent being able to specify with confidence the percentage of individuals covered by this intake.
SOURCES: *Dietary Reference Intakes for Calcium, Phosphorous, Magnesium, Vitamin D, and Fluoride* (1997); *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic Acid, Biotin, and Choline* (1998); *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids* (2000); and *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc* (2001); *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and* Sulfate (2005); and *Dietary Reference Intakes for Calcium and Vitamin D* (2011). These reports may be accessed via www.nap.edu.