EFFECT OF ORGANIC AMENDMENTS ON SOIL AGGREGATE STABILITY IN CHIPATA AND KASAMA, ZAMBIA

By

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A dissertation submitted to the University of Zambia in partial fulfillment of the requirements of the degree of Master of Science in Integrated Soil Fertility Management

THE UNIVERSITY OF ZAMBIA

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DECLARATION

I, **Kelody Muzyamba**, hereby declare that all the work presented in this dissertation is my own and has never been submitted for a degree, diploma or other qualification at this or any other University.

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APPROVAL

This dissertation of Mr. Kelody Muzyamba is approved, fulfilling part of the requirements for the award of Master of Science degree in Integrated Soil Fertility Management by the University of Zambia.

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ABSTRACT

Organic amendments have been known to improve soil physical and chemical properties in sub-Saharan Africa. However, research information on how organic amendments affect aggregate stability and the degree of their effects in comparison to others is indaquate in Zambia. The study was therefore carried out to assess the effect of organic amendments on soil aggregate stability and organic matter content on soils from Chipata and Kasama, Zambia. The specific objectives were (i) To assess the effect of organic amendments on soil aggregate stability on two Zambian soils. (ii) To assess the effect of organic amendments on soil organic matter and soil aggregate stability of two Zambian soils.(iii) To assess if there is a relationship between soil organic matter and soil aggregate stability. Soil aggregates were collected from the top 10 cm of 10 m x10 m plots in each treatment replicated five times. These aggregates were sieved through a 9.5 mm, and the retained aggregates on an 8 mm sieve were collected and used for aggregate stability analysis. Analysis of variance (ANOVA) of results showed significant differences among the means of four treatments; Sun hemp, *tephrosia vogelii* alley cropping, pigeon pea alley cropping, Animal manure, and conventional treatments on a loamy ferric luvisol. Amending soils with Sunhemp showed a significantly higher mean weight diameter (MWDd) of 2.393 compared to amending soils with *tephrosia vogelii* alley cropping MWDd 1.767 (P value <0.001***). There was a highly significant difference in the organic matter content for the Ferasols at Misamfu (P value 0.002**). The difference was significant in larger aggregates than smaller aggregates. There was a significant correlation in the 7.18 mm and 1.9 mm aggregate size distribution for Ferasols at Misamfu with Pearsons correlation of 0.292* and -0.334** respectively. Hence for a loamy ferric luvisol soil, Sunhemp and animal manure may be used to improve the condition especially for aeration and aggregate stability. Aggregate stability information is an important physical parameter that has several effects on several soil properties that can be used to improve soil productivity in Agricultural production.

Key words: Aggregate stability, Organic amendments, Organic matter, Soil aggregates.

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ACRONYMS AND ABBREVIATIONS

UNZA	University of Zambia
MWD	Mean weight diameter
MWDd	Mean weight diameter dry
MWDW	Mean weight diameter wet
SOC	Soil organic Carbon
SOM	Soil Organic Matter
OM	Organic Matter
ANOVA	Analysis of Variance
LSD	Least Significance Difference
CI	Confidence Interval

CHAPTER ONE: INTRODUCTION

1.1 Background

Soil is a primary resource in the growth of crops and provides plants with nutrients, water, and anchorage. For production to take place, the soil is disturbed to create fine tilth for better seeding and emergency. However, the interest in developing a plow less agriculture to achieve lesser disturbance on soil and the environment received attention in the past decades (Lal et al. 2007; Lal 2009). Soil disturbance may result from several factors such as soil management practices involving addition of fertilizers, irrigation practices, use of herbicides and pesticides, and tillage practices during land preparation for crop production. All these factors present a disturbance that may affect soil productivity.

Tillage management practices affect soil aggregation directly by physical disruption of the macro aggregates (Barto et al., 2010; Zhang et al., 2014) which expose the soil to agents of erosion such as water and wind. Soil disturbance also accelerates processes of eluviation and illuviation of soil particles in the soil, decomposition, humification and mineralization of organic matter in the soil. These processes contribute to low levels of organic matter and other cementing materials in the top soil and imply the soil quality such as lower pH values enhancing acidity, the decline in cation exchange capacity (CEC) resulting into the reduced water storage and nutrients in the soil.

Loss of organic matter is high in soils from areas with high temperatures and humidity levels. Sub-Saharan Africa, in particular, is most susceptible to losses of organic matter due to the attributes above. The resultant infertile soils coupled with erratic rainfall and poor management of the natural resource base, led to declining yields and increased risk of crop failure in much of the smallholder dry land farming sector of southern Africa (Thierfelder et al., 2009). Soils from these areas were generally low in nutrients, organic matter, water storage and had unstable soil aggregates. For instance, in Zambia’s high rainfall region III, the loss of nutrients increased through leaching and deep percolation for nutrients such as nitrogen in nitrate and ammonium forms (Bwembya and Yerokun, 2001). While in Zambia’s low rainfall region I, nutrients are mostly lost through runoff due to high rainfall intensity, soil disturbance in farmer’s fields and poor soil structure.

Globally, the need to improve soil quality to ensure a build-up of soil nutrients and improved water storage has been of interest. The solution to this problem has involved both chemical and physical methods. Chemical methods involve the inclusion or addition of nutrients in chemical forms to the soil that can easily improve and provide nutrients in available forms. This is done through production of fertilizers that have nutrients in concentrated quantities. Physical methods include the addition of amendments or soil conditioners that improve the physical properties of the soil. In both methods, modifications have been done to further improve the efficiency.

Production of fertilizers has been modified such as the production of chelated fertilizers and organic fertilizers which are slow release to ensure there is efficiency in the use of nutrients from the fertilizers. Organic matter addition through the use of organic fertilizers substantially increases soil structure and water holding capacity (Vengadaramana et al., 2012). Amendments such as Zeolites have too been identified to increase CEC thereby increasing nutrient and water retention (Yolcu et al. 2011). Additionally, Conservation agriculture practices which encompass minimum tillage, retaining of crop residues and crop rotation (Lungowe et al., 2010) have been implemented in the sub-Saharan countries in the last decade. Largely, improving the soil structure by increasing soil aggregate stability and raising soil CEC has been noted to be cardinal to ensure sustainable soil productivity.

Despite the blissful advantages of organic fertilizers and amendments such as Zeolites, the poor small scale farmers cannot afford to procure enough organic fertilizers and or conditioners such as Zeolites. Therefore, there is a need to consider affordable amendments for the poor small scale farmers. One of the amendments has been the introduction of improved fallows in farmer's fields, for instance, a 2-3years Sesbania fallow had shown significant results in restoring soil fertility and increasing maize production (Kwesiga et al.,1999). Others had been the addition of animal manure and using green manures (Bwembya and Yerokun, 2001).

An amendment (also known as a conditioner) is a material which when added to the soil can improve physical and chemical properties such as moisture, nutrient retention, permeability, water infiltration, drainage, aeration, structure, cation exchange capacity, and soil acidity. Organic matter is one of the identified soil amendments, and its results have been observed in several farmers' fields (Bwembya and Yerokun, 2001). Several types of organic amendments have been used to improve soil structure. Organic amendment practice is considered to be important for improving soil quality in agro-ecosystems. It has been noted that organic amendments increase soil fertility mainly by improving soil aggregate stability (Diacono and Montemurro, 2010; Zhang et al., 2014).

Soil aggregate stability is the ability of the bonds of the aggregates to resist disintegration when exposed to stresses causing their disruption such as tillage, swelling, and shrinking processes and kinetic energy of raindrops (Rohošková et al., 2014). Aggregation results from the rearrangement of particles through flocculation and cementation. Aggregate stability indicates general information about soil conditions (Rohošková et al., 2004). Soil aggregation influences transportation of liquids, gases, heat, as well as physical processes such as infiltration and aeration (Trinidad et al., 2012). It is an important soil functional unit for maintaining soil porosity and providing stability against soil erosion (Barthès and Roose, 2002; Cantón et al., 2009). Aggregate stability of soils can be measured by the dry sieving, wet-sieving or raindrop techniques. A reduction in soil aggregate stability implies an increase in soil degradation (Mbagwu, 2003).

1.2 Statement of the problem

Studies have been conducted to determine the effect of organic amendments on aggregate stability (Pan et al., 2017; Ouyang et al., 2013; Eusufzai et al., 2012;). Similar studies have been done in the sub-Saharan countries focusing on organically amended soils and the effects they present on each amendment in comparison to others (Mafongoya et al., 2016; Bouajila et al., 2011). However, research information on how organic amendments affect aggregate stability and organic matter distribution in the soil particle sizes and the degree of their effects in comparison to others appeared to be inadequate in zambia.

1.3 Justification of the study

This study involved smallholder farmers both in the selection and implementation process of the technologies. Consequently, the study enhanced understanding and lasting soil productivity instead of short-lived soil conditions that presented a great disappointment to soil productivity resulting in shifting cultivation. Further, the understanding on how organic amendments affect aggregate stability , the degree of their effects and the differences they present made it easier to set aside a blissful recommendation on which amendments easily enhanced organic matter and aggregate stability conditions.

1.4 Objectives

1.4.1 Main objective

The main objective was to assess the effect of selected organic amendments on dry soil aggregate stability and organic matter on two Zambian soils.

1.4.2 Specific objectives

1. To assess the effect of organic amendments on dry soil aggregate sizes on two Zambian soils.
2. To assess the effect of organic amendments on organic matter content in dry soil aggregate sizes of two Zambian soils.
3. To assess if there is a relationship between organic matter content and dry soil aggregate sizes on two Zambian soils.

1.4.3 Hypotheses

The null hypotheses for the study were as follows:

1. There is no significant difference in dry soil aggregate when different Organic amendments are applied to the soil.
2. There is no significant difference in organic matter content in different dry soil aggregate sizes.

3. There is no significant relationship between organic matter and different dry soil aggregate sizes.

The alternative hypothesis for the study was as follows:

1. There is at least a significant difference in dry soil aggregate between two or more organic amendments applied to the soil.
2. There is at least a significant difference in organic matter content between two or more dry soil aggregate sizes.
3. There is at least a significant difference between two or more correlations of organic matter and aggregate size distribution.

CHAPTER TWO: LITERATURE REVIEW

2.1 Soil Amendments

Use of chemical fertilizers plays a critical role in food production. However, long term use and application of chemical fertilizers reduce soil quality due to some adverse effects that may arise such as acidification and soil hardening (Blake et al., 1999, Li et al., 2011). In such cases, there is a need to reverse the effects where necessary to assure production. This could be done through the use of amendments such as lime, organic matter, and Zeolites.

An amendment is also known as a conditioner. Soil amendments may exist in two types organic and inorganic amendments. Soil amendments are used to amend depleted soils or to sustain soil productivity. They present several attributes that make them suitable for their purpose. Inorganic amendments such as Zeolites and limestone firstly have to be processed before application. As a result, due to value addition, these products are acquired at a fee which makes it difficult for small scale farmers. Thus, the focus on organic amendments that are cheap and easy to access.

2.3 Organic amendments

Organic amendments are those that are of organic origins such as from plant and animal remains. The use of organic amendments has been a big practice in most sub-Saharan Africa countries. Organic amendments have been observed to alter and improve the physical properties of the soil largely soil structure which subsequently has a direct effect on chemical, physical and biological soil properties. Improved soil structure means there are improved water holding capacity and redistribution as well as stable soil aggregates. Organic matter itself plays a dominant role in soil aggregation by increasing organic carbon (Tisdall et al., 1982) which increases the macro-porosity and then improves water infiltration (Martens and Frankenberger, 1992). Aggregation is influenced by the chemical composition of organic residues added to soils. Organic residues that decompose quickly may produce a rapid but temporal increase in aggregation, whereas organic residues that decompose slowly may produce a smaller but long-lasting improvement in aggregation (Sun et al., 1995). Organic amendments contribute several elements to the soil which may be directly important to plant growth and others may contribute to soil aggregation. For instance a study to determine effects of organic inputs on vegetable crops and on a subsequent maize crop grown in wetlands showed that soil inorganic N increased significantly from 11 mg in the unfertilized crop to 22mg in the Gliricidia treatments after cabbage, and from 10.3 mg to 37.2 mg after the onion crop (Mafongoya and Jiri, 2016). This contribution reduces amounts of fertilizer added. Further, a study conducted by Mweetwa et al., (2016) indicated that application of neem leaf extract at 10 % percent or higher could marginally improve soil Ca levels. This is vital to soil aggregation and as a nutrient to crops.

2.3.1 Contribution of Manure to soil physical properties

Several researchers have reported that farmyard manure can be potentially beneficial for soil physical, chemical and biological properties (Li and Zhang 2007, Ludwig et al., 2007, Liu et al. 2009, Li et al., 2011). Li et al. (2011) observed higher soil dissolved organic carbon and hot water extractable organic carbon contents in poultry litter and livestock manure treatments and a highly positive linear correlation between soil dissolved organic carbon, hot water extractable organic carbon and total porosity. On the contrary, Leelamanie et al. (2013) found that almost all the cow dung added samples showed extremely low percentages of water-stable aggregates demonstrating rapid destruction of aggregates. This is because aggregate floating occurred, showing the risk of aggregate floating with runoff water.

Other studies on the influence of manure on soil aggregates size distribution have reported no treatment effect (Bhatnagar et al. 1985; Hao et al. 2004), a shift to larger aggregates (Mbagwu and Piccolo 1990; Ogunwole 2005), or a shift to smaller aggregates (Whalen and Chang 2002). Other studies found that farmyard manure increased larger (1.60 mm) compared to smaller (0.13 to 0.9 mm) aggregates (Ogunwole

2005), or cattle manure slurry caused a slight increase in larger (2- 4 mm) dry-sieved aggregates compared with unamended soils (Mbagwu and Piccolo 1990). In contrast, Whalen and Chang (2002) indicated that a long-term (25-yr) solid feedlot manure application shifted aggregate sizes (rotary sieve) from larger (>7.1 mm) to smaller (0.47-1.2 mm) aggregates. The latter authors concluded that such soils might be a higher risk for wind erosion because finer (0.84 mm) soil aggregates in the semiarid prairies are more susceptible to wind erosion (Campbell et al. 1993; Larney et al.1994).

2.3.2 Contribution of Sunnhemp to soil aggregation

Due to Sunnhemp's many benefits, It has been recommended that farmers grow their maize with 80 kg/ha of Sunhemp and use it as mulch seven weeks after planting (Mabuza et al., 2016). Calonego et al. (2017) showed that Sunhemp is an interesting species to be included in the rotation due to its capacity to increase soil macroporosity in clay soils with poor aeration. It was found that mechanical management of soil compaction would not be the best option since it can be substituted by cover crops, especially sunn hemp, which resulted in an average increase of 183 kg/ha in soybean yields in 10 seasons. It was further noted that one of the factors explaining this increase was increased soil macroporosity, which was very low at the beginning of the experiment. This could be due to root growth in the soil profile which favors particle aggregation and so the remediation of degraded or compacted soils (Castro et al., 2011).

Mecedes et al. (2005) indicated that when analyzing absolute values of Mean weight diameter (MWD), Sunn-hemp improved stability on 18 November 2002 (3.57 mm) and 18 December 2003 (3.49 mm). Reinert (1993), working with gramineous and leguminous as aggregation recovering agents, found vast seasonal variation and concluded that experiments conducted with few analyses could lead to erroneous interpretations. Further stated that to evaluate the transitory effects of the cover plants in soil parcels, a sampling in a shorter space of time and throughout several years would be appropriete.

The effects of the residues of crops and cover plants on soil aggregation are dependent on the quality, quantity, and type of management used with this added material (degree of residue fractionation), apart from climatic factors and the specific characteristics of the soil (Gilmour et al. 1998; House and Stinner 1987).

Aggregation is influenced by the chemical composition of organic residues added to soils. Organic residues that decompose quickly may produce a rapid but temporal increase in aggregation, whereas organic residues that decompose slowly may produce a smaller but long-lasting improvement in aggregation (Sun et al 1995).

2.3.3 Contribution of Tephrosia Vogeli to soil aggregation.

Tephrosia vogelii is native to tropical Africa. It is found in widely varying habitats, including savanna-like vegetation, grasslands, forest margins and shrublands, waste lands and fallow fields. It occurs in climates with an annual rainfall of 850-2650 mm and annual mean temperature of 12.5-26.2^{o} C and is found up to 2100 m altitude. *Tephrosia vogelii* is a known nitrogen fixing species, cultivated as green manure in Indonesia and many other parts of Africa (Mwaura et al. 2014).
It is used as a soil improver in central Africa, Indonesia, the Philippines, and Peninsular Malaysia it is used as green manure, e.g., in coconut plantations (Orwa et al.2009). Green manures have the potential to increase soil organic matter (Allison, 1973) and reduce erosion (Creamer et al., 1997) and thus improve the physical characteristics of the soil. Munthali et al. (2014) found that there was an increase in Soil Organic Matter (SOM) in some plots for both *T. vogelii* and *T. candida* fallows. The increase in SOM ranged from 1.5% to 32.7%.

2.3.4 Contribution of Cowpea (Modified Fundikila) to soil physical properties

Fundikila is a practice in which plant biomass, mostly grass and other vegetative matter, is buried in big ridges towards the end of the rainy season . Oliveira et al (2019) conducted a study in the topsoil (0-20 cm) by wet sieving that revealed despite differences in carbon (C)inputs to the soil, soil organic carbon (SOC) storage was not enhanced with legume cultivation and indicated that this may be due to the short duration of the experiment or to the low clay content (10%) and very low reactivity of the clay-size minerals (kaolinite-dominated) of the soil, which seem to have weakened SOC protection.

However, non-cultivated controls had up to three times higher SOC stocks, indicating that organic C can be stored in this soil under adequate conditions. Nonetheless, a legume-effect on soil aggregation was observed. Introducing irrigated cowpea in the rotation maintained soil structure, as evidenced by a similar macroaggregate (Magg) (> 250 μm, Magg) content to the baseline, which was deteriorated in the fertilized cereal monoculture in the respective site (less Magg than the baseline).

2.3.5 Contribution of Pigeon Pea to soil physical properties

Saha et al. (2011) indicated that soil physical properties, namely, bulk density, hydraulic conductivity of bulk soil and the mean weight diameter of aggregates did not show any significant difference between initial (before sowing of Pigeon pea) and final (after crop harvest) stage. The oxidizable organic carbon increased to nearly 1.5-fold (from an initial level of 1.12% to 1.72%) under elevated CO_2 conditions although for ambient it decreased by 0.94%.

Nascente and Ston (2018) showed that improvement in soil physical properties under cover crops, especially under millet + pigeon pea and millet + pigeon pea + *Urochloa*, is due to the beneficial influence of grasses on the structure and stability of soil aggregates, as demonstrated by several other researchers (Tisdall and Oades, 1979; Silva and Mielniczuk, 1997; Rilling et al, 2002). This is attributed to the high root density, which promotes the aggregation of the particles by the constant soil water uptake, periodic renewal of the root system and the uniform distribution of soil exudates, which stimulate microbial activity, whose byproducts act in the formation and stabilization of aggregates (Silva and Mielniczuk, 1997).

2.3.6 Contribution of Traditional Fundikila to soil physical properties.

The traditional Chitemene and fundikila shifting cultivation systems in northern Zambia and its surroundings heavily depend on exploiting miombo litter (Matthews et al., 1992). Several factors affect the response of crops to the application of transferred biomass and have been reviewed by Rao (1994). Major factors are the chemical composition of the litter of different species and the method and timing of application. Results obtained in Zambia illustrate the impact of these factors. These results confirm that incorporation of the litter into the soil close to the time of maize planting produces the greatest maize yield response. However, with species that decompose rapidly (such as gliricidia and sesbania), the timing is less critical, and incorporation may be delayed for 3 or 4 weeks after planting (Read et al., 1985).

2.3.7 Effect of Conventional Tillage on soil physical properties

Tillage systems have shown to have a direct influence on Organic matter content of the soil and aggregate stability (Guerif et al., 2001). Aziz et al. (2013), observed a significant impact of no-tillage on different physical-chemical and biological parameters. They estimated significantly higher soil quality index in soil under No-till than conventional tillage. According to Hernanz et al. (2002), aggregate stability could be an indicator of soil quality, directly related to OM. Mecedes et al. (2005) observed that conventional tillage had the highest OM value of 39 g/dm^3 and the highest MWD of 3.89 mm compared to OM value obtained in no-till the field. They further observed that under these conditions, the contents of OM decreased concurrently with a decrease in the MWD of the aggregates. Further, MWD was observed to decrease by 1.18 mm at a depth of 0–5 cm with respect to 3.89 mm MWD at initial project intervention (Mecedes et al., 2005). Moreover, in a 20-year study using maize in Kentucky, the researchers found that the higher content of OM is confined to the top 5 cm of soil (Ismail et al., 1994).

2.3.8 Effect of Soil Organic Carbon on soil physical properties

Nutrient distribution within different sized aggregates is important because root growth and nutrient uptake are generally greater in smaller than larger aggregates (Wiersum 1962; Cornforth 1968; Misra et al. 1988; Wang et al. 2001). Some studies have reported greater C, N, and P concentrations in larger compared with smaller aggregates (Bhatnagar and Miller 1985; Bhatnagar et al.1985; Hao et al. 2004), while others found the reverse trend (Mbagwu and Piccolo 1990; Whalen and Chang 2002). Mbagwu and Piccolo (1990) applied cattle slurry to a Cremona soil in Italy and generally found greater concentrations of total C, total N, and available P in smaller (0.25 mm) than larger (0.25 to 4 mm) dry-sieved aggregates. Whalen and Chang (2002) found that dry-sieved aggregates in soils amended with feedlot manure for 25 yr tended to have the highest total C, N, and P contents in the smaller (0.47 to 2.0 mm) than larger (2 to 38 mm) fraction. Contrary, some other researchers have observed that the correlation between organic matter and MWD is not always significant and that some values for MWD determined may not always correspond with the organic matter (Tisdall et. al, 1982, Mercedes et al., 2006). Mecedes et al. (2005) found that sampling dates for the horizon 0–5 cm and at 5–15 cm differences were not significant.

In a study to compare forest soils and tea garden, soils in the forest had higher organic matter than those of tea garden at 0-30 cm depth (Abrishamkesh et al., 2010). Abrishamkesh et al.(2010) further found that Mean weight diameter, geometric mean diameter of aggregates and weight percent of aggregates in > 4 mm class were significantly greater in forest soils, but weight percent of aggregates in the smaller diameter class of 0.5-0.25 mm and fractal dimension of aggregates were greater in tea garden soils at 0-30 cm depth.

2.3.0 Effect of organic amedments on Soil moisture retention

Mohawesh *et al*. (2005) showed that the saturated water content decreased with the increase in bulk density, and as a result, the inflection point on the retention curve shifted to a lower matric potential. Tuli *et al*. (2005) reported that the air and water permeabilities of undisturbed soil samples were significantly higher than those of disturbed samples, attributed to the changes of soil structure and macro-pore (Ouyang et al.,2013).

A study was done by Eusufza et.al (2012) to examine the effect of compost, rice straw, and sawdust amendment showed that volumetric water content increased in all amended soils, compared with the control.

A research conducted by Thierfelder et. al (2009) focusing on the effect of CA techniques on soil moisture relations in two researcher-managed trials in Zambia and Zimbabwe indicated significantly higher water infiltration on both sites on CA fields compared to conventionally ploughed fields.

A study set to examine the effect of compost, rice straw and sawdust amendment on hydraulic and m3/m3 pore characteristics of a clay loam soil. With amendments applied at an application rate of 0.2 (apparent soil m2. volume) in three rectangular plots each comprising an area of 3.0. Volumetric water content increased in all amended soils, compared with the control. Unsaturated hydraulic conductivity was almost identical for straw and sawdust at all pressure heads, al- though that for compost amended soils were much higher. Field saturated hydraulic conductivity (Kfs) was higher in organic matter amended soils as were a number of macropores (14.7% - 29.2%). Contribution of each pore class to the total saturated flux was evaluated from the hydraulic conductivity and water retention measurement. Collectively, results demonstrated that organic matter generated as an agricultural by-product could effectively be used to improve soil quality (Eusufzai et al., 2012).
Despite these findings in other countries, a comparison of the effects of organic amendments on hydraulic properties lacks in Zambia.

2.4.1 Use of organic amendments in Zambia

With declining fertility levels of soils and the high cost of agricultural inputs, such as commercial fertilizers and pesticides, the use of organic inputs has increased in Zambia over the years (Mweetwa.,2016). This is the reason for Zambia in particular since 1996, has had a growing coalition of stakeholders from the private sector, government and donor communities that has been promoting a new package of agronomic practices for smallholders farmers to improve soil nutrient composition (Haggblade et al.,2003). Most farmers are unable to adequately procure fertilizers for their fields, mostly and partly due to high costs of fertilizers which exacerbates lower maize yields resulting in food insecurity. Following these practices, several research works have been done to determine nutrient addition and soil structure quality.

Several studies in the last decade conducted in eastern Zambia demonstrated the dramatic potential of two- or three-year sesbania fallows in restoring soil fertility and increasing maize yields. Analyses showed that these improved fallow systems were feasible, profitable, and acceptable to farmers (Kwesiga et al., 1999). The practices have proven signs of improving soil nutrient composition and specific benefits include increased organic matter, improved water retention, improved soil fertility, reduced soil erosion, reduced weed infestation and crop productivity (Sosola et al., 2010).

Fertilizer application is known to increase crop yields and mitigate net soil nutrient mining due to continuous removal. However, smallholder farmers rarely apply adequate fertilizers because of high cost, limited availability and lack of awareness.

An experiment was conducted to evaluate the effect of chicken manure on cassava root and biomass yield at Kabangwe and Mansa, two locations representing agroecological zones II and III, respectively, in Zambia. To explore alternatives to soil fertility management for smallholder farmers, the effect of sole chicken manure and mineral fertilizers was evaluated on cassava. The study showed that the application of chicken manure significantly increases the yield and biomass production of cassava and is economically efficient. (Biratu et al., 2018).

2.4.3 Soil structure

Most of the soils have proved to be poor in most parts of Zambia (CF, 2007). Most of the farm fields are left to farrow or abandoned after a few years of use (CF, 2007). After which farmers move on to other fields. There is ample evidence that the methods we currently use to grow crops are destroying our land and undermining our future (CF, 2007).

Soil structure is a critical soil property, which influences many processes in the soil. It is stability expressed by the stability of soil aggregates, directly or indirectly influences other physical, chemical and biological properties of the soil and can be used as an indicator of soil degradation (Rohošková et al.,2004).

A soil with a good structure consists of aggregates that have a good distribution of both small and large pores. The pores allow for the entry and movement of water and air into the soil. The small pores are essential for the retention of water, while the large pores are essential for the movement of air and water in the soil profile. Large pores allow water to easily move or percolate through the soils when the soil is wet or saturated with water and reduces the chances of water stagnation especially after heavy rainfall (Shitumbanuma, 2012).

2.4.3 Physical fertility and Aggregate stability

Soil aggregation is considered a soil quality indicator that provides information on the soil's ability to function as a basic component of the ecosystem. Soil aggregation influences the transportation of liquids, gases, and heat, as well as physical processes such as infiltration and aeration (Nimmo, 2004). Soil aggregation integrates edaphic properties (physical, chemical, and biological), it is easy to measure, and it is sensitive to variations due to weather and land use (Seybold and Herrick, 2001). Also, it is a good indicator of soil erosion and degradation (Ruiz-Sinoga and Martinez-Murillo, 2009). Consequently, it is considered an excellent tool to evaluate soil quality (Martínez-Trinidad1 et al., 2012).

Soil aggregate stability is an important parameter affecting soil credibility and soil crusting potential and plays a key role in ecosystem functioning as it affects water, gas and nutrient fluxes and storage and, therefore, influences the activity and growth of plants in the soil (Owusu et al.,2015).

Soil texture plays an important role in the development of root, retention of water, the capacity of infiltration and porosity of soil (Neves et al., 2003). Structural stability describes the ability of the soil to retain its aggregation and pore space when exposed to external forces such as wind, water, cultivation/tillage (Nweke et al.,2015).

2.4.4 Cementing agents in the soil

Many substances act as cementing agents in the soil. These include carbonates, Clay particles and end products of decomposition in the soil. Soil organic carbon acts as a binding agent and is the key constituent in the formation of aggregates (Tisdall and Oades, 1982; Bronick and Lal, 2005; An et al., 2008)

Aggregate formation and stabilization promotes long term carbon sequestration and soil structural stability and is affected by various factors, including clay content, and types and amount of soil organic matter (SOM) (Six et al., 2004). Organic materials are the main agents of formation and stabilization of macroaggregates, including persistent cementing agents, such as humic matter, and transient and temporary bonding agents, such as fungal hyphae and microbial extracellular polysaccharides (Six et al., 2004). Acting as a habitat and substrate for soil microorganisms, biochar added Aggregate in the soil can increase microbial activities formation and stabilization promotes long term carbon (Pietikäinen et al., 2000) Organic materials are the primary agents the adjacent Oxisols (Lehmann and Joseph, 2009)(Wang et al.,2013).

2.4.5 Aggregate Stability indices

There are several aggregate stability indices that can be considered. A typical example and, perhaps, the mostly widely used of such indices is the mean-weight diameter (MWD) of aggregates. The use of such indices to assess erodibility may prove suitable in temperate soils, but may not in highly weathered tropical soils known for their oxyhydroxide mineralogy and very stable microgranular structure (Igwe et al., 2013). The aggregate distribution is mainly determined using the dry sieving method (Chepil, 1952), and aggregate stability is determined using the Yoder method (modified by Kemper and Rosenau, 1986).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study site location and description

The study was carried out at two sites namely Msekera research station in Eastern province and Misamfu research station in Northern Province of Zambia. Misamfu study site is located along latitude 10°10′ S and longitude 31° 26′ E. With an elevation of 1536 m above sea level, this area receives an annual average rainfall of 1000 mm. The soil in this area is characterized as Ferrasol with the classification of map units according to the FAO/UNESCO soil map of the world legend Figure 1.

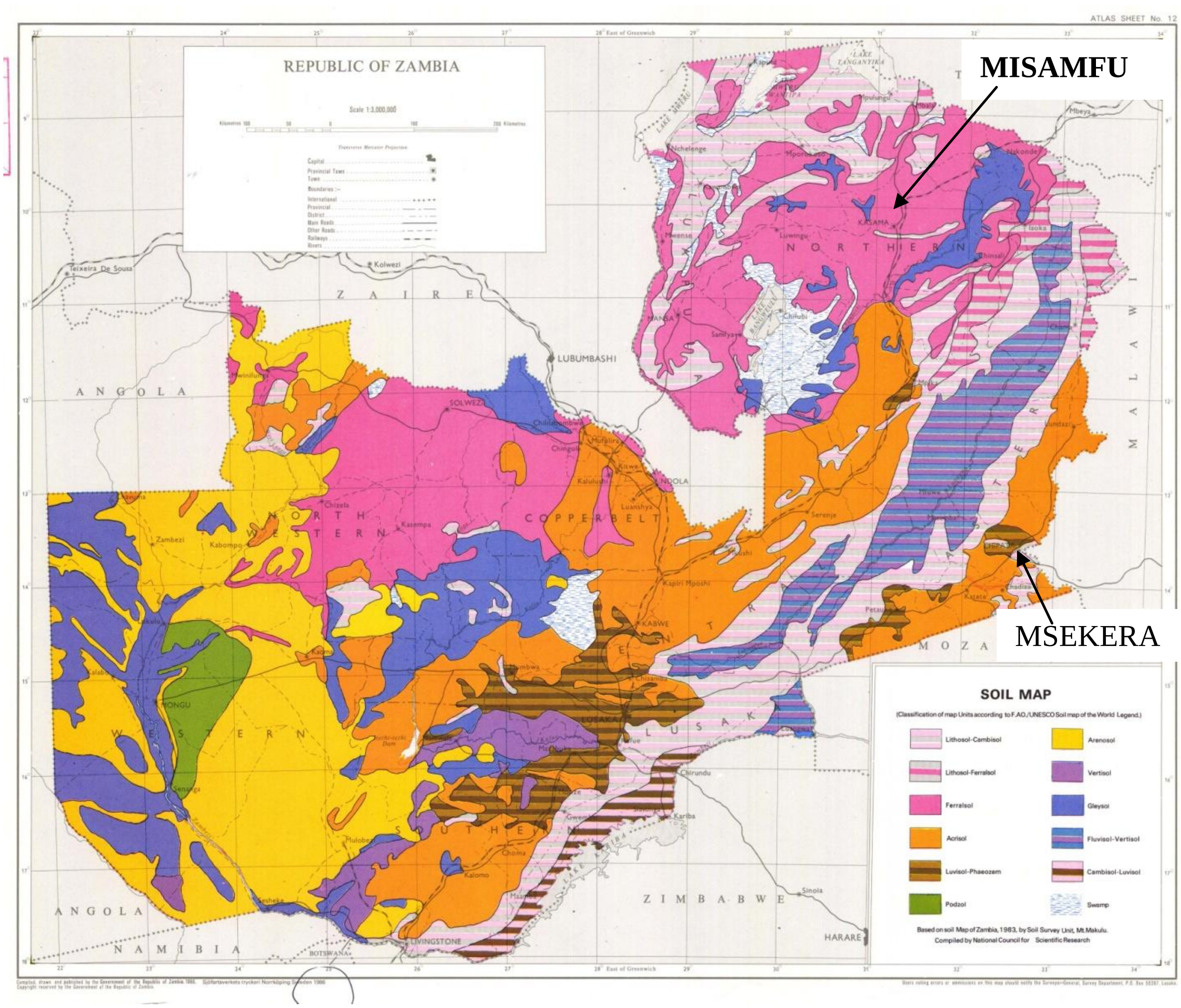


Figure 1: Soil Map of Zambia (Source: Soil Survey, 1983)

Msekera research station is located along latitude 13° 38′ S and longitude 32° 39′ E with an altitude of 1025 m. The area receives an annual rainfall of between 800mm to 1000mm. The soils at Msekera were loamy ferric luvisols according to the FAO/UNESCO classification.

3.2 Experimental design and description of treatments

The trials were set in a randomized complete block design (RCBD) for a period of three seasons in both sites; 2015/16, 2016/17 and 2017/18 farming seasons. The treatments in Misamfu where traditional Fundikila, modified Fundikila, Conventional farming, tephrosia Vogeli alley cropping and pigeon peas alley cropping all replicated four times as shown in Table 1 below. At Msekera, the treatments were conventional farming, tephrosia alley cropping, pigeon peas alley cropping, Sunnhemp interplant and animal manure as shown in Table 1 below.

Table 1: Treatment design for the experiment

Study Site	**Treatments**	**Replicates**
Kasama	Traditional fundikila + ½ rate fertilizer	4
	Modified fundikila + ½ Fertilizer rate	4
	Conventional farming + recommended rate of fertilizer	4
	Tephrosia vogelii alley cropping + ½ rate of fertilizer	4
	Pigeon peas alley cropping + ½ rate of fertilizer	4
Chipata	Conventional farming + recommended rate of fertilizer	5
	Animal manure + ½ rate of fertilizer	5
	Pigeon peas alley cropping + ½ rate of fertilizer	5
	Tephrosia vogelii alley cropping + ½ rate of fertilizer	5
	Sunnhemp interplant + ½ rate of fertilizer	5

3.2.1 Traditional fundikila

This is a practice in which plant biomass, mostly grass and other vegetative matter, is buried in big ridges towards the end of the rainy season, from March to April. Before the start of the subsequent rainy season, the ridges are flattened to spread the buried organic matter in the field. The farmer can then plant crops on the flat surface, or smaller ridges will be made where the crop will be planted.

3.2.2 Modified fundikila

As opposed to the traditional fundikila, instead of burying grass or other biomass that have low nutrient levels, this practice involved the growing of a green manure crop (velvet beans), which would then be buried in the big ridges. The rest of the procedure was the same as the traditional fundikila.

3.2.3 *Animal manure*

Cattle manure was used as basal and top dressing fertilizer at rates of 10 tons per hectare. This was an arbitrary rate whose choice was guided mainly by the nutrient (mostly N, P, K) requirement of maize and the practical aspects of obtaining, transporting and applying the manure by the farmers.

3.2.4. *Tephrosia and Pigeon pea alley cropping*

Tephrosia seed was drilled in between the lines maize. To encourage more biomass formation and reduce the possibility of the Tephrosia forming big woody branches, a very close spacing was used. Depending on the growing vigor, the Tephrosia would have to be trimmed once or twice during the rainy season to avoid shading the main crop. The biomass from the trimming will be used as mulch in between lines of the main crop. For pigeon pea alley cropping,the planting and the management was similarly done as for Tephrosia alley cropping.

3.2.5 *Green manure interplants*

Black sunnhemp was planted in between the lines of the maize after the first weeding of the main crop. However, due to erratic rainfall, the planting of sunnhemp was delayed at all the on-farm trials. This resulted in a poor establishment of the sunnhemp as the maize crop was shading it. It was envisaged that the green manures was to be trimmed once during the growing season to avoid competition with the main crop, but due to the poor establishment, the Sunnhemp was only trimmed at the on-station trial plot and not at the on-farm trials.

3.2.6 *Conventional farming*

Conventional farming refers to the chemical fertilizer-based farming system that is widely practiced by most of the small scale farmers in Zambia. This system is characterized by maximum soil disturbance and heavy reliance on chemical fertilizers. This treatment consisted of maize being planted on small ridges and fertilized at a rate of 200 kg/ha D

3.3 Agronomic practices

3.3.1 Land preparation

Except for the conventional plots, land preparation in all the 10 m by 10 m trial plots consisted of making conservation basins spaced at 90 cm inter-row and 70 cm intra-row. This gave a total of 11 rows and 157 basins per plot. For the pigeon pea and tephrosia alley cropping, small shallow planting holes were made by use of a hoe. The sunnhemp was planted on loosened soil after the first weeding of maize. In the conventional plots, small ridges spaced at 1 m apart were used. This is the common cultural practice among the farmers.

3.3.2 Pigeon pea and Tephrosia

The alley cropping of both maize-pigeon pea and maize-tephrosia consisted of a 1:1 row proportion. One row of pigeon pea or tephrosia every after a row of maize. Based on this, the pigeon peas and tephrosia were planted at an inter-row spacing of 90 cm (to suit the spacing of maize) and intra-row spacing of 10 cm and 30 cm for tephrosia and pigeon pea respectively.

To ensure that the required plant population was achieved, a higher seed rate was used. Tephrosia was drilled along small furrows in between the maize lines. Thinning was later done to achieve a spacing of 10 cm from plant to plant. Four seeds of pigeon pea were initially planted per station. These were later thinned to three.

It was envisaged that tephrosia and pigeon peas will be planted only once in the 2015/16 season. In the 2016/17 and 2017/18 seasons, trimming off the tephrosia and pigeon peas was done to prevent shading of the maize. The number of times of trimming was dependent on the vigor with which the two species grew. To avoid killing the tephrosia and pigeon peas, trimming was only done during the rainy season. Both the tephrosia and pigeon peas were planted at the same time as maize.

ZPP 14 (*Mwayi watu*) and *Tephrosia vogelii* were the varieties of pigeon peas and tephrosia, respectively that were used.

3.3.4 Sunnhemp

The sunnhemp seed was broadcasted in-between the lines of maize at a rate of 200 kg/ha translating to 2 kg per plot after the first weeding of maize. This high seed rate was to ensure maximum soil cover and more biomass production.

Attempts were made to ensure that the Sunnhemp seed produced at the end of the 2015/16 season was left in the field to germinate in the 2016/17 season. This allowed dibble planting of maize in between the germinating Sunnhemp plants in the 2016/17 season and ensured that Sunnhemp was planted once.

3.3.5 Basal dressing Fertilization

Cattle manure was applied at a rate of 10 ton/ha, translating to about 625 g per basin. At this rate, approximately 46.5 kg N, 24.5 kg P and 23.5 kg K was supplied per hectare (based on the test results on KATC manure done by UNZA - June 2013). Half of the recommended rate of D compound was applied in combination with the cattle manure to supplement the N supplied through the manure which was less than half of that required for the growth of a maize crop.

3.3.6 Top dressing fertilization

Cattle manure for top dressing was used at a rate of 10 tons/ha or 625 g per basin. No synthetic fertilizer was to be applied as a top dressing to the manure plots. In one set of conventional plots, the recommended rate of fertilizer of 200 kg/ha urea was t applied.

In the other conventional plots, half of the recommended rate of chemical fertilizer was used. Some plots with Sunnhemp and pigeon pea interplants received a half rate of chemical fertilizer (100 kg/ha D-cpd and 100 kg/ha urea) while the other plots with these interplant received the recommended rate of fertilizer in the first year. With more biomass forming in the second year, a lower rate of fertilizer or no fertilizer at all was applied to the plots having pigeon pea and Sunnhemp interplants.

3.4 Soil Sampling

A sampling of soils was conducted in April 2018 at the end of 2017/2018 agricultural season. This was the third season after project intervention. Soil samples were obtained from existing plots from the top 0-10 cm within each plot using a hand hoe. The 10 m 10 m plots were sub-divided into four (4) quadrants from which an approximately 1.5 Kg sample was collected from each quadrant, and a fifth sample was collected from the centre of the quadrants. For each site Msekera in Chipata and Misamfu in Kasamaa total of 125 samples for five (5) treatments and five (5) replications and a total of 187.5 Kg were collected for all the on station treatments for soil aggregate stability determination, three (3) composite samples for soil characterization and 125 undisturbed samples for hydraulic properties.

3.4.0 Soil characterization

Two composite samples where collected from each site Misamfu and Msekera from which soil characterization was based. The soil was characterized for pH in 0.01 M $CaCl_2$, cation exchange capacity (CEC), organic matter using the Walkley and Black Method, total nitrogen using Kjeldahl method and soil texture using the hydrometer method..

3.4.1 Measurement of Soil Reaction (pH)

10 grams of air dried soil was weighed into 50 ml plastic bottle to which 25 ml of 0.01M $CaCl_2$ was added. The suspension was then shaken on a mechanical shaker for 30 minutes. After shaking, the pH of the suspension was measured using a digital pH meter with a glass-calomel electrode.

3.4.2 Determination of Exchangeable Acidity

Ten (10) grams from each of the composite samples was weighed into 100 ml plastic bottles to which 100ml of 1M KCl was added. The suspension was shaken on the mechanical shaker for 1 hour. After shaking, the samples were filtered and 25 ml of the filtrate was pipetted into 250 ml flat conical flasks to which 100 ml of distilled water was added and mixed thoroughly. Later 5 drops of phenolphthalein indicator were added to the solution. The solution was titrated with 0.01N NaOH to a permanent pink end point. The volume of base consumed was used to calculate the total exchangeable acidity of the soil samples.

Equation 1:

$$\frac{meq}{100g} = \frac{eq}{L}\ (Vol\ s - Vol\ b)mL * \left(\frac{Vol\ of\ extract}{Vol\ of\ aliquot}\right) * \frac{100}{g\ sample}$$

Where;

Vol s = Volume of NaOH used to titrate against sample

Vol b = Volume of NaOH used to titrate against blank

3.4.3 Determination of Organic Carbon Content

The Organic Carbon content was determined using the Walkley and Black Method. One gram of soil from each replicate was weighed into a 250 cm^3 conical flask to which 10 ml of 1.0 N potassium dichromate ($K_2Cr_2O_7$) was added using a pipette. Then 20 cm^3 of concentrated sulphuric acid (H_2SO_4) was added rapidly using an automatic pipette under fume hood. The mixture was swirled gently until soil and solutions were mixed then it was swirled vigorously for one minute. The suspension was left in a fume hood for 30 minutes, and then 150 cm^3 of distilled water and 10 cm^3 of concentrated phosphoric acid (H_3PO_4) were added. Ten drops of the diphenylamine solution indicator was added and titrated with Iron (II) sulphate solution up to green colour end point. The volume of Iron (II) sulphate consumed was recorded and later used to calculate soil organic carbon content.

Equation 2:

$$\%OC = \frac{4[N\ (Vol\ b - Vol\ s)]x100}{mass\ of\ soil\ (g)}$$

Where

%OC = percentage organic matter content of the soil

Vol b = volume (L) of iron (II) sulphate used to titrate against blank

Vol s = volume (L) of iron (II) sulphate used to titrate against sample

N = normality of iron sulphate

3.4.4 Determination of Total Nitrogen Content

1 gram of soil of each compsite samples sieved through 2.00 mm was placed into Kjeldah flasks, and then 3 grams of mixed catalyst and 10 ml concentrated sulphuric acid were added. The flasks were placed onto the Kjeldah digestion block. The samples were digested for 45 minutes after which they were removed from heater and allowed to cool. The digest were transferred quantitatively from the flasks into 100 ml plastic containers and made to 100 ml volume with distilled water. Fifteen (15) ml of the digest and 10 ml of 10M NaOH were put into the distillation flasks. The distillate was collected for 5 minutes in a conical flask containing 15 ml boric acid indicator solution. Later the captured distillate was titrated with 0.01M HCl until the colour changed from green to purple, the volume of acid consumed was used to calculate percentage total nitrogen in the sample. The following formula was used to find the percentage N content of the soil.

Equation 3 :

$$\%N = \frac{eq}{L} * (Sample\ Vol - Blank\ Vol)L * \frac{14gN}{eq} * \frac{extract\ Vol}{aliquot\ Vol} * \frac{1}{gsoil} * 100$$

3.4.5 Determination of Bray 1 Available Phosphorus

The Bray 1 method was used to extract phosphorus from the soil. Three grams of air dry soil that had passed through a 2 mm sieve was weighed into a plastic container of approximately 50 ml to which 21 ml of the extracting solution was added. The extracting solution was made by adding 15 ml of 1M NH_4F and 25 ml of 0.5M HCl to 460 ml of distilled water. The suspension was shaken for one minute on the mechanical shaker after which it was filtered. Reagent B was prepared by dissolving 1.056 g of ascorbic acid into 200 ml of reagent A. For reagent A, ammonium molybdate was dissolved in 25 ml of distilled water, 0.29 g of potassium antimony titrate in 100 ml of distilled water and mixing them with 2.5M H_2SO_4 in a 2000 ml Volumetric flask and making up to volume with distilled water.

From the filtrate 5 ml was pipetted into a 25 ml volumetric flask and 4 ml of reagent B was added to it before making up to the volume with distilled water, then the solution was allowed to stand for 15 minutes to allow the colour to develop. After standardizing the spectrophotometer with a blank and a 1 ppm P solution the concentration of P in samples were read at a wavelength of 882 nm. The formula below was used to convert milligrams of P per litre solution (mgP/L) to milligrams of P per kilogram of soil.

Equation 4

$$\frac{mgP}{kg} = Reading\left(\frac{mgP}{L}\right) * volume\ of\ extrac(L) * \frac{1}{gsoil} * DF * \frac{1000g}{kg}$$

3.4.6 Determination of CEC in Ammonium Acetate Buffered at pH 7

The CEC of the soil was determined using the leaching method. Five (5) grams of air dried soil was put on Whatman No. 1 filter paper which was mounted on the funnel. Then 4 portions of 25 ml 1M NH_4Ac buffered at pH 7.0 were leached through the soil followed by 4 portions of 25 ml of ethanol. Later 2 portions of 25 ml 1M KCl were leached through the soil, 15 ml of KCl leachate was distilled and the distillate was captured in 10 mL boric acid indicator for 5 minutes. The distillate was titrated with 0.01N HCl and the volume was used to determine the CEC of the soil using the formula indicated below.

Equation 5 :

$$\frac{meq}{100g} = \frac{eq}{L}(\ Vol\ s - Vol\ b)mL * \left(\frac{Vol\ of extract}{Vol\ of\ aliquot}\right) * \left(\frac{100}{g\ sample}\right)$$

Where;

Vol s = Volume of HCl used to titrate against the sample

Vol b = Volume of HCl used to titrate against the blank

3.4.7 Determination of Exchangeable Ca, Mg and K

Ten grams of soil was weighed in 100 ml plastic containers to which 50 ml of ammonium acetate (1M NH_4OAc) buffered at pH 7.0 was added. The sample was shaken for 30 minutes on the mechanical shaker and then filtered using Whatman No. 1 filter paper. From the filtrate concentrations of potassium (K) and sodium (Na) were measured on Atomic Absorption Spectrophotometer using Emission. For Ca and Mg, 5 ml was obtained from the filtrate and transferred into a 25 ml volumetric flask to which 5 ml of 5000 ppm strontium chloride ($SrCl_2$) solution was added and this was made up to the volume with Ammonium acetate. Concentrations of Ca and Mg were then determined on the Atomic Absorption Spectrophotometer (AAS) AAnalyst 400, PerkinElmer. The concentrations of cations in solution were read in mg/L. The concentrations of the cations were converted from mg/L to cmol/kg of soil using the following formula.

Equation 6:

$$\frac{cmol\ cation}{kgsoil} = \frac{mg}{L} * extract\ Vol\ (L) * \frac{1}{gsoil} * DF * \frac{1000g}{kg} * \frac{cmol}{mg\ of cation}$$

3.4.8 Determination of Total N

In order to determine total N in the soil samples, 0.5g of the sample was put in digestion tubes to which 7 ml of H_2SO_4 plus salicylic acid was added. The mixture was left to stand for 30 minutes then 1 g of sodium thiosulphate was added, shaken and left to stand for 15 minutes. Later 3 ml of concentrated sulphuric acid and 1 g of mixed catalyst were added and then the sample was digested on a digestion block. After digestion, the content were transferred quantitatively from the tubes to 100 ml plastic containers and made to the mark. The distillation process was done as in 3.3.5.

Equation 7

$$\%N = \frac{eq}{L} * (Vol\ s - Vol\ b)L * \frac{14gN}{eq} * \left(\frac{Vol\ of\ extract}{Vol\ of\ aliquot}\right) * \frac{1}{g\ sample} * 100\%$$

Where;

Vol s = Volume of HCl used to titrate against the sample

Vol b = Volume of HCl used to titrate against the blank

3.4.9 Soil Texture

50 grams sample of air dried soil was weighed and placed in a dispersing cup. Then, 50 ml of 5% Calgon(Sodium hexametaphosphate solution) dispersing agent was added and half-filled the cup with distilled water. The mixture was then stirred continuously for 5 minutes. The suspension was transferred into the sedimentation cylinder using a stream of water and brought the level of the liquid to the mark with distilled water. The temperature of the suspension was then measured. The plunger was then inserted and mixed the contents thoroughly by moving the plunger up and down. Twenty seconds after removing the plunger, a hydrometer was carefully lowered and the reading was taken after 40 seconds to determine the silt and clay content.Another reading was taken after 2 hrs to determine the clay content . Then the textural class was obtained from the particle size analysis on the USDA Textural Triangle.

3.5 Mean Weight Diameter dry (MWDD)

The mean-weight diameter of dry aggregates was measured by the method described by the Kemper and Chepil (1965). Instead of 250g of soil aggregates, a 100g of dry soil aggregates, initially sieved through a 9.5mm and retained on 8 mm sieve was placed on top of a nest of sieves of diameters 8, 6.35, 4.75, 2.8, 1 and 0.5mm enclosed on top with a collector at the bottom and determining the mass of aggregates on each sieve that resists break down after mechanically shaking for 10 minutes. The mean weight diameter of dry aggregate (MWDD) was then computed using equation 8 below.

Equation 8:

$$MWDD = \frac{\sum_{i=1}^{n}(XiWi)}{\sum_{i=1}^{n} Wi}$$

Where :

MWDD is mean weight diameter of dry aggregates

$\bar{x}i$ is the mean diameter between the two sieves (mm); and

Wi is the weight fraction of aggregates remaining on the sieve (%)

3.6 Percent soil Organic matter in aggregate fractions

For every set of dry aggregates retained on each sieve, Organic matter was determined to determine its influence on aggregation. The loss-on-ignition (LOI) method for the determination of organic matter was used. This method involved the heated destruction of all organic matter in the soil.

Soil retained on each sieve from samples was crushed with pestle and mortar. Then 3 to 5 g of soil was weighed into a previously weighed metallic cane and dried in a drying cabinet for 24 hours at 105 °C. The metallic cane with the sample was left to cool in desiccators then weighed.

To determine loss on ignition, approximately 1-3 grams of oven dry sample was weighed onto the crucibles. The crucibles with the dried soils were placed in the calcinating oven and calcinated for 3 hours at 550°C. The crucible with the sample was left to cool in the oven and then weighed. The results were computed using equation 9 and 10 below for both dry matter and loss on ignition.

Calculation:

Equation 9

$$\%dry\ matter = \frac{(M3-M1)\times 100}{M2}$$

Equation 10 : $\%loss\ on\ ignition = \frac{(M3-M4)\times 100}{(M3-M1)}$

where :

M1 = weight of crucible
M2 = weight of soil sample before drying
M3 = weight of crucible with sample after drying
M4 = weight of crucible and sample after calcinations

3.7 Correlation computation

Results of MWDd and percent organic matter where used in the determination of the pearsons correlation. Excel spreadsheet was used to produce the correlation plots.

3.8 Statistical analysis

Analysis of variance (ANOVA) was used to determine significant differences among treatments and Least significant difference (LSD) was used to compare means. R version 3.4.4 statistical package was used to run the analyses .

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Characterization of soils before and after the project interventions

The selected properties of the soils on study sites; in Chipata and Kasama are presented in Table 2. The analysis of soils indicates that the soils were acidic with a pH of less than 4.50 in 0.01M $CaCl_2$ at both Msekera and Misamfu. The textural classes were sandy clay loam at Msekera and loamy sand at Misamfu. Several other properties are summarized in Table 2 below.

Table 2: Soil characterization at Msekera and Misamfu

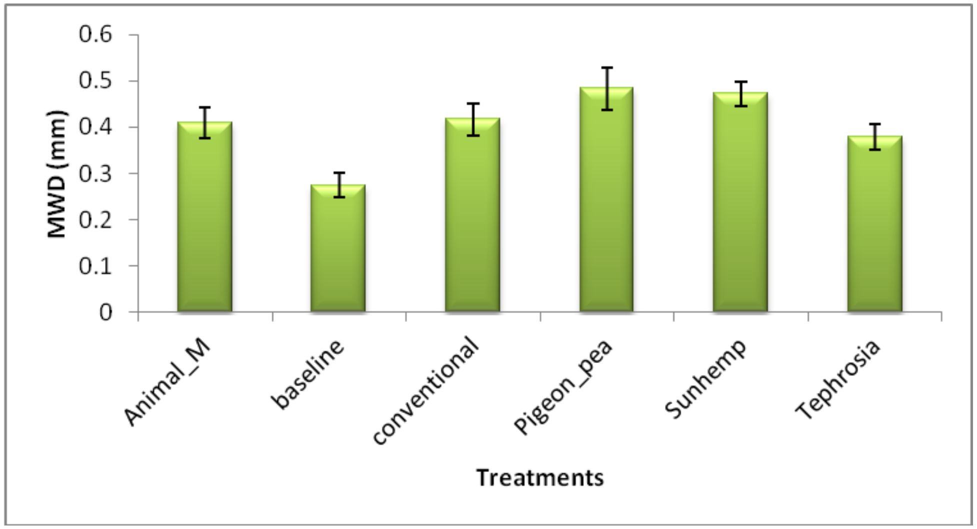
Sample ID	pH CaCl2	OM	N	P	K	Ca	Mg	Na	Acidity	Al3+	H+
		%		mg/kg	cmol/kg						
Misamfu	4.185	3.00	0.175	7.41	0.46	1.03	1.85	0.47	0.34	0.24	0.1
Msekera	4.225	2.32	0.175	6.30	0.45	1.73	1.75	0.71	0.3	0.24	0.06
Misamfu Base line	3.79	2.22	0.14	18.64	0.41	0.6	0.85	0.47	0.4	0.32	0.08
Msekera Base line	4.28	2.08	0.28	8.91	0.63	3.83	2.58	0.78	0.28	0.16	0.12

Sample ID	ECEC	Sand	Clay	Silt	Textural Class USDA
	cmol/kg	%			
Misamfu	4.1	81	12.4	6.6	Loamy Sand
Msekera	4.95	64	24.4	11.6	Sandy Clay Loam
Misamfu Base line	2.7	80	11.4	8.6	Loamy Sand
Msekera Base line	8.1	60	29.4	10.6	Sandy Clay Loam

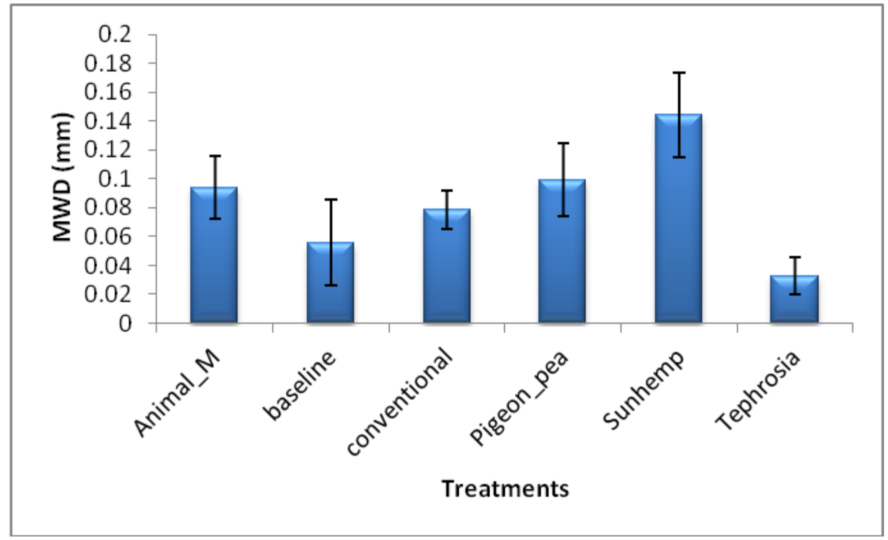
4.2 Effect of organic amendments on dry aggregate stability fractions

Mean weight diameter dry (MWDd) of soils amended with Sunnhemp was found to be 2.393 and Pigeon Pea 2.125 which were very highly significantly different from loamy ferric luvisol soils amended with Tephrosia alley cropping with a MWDd of 1.767 (P <0.001) at 95% confidence interval as illustrated in Figure 2a below. For MWDd under Sunnhemp treatment , the reason could be due to root growth in the soil profile which favors particle aggregation and so the remediation of degraded or compacted soils (Castro et al., 2011). Nascente et al. (2018) showed that the improvement in soil physical properties is due to cover crops, especially under millet + pigeon pea and millet + pigeon pea + *Urochloa*. The beneficial influence of grasses on the structure and stability of soil aggregates was demonstrated by several other researchers (Tisdall and Oades, 1979; Silva and Mielniczuk, 1997; Rilling et al, 2002), and is attributed to the high root density, which promotes the aggregation of the particles. MWDd of loamy ferric luvisol soils amended with Animal manure 2.065 and conventional 1.946 were not significantly different from soils amended with tephrosia alley cropping with MWDd of 1.767 . MWDd for Sunnhemp was significantly different from MWD for Animal Manure, Conventional, and Tephrosia but not significantly different from MWDd for Pigeon peas. MWDd for Pigeon pea was not significantly different from MWDd for conventional, animal manure but significantly different from MWDd for Tephrosia.

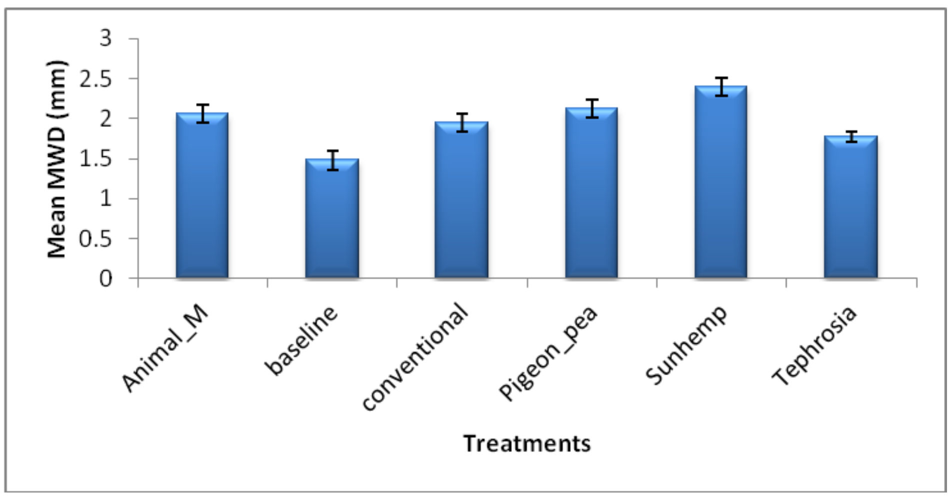
Loamy ferric luvisol Soils amended with Sunnhemp, and Pigeon pea arrey cropping presented a larger amount of retained aggregates in the 8.75mm compared to Tephrosia, and the two treatments were significantly different from Tephrosia alley cropping with a P-value of 0.012 at 95% confidence interval as illustrated in Figure 2b below.



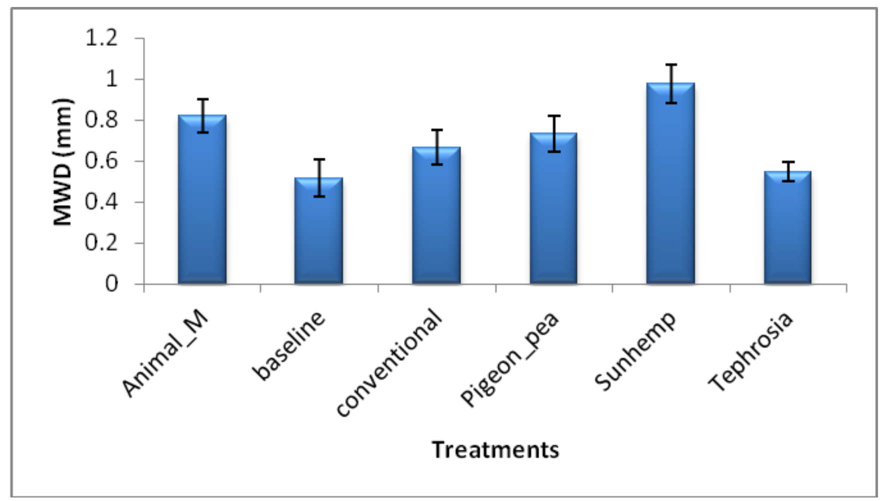
a) Effect of treatment on MWD (Ѳ=5.55mm) at Msekera



b) Effect of treatment on MWD(Ѳ= 8.75 mm) at Msekera



c) Effect of treatment on MWD at Msekera



d) Effect of treatment on MWD(Ѳ=7.18 mm) at Msekera

Figure 2: Effect of treatment on MWD for selected soil aggregates at Msekera

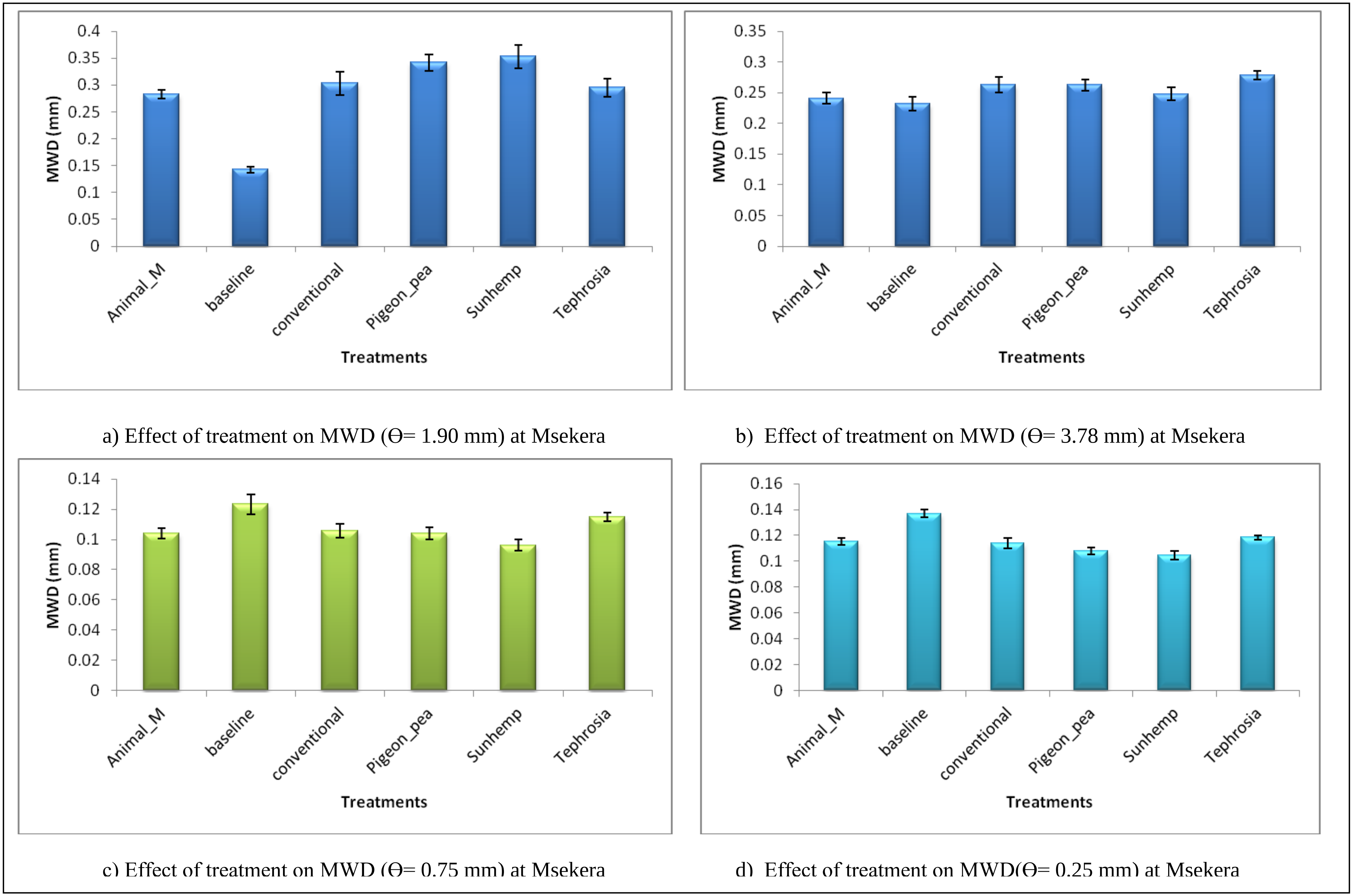
In the 6.35-8.0 mm aggregate distribution, Sunnhemp MWDd was significantly stable compared to pigeon pea , Conversional, tephrosia, and baseline MWDd while not significantly different from that of Animal manure MWDd with a P value of 0.002* at 95% confidence interval as illustrated in Figure 2d above.

In the 2.8-4.75 mm range Figure 3a, Sunnhemp indicated very highly significantly stable aggregates compared to Animal Manure, Conventional, Tephrosia and baseline aggregates while not significantly different from that of Pigeon pea with a P value of <0.001*** at 95% confidence interval. Generally, Sunnhemp and Pigeon Pea aggregate indicated a significantly higher MWDd in the larger aggregate sizes while Conventional, Tephrosia and baseline aggregates indicated significantly higher amounts of aggregates in the smaller aggregate size fractions.

In the 1.0-2.8 mm fractions figure 3b , Tephrosia indicated a significantly higher MWDd of stable aggregates compared to Baseline, Animal manure, and Sunnhemp while not significantly different from Tephrosia and Conventional witha P value of a 0.048 * at 95% confidence interval.

In the 0.5-1.0 mm fraction, Baseline aggregate indicated significantly higher amounts of aggregates compared to Sunnhemp, Animal Manure, Conventional and Pigeon Pea while not significantly different from Tephrosia with a P value of 0.002 ** at 95% confidence interval.

In the <0.5 mm fraction Baseline, Tephrosia and conventional aggregate amounts were very highly significantly different from Sunnhemp. Baseline was also very highly significantly different from Sunnhemp, Tephrosia, Conventional, Pigeon pea and Animal Manure with a P value of <0.001*** at a 95% confidence interval.
Loamy ferric luvisol soils amended with Tephrosia presented a higher amount of aggregates in the 0.25mm fraction after shaking, and it was significantly different from loamy ferric luvisol soils amended with Sunhemp and Pigeon peas with a P value of a 0.013 at 95% confidence interval while not significantly different with soils amended with Animal manure and conventional treatments.



a) Effect of treatment on MWD (Ɵ= 1.90 mm) at Msekera

b) Effect of treatment on MWD (Ɵ= 3.78 mm) at Msekera

c) Effect of treatment on MWD (Ɵ= 0.75 mm) at Msekera

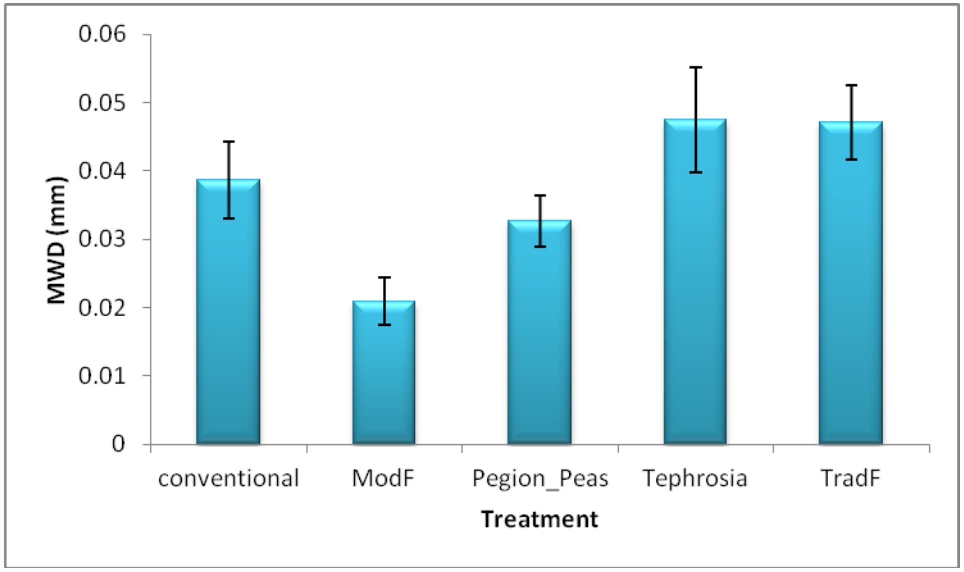
d) Effect of treatment on MWD(Ɵ= 0.25 mm) at Msekera

Figure 3: Effect of treatment on MWD for the selected smaller aggregates at Msekera

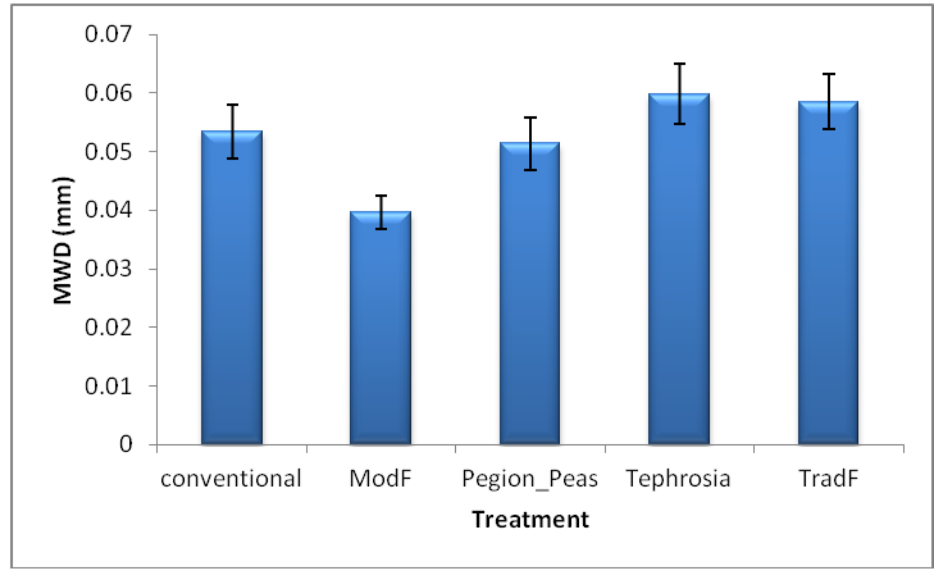
The MWDd for the distributions 8.0-9.5 mm, 6 .35-8.0 mm, 4.75-6.35 mm and 0.5-1.0 mm did not present any significant differences from the different organic amendments treatments. However, in the ranges, 2.8-4.75 mm, 1.0-2.8 mm and <0.5 mm distributions presented some significant differences from the different organic amendments. As indicated in Figure 3a, Traditional Fundikila with MWDd 0.047, Tephrosia MWDd 0.047 and Conventional MWDd 0.039 was highly significant different compared to that of Modified fundikila MWDd 0.021 with a P value of 0.007** at 95% confidence interval. In the 1.0-2.8 mm,Figure 6 , MWDd of Traditional Funkila 0.059, Tephrosia 0.059 and conventional 0.053 were significantly different from Modified fundikila 0.040 while not significantly different from that of Pigeon Peas 0.051 with a P value of 0.01* at 95% confidence interval. In the <0.5 mm fractions MWDd for Modified Fundikila 0.201, Pigeon Peas 0.199 and conventional 0.199 where significantly different from MWDd of Traditional Fundikila 0.194 though not significantly different from that of Tephrosia with a P value of 0.041* at 95% confidence.

Other studies on the influence of organic amendments such as animal manure on soil aggregates size distribution have reported no treatment effect (Bhatnagar et al. 1985; Hao et al. 2004 a shift to smaller aggregates (Whalen and Chang 2002). Hao et al. (2004) also reported no manure effect on geometric mean diameter (GMD). Other studies found that farmyard manure increased larger (1.60 mm) compared to smaller (0.13 to 0.9 mm) aggregates (Ogunwole 2005), or cattle manure slurry caused a slight increase in larger (2- 4 mm) dry-sieved aggregates compared with unamended soils (Mbagwu and Piccolo 1990). In contrast, Whalen and Chang (2002) indicated that a long-term (25-yr) solid feedlot manure application shifted aggregate sizes (rotary sieve) from larger (>7.1 mm) to smaller (0.47-1.2 mm) aggregates.

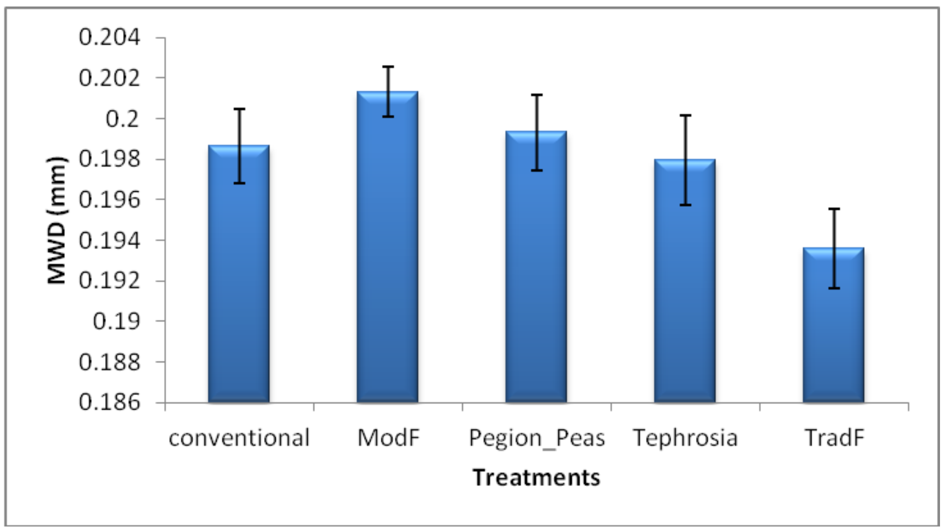
In the entire sample population figure 4c, MWDd for Traditional Fundikila 0.564 and Tephrosia 0.514 were significantly higher compared to that of Modified Fundikila 0.427. MWDd of Traditional Fundikila was significantly different from that of Pigeon Pea with a P value of 0.018* at a 95% confidence interval.



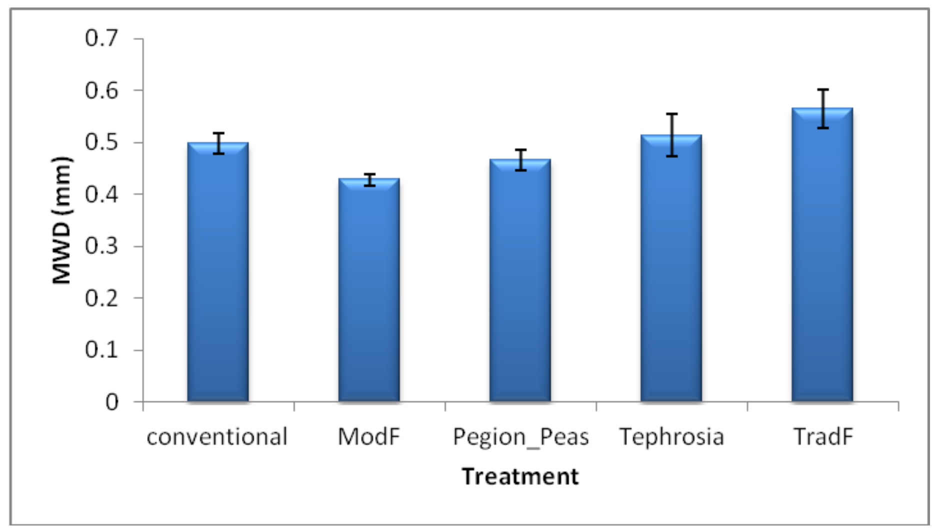
a) Effect of treatment on MWD (ϴ=3.78 mm) at Misamfu



b) Effect of treatment on MWD(ϴ=1.90 mm) at Misamfu



c) Effect of treatment on MWD at Misamfu



d) Effect of treatment on MWD (ϴ=2.50 mm)

Figure 4: Effect of treatment on MWD for selected soil aggregates at Misamfu

4.3 Soil Organic Matter distribution in different dry aggregates

Comparing the Soil organic matter among the treatments on a Ferrasol soil,it was found to be significantly different as indicated in Figure 5 and 6. There was a highly significant difference in organic matter content between aggregates amended with Modified fundikila and traditional fundikila treatments. Organic matter in aggregates amended with Modified Fundikila was significantly higher than organic matter in aggregates amended with Traditional fundikila. For the Ferrasol dry aggregates at Misamfu there was a highly significant difference in the O.M content composition among the treatments and the significant difference was between Modified fundikila and traditional fundikila with a P value of 0.005**. Modified Fundikila O.M composition presented a significantly higher amount compared to traditional fundikila treatments. This can be obsaved in the plot of means presented in figure 6. There was a significant difference between Tephrosia and Traditional Fundikila with a P value of 0.005**. Tephrosia treatment presented a significantly higher amounts of O.M compared to Traditional fundikila.

Specifically,in the 3.78 mm as presented in Figure 7 below for Ferrasol soil aggregates at misamful there was a highly significant difference in the O.M distribution between Modfied fundikila and conventional treatments with Modfied Fundikila being significantly higher than Conventional treatments. There was a highly significant difference between Modified fundikila and traditional fundikila. There was a significant difference between Modified Fundikila and Pigeon Peas while there was no significant difference with the other combinations. There was no significant differences in the other soil size distribution.

Some studies have reported higher C, N, and P concentrations in larger compared with smaller aggregates (Bhatnagar and Miller 1985; Bhatnagar et al.1985; Hao et al. 2004), while others found the reverse trend (Mbagwu and Piccolo 1990; Whalen and Chang 2002). Mbagwu and Piccolo (1990) applied cattle slurry to a Cremona soil in Italy and generally found higher concentrations of total C, total N, and available P in smaller (0.25 mm) than larger (0.25 to 4 mm) dry-sieved aggregates. Whalen and Chang (2002) found that dry-sieved aggregates in soils amended with feedlot manure for 25 yr tended to have the highest total C, N, and P contents in the smaller (0.47 to 2.0 mm) than larger (2 to 38 mm) fraction.

For the various distribution sieve sizes, there was no significant difference in the organic matter content for loamy ferric luvisol soils . Some values of organic matter content found appeared to be very high. This could be due to the methodology used in the preparation of the samples for the ashing process; there was no sieving of the soil aggregates to remove any residues. This meant that if the aggregates had plant particles, they were ashed together and would have resulted in the deviation of the results.

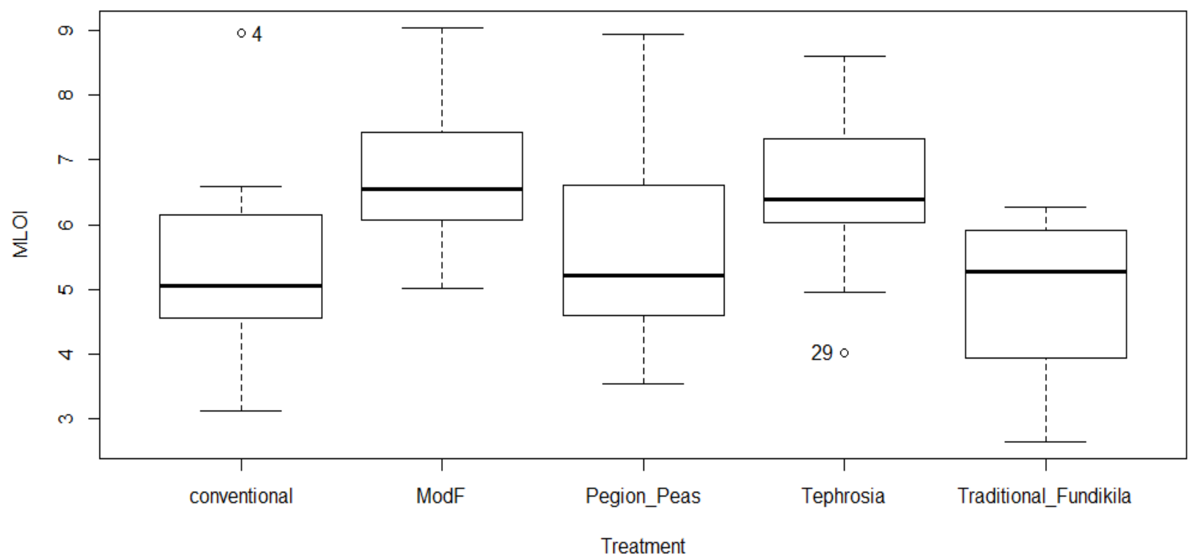


Figure 5: Effect of organic amendments on SOM at Misamfu

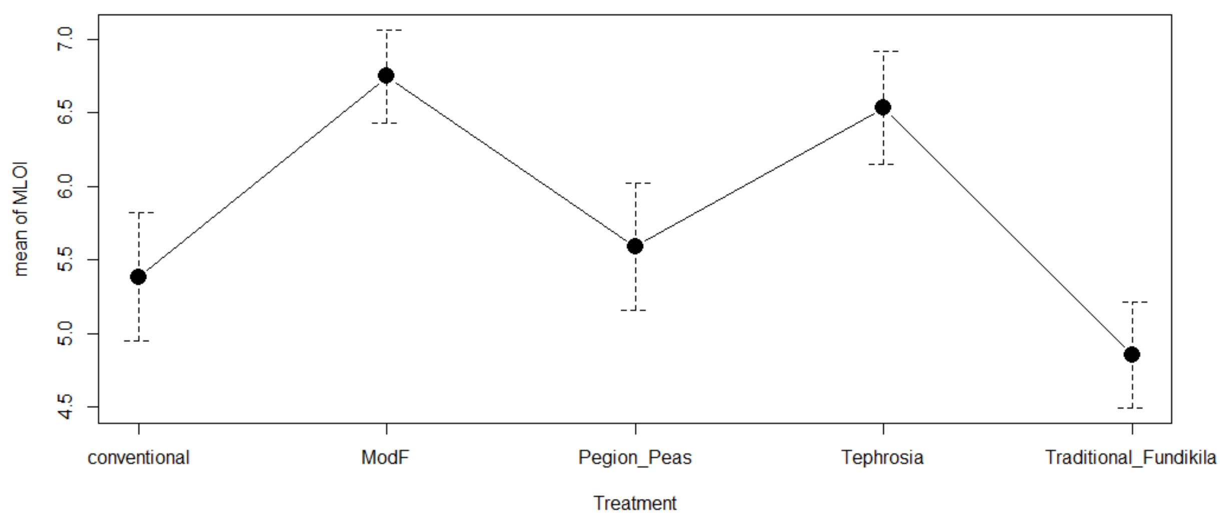


Figure 6: Effect of organic amendment on SOM at Misamfu

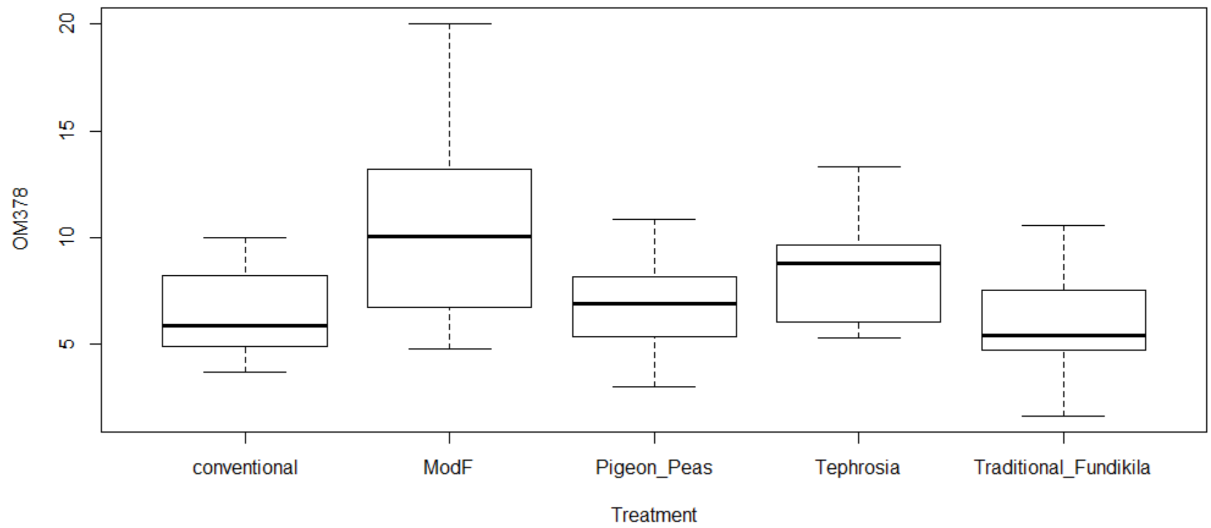


Figure 7: Effect of organic amendments on SOM(ϴ= 3.78 mm) at Misamfu

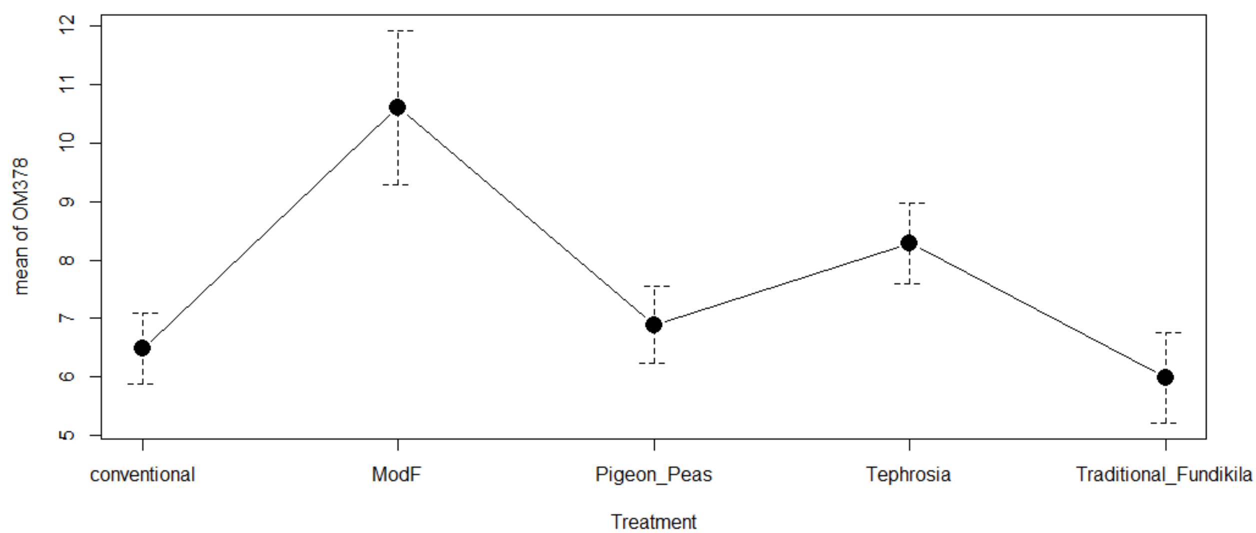


Figure 8: Effect of organic amendments on SOM(ϴ= 3.87 mm) at Misamfu

4.4. Effect of organic amendment on the correlation of MWD and OM

The mean values of soils treated with different organic amendments showed a general significant positive Pearson correlation for loamy ferric luvisol soil at Msekera as indicated in Figure 9 below, and the correlation in the 8.75mm was significant as indicated in Figure 10 below though the other soil distributions did not show any significant correlation. The findings for loamy ferric luvisols at Msekera are similar with some other researchers who observed that the correlation between organic matter and MWD is not always significant and that some values for MWD determined may not always correspond with the organic matter (Tisdall and Oades, 1982, Mercedes et al., 2006). For Ferrasol soils at Misamfu site showed a significant negative Pearson's correlation in the 1.90 mm as indicated in Figure 11 while generally did not show any significant correlation. Others did not show any significant correlation.

Figure 9 below indicates that there was a significant general positive correlation between the means of MWDd and SOM.

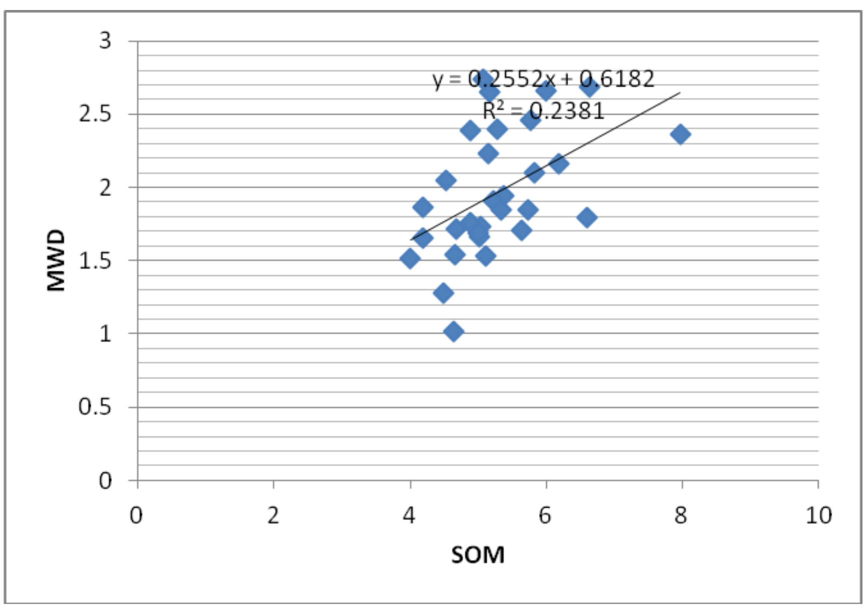


Figure 9: Relationship of the overall MWD and SOM at Msekera

There was a significant positive Pearson's correlation in the 8.75mm for the Msekera red soils.

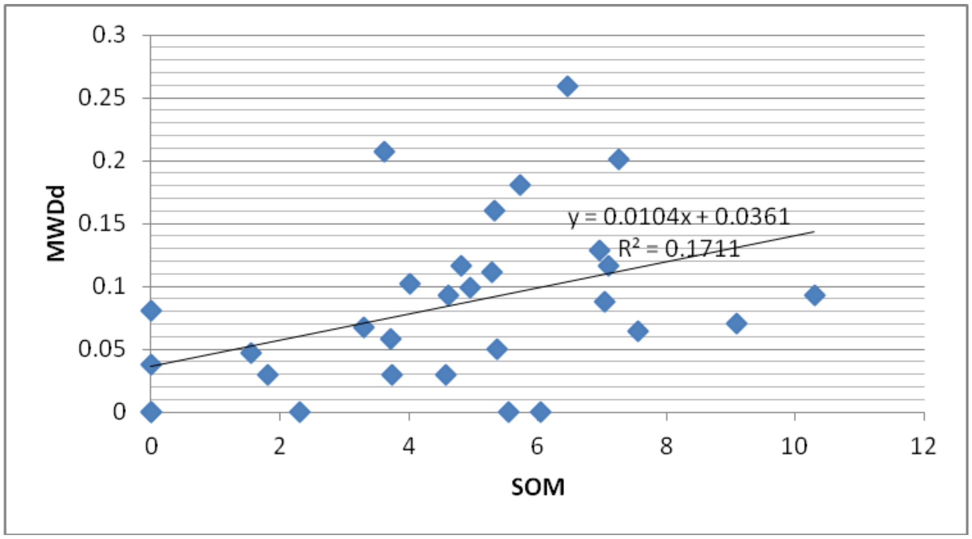


Figure 10: Relationship between MWDd(ϴ=8.75 mm) and SOM at Msekera

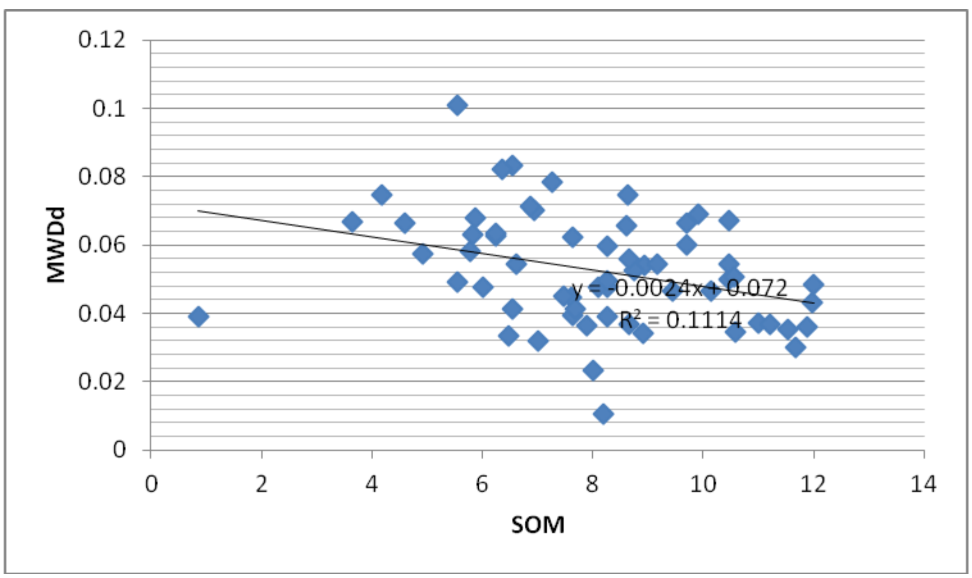


Figure 11: Relationship between MWDd(ϴ= 1.90 mm) and SOM at Misamfu

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The main objective was to determine the effect of organic amendments on aggregate stability and organic matter content on two Zambian soils. The results showed a significant effect on the different amendments added to the soil. At Msekera , Sunnhemp MWDd 2.393 , Animal manure MWDd 2.065, and pigeon pea MWDd 2.125 showed a highly significant difference from Tephrosia MWDd 1.767 inter plants. Hence for a loamy ferric luvisol,as indicated at Msekera , Sunnhemp, and Animal manure may be used to improve the condition especially for aeration and aggregate stability.

There was a significant difference in the organic matter content for the Ferrasol soil at Misamfu site.The difference was significant in larger aggregates than smaller aggregates i.e in the 3.78mm.For the Loamy ferric luvisols at Msekera,there was no significant difference in the organic matter content in the different soil size distribution. Despite the difference in the aggregate stability presented by Sunnhemp and Animal manure. This could be due to differences in the source of the organic amendment.

There was a general significant correlation for the loamy ferric luvisols at Msekera while no significant correlation for the other soil size distributions.

There was a significant correlation in the 7.18 mm and 1.9 mm soil size distributions for Ferrasol soils at Misamfu while other soil distributions were not significant.

Thus we reject the null hypotheses and accept the alternatives that at least there is a significant difference between each pair of items.

5.2 Recommendations

There is a need to determine the effect on the hydraulic properties such as infiltration rate, moisture retention, and hydraulic conductivity. This is because soil moisture distribution in the soil is a critical parameter for crop growth.

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APPENDICES

Appendix 1: Effect of treatment on MWD at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	4	1.985	0.496	3.513	0.011	*
Trt	5	4.764	0.953	6.746	3.48E-05	***
Residuals	70	9.88	0.141			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Mean Square Error: 0.141

Appendix 2: Effect of organic amendments on MWD at Msekera

	MWD	groups
Sunhemp	2.393	a
Pigeon_pea	2.125	ab
Animal_M	2.065	b
conventional	1.946	bc
Tephrosia	1.767	cd
baseline	1.482	d

Treatments with the same letter are not significantly different.

Appendix 3: Effect of treatment on MWD (ϴ=8.75 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	4	0.054	0.014	2.132	0.086	.
Trt	5	0.102	0.020	3.209	0.012	*
Residuals	70	0.446	0.006			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Mean Square Error: 0.006367879

Appendix 4: Effect of organic amendments on MWD(ϴ=8.75 mm) at Msekera

	d875	groups
Sunhemp	0.144	a
Pigeon_pea	0.099	ab
Animal_M	0.094	ab
conventional	0.078	bc
baseline	0.056	bc
Tephrosia	0.033	c

Treatments with the same letter are not significantly different.

Appendix 5: Effect of treatment on MWD(ϴ= 7.18 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	4	1.249	0.312	3.805	0.007	**
Trt	5	1.809	0.362	4.408	0.002	**
Residuals	70	5.747	0.082			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 6: Effect of organic amendments on MWD(ϴ=7.18 mm) at Msekera

	d718	groups
Sunhemp	0.975	a
Animal_M	0.820	ab
Pigeon_pea	0.733	bc
conventional	0.665	bc
Tephrosia	0.548	c
baseline	0.517	c

Appendix 7: Effect of treatment on MWD(ϴ= 5.55 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	4	0.092	0.023	1.394	0.245	
Trt	5	0.233	0.047	2.834	0.022	*
Residuals	70	1.150	0.016			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 8: Effect of organic amendments on MWD(ϴ= 5.55 mm) at Msekera

	d555	groups
Pigeon_pea	0.483	a
Sunhemp	0.472	ab
conventional	0.416	ab
Animal_M	0.409	ab
Tephrosia	0.380	bc
baseline	0.274	c

Treatments with the same letter are not significantly different.

Appendix 9: Effect of treatment on MWD(ϴ= 3.78 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	4	0.010	0.002	0.58	0.68	
Trt	5	0.196	0.039	9.08	0.00	***
Residuals	70	0.302	0.004			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 10: Effect of organic amendments on MWD(ϴ= 3.78 mm) at Msekera

	d378	groups
Sunhemp	0.353	a
Pigeon_pea	0.342	ab
conventional	0.303	bc
Tephrosia	0.295	bc
Animal_M	0.283	c
baseline	0.143	d

Treatments with the same letter are not significantly different.

Appendix 11: Effect of treatment on MWD (ϴ=1.90 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	4	0.010	0.002	1.773	0.144	
Trt	5	0.016	0.003	2.361	0.049	*
Residuals	70	0.096	0.001			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 12: Effect of organic amendments on MWD (ϴ= 1.90 mm) at Msekera

	d190	groups
Tephrosia	0.279	a
conventional	0.263	ab
Pigeon_pea	0.263	ab
Sunhemp	0.248	b
Animal_M	0.241	b
baseline	0.232	b

Treatments with the same letter are not significantly different.

Appendix 13: Effect of treatment on MWD(ϴ= 0.75 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	4	0.001	0.000	1.520	0.206	
Trt	5	0.004	0.001	4.205	0.002	**
Residuals	70	0.014	0.000			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 14: Effect of organic amendments on MWD (ϴ= 0.75 mm) at Msekera

	d75	groups
Baseline	0.123	a
Tephrosia	0.115	ab
Conventional	0.106	bc
Pigeon_pea	0.104	c
Animal_M	0.104	c
Sunhemp	0.096	c

Treatments with the same letter are not significantly different.

Appendix 15: Effect of treatment on MWD(ϴ= 0.25 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	4	0.001	0.000	1.92	0.12	
Trt	5	0.005	0.001	7.53	0.00	***
Residuals	70	0.009	0.000			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 16: Effect of organic amendments on MWD(ϴ= 0.25 mm) at Msekera

	d25	groups
baseline	0.137	a
Tephrosia	0.118	b
Animal_M	0.115	bc
conventional	0.114	bc
Pigeon_pea	0.108	cd
Sunhemp	0.104	d

Treatments with the same letter are not significantly different.

Appendix 17: Effect of treatment on MWD at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	3	0.027	0.009	0.923	0.436	
Trt	4	0.126	0.032	3.277	0.018	*
Residuals	52	0.501	0.010			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 18: Effect of organic amendments on MWD at Misamfu

	MWD	groups
TradF	0.564	a
Tephrosia	0.514	ab
conventional	0.498	abc
Pegion_Peas	0.466	bc
ModF	0.427	c

Treatments with the same letter are not significantly different.

Appendix 19: Effect of treatment on MWD(ϴ= 3.78 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	3	0.000	0.000	0.385	0.765	
Trt	4	0.006	0.001	3.987	0.007	**
Residuals	52	0.019	0.000			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 20: Effect of organic amendments on MWD (Ɵ= 3.78 mm) at Misamfu

d378	groups	
Tephrosia	0.047	a
TradF	0.047	a
conventional	0.039	a
Pegion_Peas	0.033	ab
ModF	0.021	b

Treatments with the same letter are not significantly different.

Appendix 21: Effect of treatment on MWD(Ɵ= 1.90 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	3	0.002	0.001	3.091	0.035	*
Trt	4	0.003	0.001	3.699	0.010	*
Residuals	52	0.011	0.000			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 22: Effect of organic amendments on MWD(Ɵ= 1.90 mm) at Misamfu

	d190	groups
Tephrosia	0.060	a
TradF	0.059	a
conventional	0.053	a
Pegion_Peas	0.051	ab
ModF	0.040	b

Treatments with the same letter are not significantly different.

Appendix 23: Effect of treatment on MWD(Ɵ= 0.25 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Block	3	0.000	1.18E-04	3.256	0.029	*
Trt	4	0.000	9.72E-05	2.685	0.041	*
Residuals	52	0.002	3.62E-05			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 24: Effect of organic amendments on MWD(Ө= 0.25 mm) at Misamfu

	d250	groups
ModF	0.201	a
Pegion_Peas	0.199	a
conventional	0.199	a
Tephrosia	0.198	ab
TradF	0.194	b

Treatments with the same letter are not significantly different.

Appendix 25: Effect of treatment O.M at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Treatment	4	30.48	7.621	4.22	0.005	**
Residuals	55	99.3	1.805			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 26: Effect of organic amendments on O.M at Misamfu

	Mean	G1	G2
ModF	6.746	A	
Tephrosia	6.534	A	
Pegion_Peas	5.589	A	B
conventional	5.386	A	B
Traditional_Fundikila	4.855	B	

Appendix 27: Effect of treatment on O.M (Ө=8.75 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	13.33	3.333	1.265	0.295
Residuals	55	144.96	2.636		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 28: Effect of treatment on O.M(Ө= 7.18 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	63.9	15.98	1.243	0.304
Residuals	55	707.5	12.86		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 29: Effect of treatment on O.M (ϴ=5.55 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	80.2	20.05	1.475	0.222
Residuals	55	747.9	13.6		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 30: Effect of treatment on O.M (ϴ=3.78 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Treatment	4	166.6	41.64	4.841	0.00204	**
Residuals	55	473.1	8.6			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 31: Effect of organic amendment on O.M(ϴ= 3.78 mm) at Misamfu

	Mean	**G1**	**G2**
ModF	10.611	A	
Tephrosia	8.285	A	B
Pegion_Peas	6.890	B	
conventional	6.485	B	
Traditional_Fundikila	5.986	B	

Appendix 32: Effect of treatment on O.M(ϴ= 1.90 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	18	4.499	0.867	0.49
Residuals	55	285.5	5.191		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 33: Effect of treatment on O.M(ϴ= 0.75 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	14.26	3.566	1.724	0.158
Residuals	55	113.75	2.068		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 34: Effect of treatment on O.M (ϴ=0.25 mm) at Misamfu

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	9	2.249	1.675	0.169
Residuals	55	73.86	1.343		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 35: Effect of treatment on O.M at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	5	4.839	0.968	1.533	0.217
Residuals	24	15.151	0.631		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 36: Effect of treatment on O.M(ϴ= 8.75 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	5	51.25	10.25	1.577	0.204
Residuals	24	155.96	6.498		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 37: Effect of treatment on O.M (ϴ=7.18 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	5	15.16	3.033	1.02	0.428
Residuals	24	71.33	2.972		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 38: Effect of treatment on O.M (ϴ=5.55 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	5	14.03	2.806	0.74	0.601
Residuals	24	91.06	3.794		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

Appendix 39: Effect of treatment on O.M (ϴ=3.78 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	5	5.19	1.037	0.596	0.703
Residuals	24	41.77	1.74		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 40: Effect of treatment on O.M (ϴ=1.90 mm) at Msekera

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	5	24.57	4.915	1.367	0.272
Residuals	24	86.3	3.596		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 41: Effect of treatment on O.M(ϴ= 0.75 mm) at Msekera red soil

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	5	6.703	1.341	1.186	0.345
Residuals	24	27.128	1.13		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 42: Effect of treatment on O.M (ϴ=0.25 mm) at Msekera

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Treatment	5	5.61	1.123	0.619	0.687
Residuals	24	43.55	1.815		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 43: Mean weight diameter dry at Msekera, Chipata

Aggregate range (mm)	Mean range (mm)	Treatment means						Pr(>F)
		SunnH.	Pigeon pea	A.Man	Conv.	Teph	baseline	
9.5-8.0	8.75	0.144 a	0.099 ab	0.094 ab	0.078 bc	0.033 c	0.056 bc	0.012*
8.0-6.35	7.18	0.975 a	0.733 bc	0.820 ab	0.665 bc	0.548 c	0.517 c	0.002 **
6.35-4.75	5.55	0.472 ab	0.483 a	0.409 ab	0.416 ab	0.38 bc	0.274 c	0.022 *
4.75-2.8	3.78	0.353 a	0.342 ab	0.283 c	0.303 bc	0.295 bc	0.143 d	<0.001***
2.8-1.0	1.9	0.248 b	0.263 ab	0.241 b	0.263 ab	0.279 a	0.232 b	0.049 *
1.0-0.5	0.75	0.096 c	0.104 c	0.104 c	0.106 bc	0.115 ab	0.123 a	0.002 **
<0.5	0.25	0.104 d	0.108 cd	0.115 bc	0.114 bc	0.118 b	0.137 a	<0.001***
	Total	**2.393 a**	**2.125 ab**	**2.065 b**	**1.946 bc**	**1.767 cd**	**1.482 d**	**<0.001*** **

Appendix 45: Mean weight diameter dry (MWDd) at Misamfu, Kasama

Aggregate distribution (mm)	Mean of distribution (mm)	Treatments MWD					
		TradF	Tephrosia	Conventional	Pigeon _Peas	ModF	Pr(>F)
9.5-8.0	8.75	0.0315 a	0.000 a	0.011 a	0.003 a	0.000 a	0.078
8.0-6.35	7.18	0.057 a	0.044 a	0.035 a	0.0284 a	0.017 a	0.408
6.35-4.75	5.55	0.056 a	0.053 a	0.048 a	0.034 a	0.028 a	0.051
4.75-2.8	3.78	0.047 a	0.047 a	0.039 a	0.033 ab	0.021 b	0.007**
2.8-1.0	1.9	0.0585 a	0.0598 a	0.053 a	0.051 ab	0.040 b	0.010*
1.0-0.5	0.75	0.120 a	0.111 a	0.114 a	0.120 a	0.121 a	0.312
<0.5	0.25	0.194 b	0.198 ab	0.199 a	0.199 a	0.201 a	0.041*
	Total	**0.564 a**	**0.514 ab**	**0.498 abc**	**0.466 bc**	**0.427 c**	**0.018***

Appendix 46: Effect of treatment on the Correlation of MWDd and OM

Site	Soil distribution (mm)	Pearson Correlation	Sig. (1-tailed)	N
Msekera	TMWD	.488**	0.003	30
	8.75	0.414*	0.012	30
	7.18	0.279	0.068	30
	5.55	0.257	0.085	30
	3.78	0.115	0.272	30
	1.9	0.015	0.468	30
	0.75	0.182	0.168	30
	0.25	-0.226	0.115	30
Misamfu	TMWD	-0.104	0.215	60
	8.75	0.096	0.265	45
	7.18	.292*	0.026	45
	5.55	0.045	0.37	57
	3.78	-0.2	0.063	60
	1.9	-.334**	0.005	60
	0.75	-0.086	0.258	60
	0.25	-0.019	0.443	60