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Effect of Organic Matter on Soil Aggregate Stability in Rufunsa District, 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 Rufunsa, 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 Rufunsa (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 Rufunsa 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.

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 (Aziz, Mahmood, and Islam, 2013). 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).

Soil is a crucial component of the environment, providing essential services such as nutrient cycling, water filtration, and support for plant growth. However, soil degradation poses a threat to global food security, with one of the main causes being the loss of soil structure and stability. Soil aggregate stability, the ability of soil particles to remain bound together in stable aggregates, is an important indicator of soil health and resilience. It also affects various soil processes, such as water infiltration, nutrient availability, and erosion resistance.

Organic matter, a key component of soil, plays a vital role in maintaining soil aggregate stability. It acts as a binding agent, cementing soil particles together and improving soil structure. However, with the increasing use of chemical fertilizers and intensive land use practices, there has been a decline in organic matter content in many soils worldwide. In Rufunsa District, located in the Eastern Province of Zambia, the main land use is subsistence agriculture, and there has been a shift towards the use of chemical fertilizers, potentially affecting soil aggregate stability.

Soil structure and its stability are crucial factors influencing agricultural productivity and ecosystem health. Soil aggregates, which are clusters of soil particles bound together, play a vital role in land management practices, water infiltration, root growth, and nutrient retention. The stability of these aggregates is significantly determined by the presence and quality of organic matter in the soil. This matter includes decomposed plant and animal residues, microbial biomass, and humus, which contribute to the binding of soil particles through various physical, chemical, and biological processes. In Rufunsa District, Zambia, the interplay between soil organic matter and aggregate stability is an under-researched area, despite the region's reliance on agriculture. Understanding this relationship is crucial for informing sustainable land management practices that enhance soil quality and agricultural resilience.

Soil aggregate stability is a critical property influencing soil health, productivity, and resistance to erosion. It refers to the ability of soil aggregates—groups of soil particles that bind together to resist disintegration when subjected to external forces such as water or wind. Soil structure, particularly the stability of aggregates, plays a significant role in various ecological and agricultural processes, including water infiltration, root penetration, and microbial activity.

In Rufunsa District, located in Zambia's Lusaka Province, agriculture is a primary livelihood. However, the region faces challenges related to soil degradation, partly due to low organic matter content and unsustainable farming practices. Organic matter, comprising decomposed plant and animal residues, plays a pivotal role in enhancing soil structure by binding soil particles together, thereby improving aggregate stability (Islam, 2013). The decline in soil organic matter (SOM) due to continuous cultivation, deforestation, and improper land management practices threatens the sustainability of agricultural productivity in the district.

Understanding the relationship between organic matter and soil aggregate stability in Rufunsa District is essential for developing strategies to enhance soil health and ensure long-term agricultural productivity (Aziz, Mahmood, and Islam, 2013). This study focuses on investigating how varying levels of organic matter influence soil aggregate stability in the region, providing insights that could inform better land management practices.

Soil aggregate stability is an important property of soil that influences soil structure, water infiltration, and soil erosion. In agricultural systems, soil aggregate stability is crucial for maintaining soil health and productivity (Aziz, Mahmood, and Islam, 2013). Organic matter has been identified as a key factor in improving soil aggregate stability by providing essential nutrients and promoting the formation of stable soil aggregates. In Rufunsa District, Zambia, where agriculture is a major source of livelihood for the local population, understanding the effect of organic matter on soil aggregate stability is essential for sustainable land management practices.

Soil aggregate stability is a critical factor in maintaining soil health and productivity. It refers to the ability of soil aggregates to resist disintegration when subjected to external forces such as water erosion. Organic matter plays a significant role in enhancing soil structure by binding soil particles together, thereby improving aggregate stability (Aziz, Mahmood, and Islam, 2013). In Rufunsa District, Zambia, agricultural practices and land management strategies have a profound impact on soil health. Understanding the effect of organic matter on soil aggregate stability can inform sustainable agricultural practices and soil conservation efforts in the region.

The soil is a vital component of the ecosystem, playing a crucial role in supporting plant growth and overall environmental health. Soil aggregate stability refers to the ability of soil particles to clump together and resist external forces such as erosion, compaction, and water runoff. Organic matter, which includes plant residues, roots, and organic amendments, significantly influences soil aggregate stability (Aziz, Mahmood, and Islam, 2013). In Rufunsa District, Zambia, where agriculture is the primary source of livelihood for many communities, understanding the effects of organic matter on soil aggregate stability is of great importance.

One of the main factors that can impact soil aggregate stability is the type and amount of organic matter present in the soil. Organic matter helps to bind soil particles together, creating stable aggregates that are less prone to erosion and compaction. In Rufunsa District, where traditional farming practices such as slash-and-burn agriculture are common, there is often a lack of organic matter in the soil due to the continuous removal of crop residues. This can lead to a decrease in soil aggregate stability, resulting in soil degradation and reduced crop productivity (Aziz, Mahmood, and Islam, 2013).

Another factor that can influence soil aggregate stability is the microbial activity in the soil. Microorganisms play a crucial role in decomposing organic matter and releasing nutrients that are essential for plant growth. In soils with high microbial activity, organic matter is broken down more quickly, leading to an increase in soil aggregate stability. However, in soils with low microbial activity, organic matter accumulates and can actually decrease soil aggregate stability (Aziz and Islam, 2013). Understanding the relationship between organic matter, microbial activity, and soil aggregate stability is essential for developing sustainable agricultural practices in Rufunsa District.

Soil structure is another important factor that can affect soil aggregate stability. Soil structure refers to the arrangement of soil particles and organic matter in the soil. In soils with good structure, organic matter is evenly distributed throughout the soil profile, creating stable aggregates that are resistant to erosion and compaction (Aziz, Mahmood, and Islam, 2013). However, in soils with poor structure, organic matter tends to accumulate near the surface, leading to the formation of unstable aggregates that are easily broken apart. Improving soil structure through the addition of organic matter and other soil amendments can help to increase soil aggregate stability and promote sustainable agriculture in Rufunsa District.

In addition to the physical and biological factors that influence soil aggregate stability, environmental factors such as rainfall intensity and land use practices can also play a role. In Rufunsa District, where rainfall is variable and often unpredictable, soil erosion is a significant problem that can lead to the loss of soil organic matter and a decrease in soil aggregate stability. By studying the effects of organic matter on soil aggregate stability in different land use systems, researchers can gain valuable insights into how to develop sustainable farming practices that promote soil health and productivity in Rufunsa District (Aziz, Mahmood, and Islam, 2013).

Soil aggregate stability is a critical factor influencing soil health and productivity. It refers to the ability of soil particles to bind together to form clusters or aggregates, which are essential for maintaining soil structure, water retention, and aeration (Aziz, 2013). In the Rufunsa District of Zambia, where agriculture plays a significant role in the local economy, understanding the factors that influence soil aggregate stability is paramount for sustainable land use practices.

Organic matter is a key component of soil that affects not only the fertility but also the physical structure of the soil. It serves as a food source for soil microorganisms, enhances microbial activity, and contributes to the formation of stable soil aggregates (Aziz and Mahmood, 2013). The Rufunsa District, known for its diverse ecosystems and agricultural practices, often faces challenges such as soil erosion and nutrient depletion, underscoring the need to investigate the role of organic matter in enhancing soil aggregate stability within this region.

1.2 Statement of the problem

Studies have been conducted to determine the effect of organic matter 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. The decline in soil organic matter content due to intensive agricultural practices has raised concerns about its negative impact on soil aggregate stability. However, the specific effect of organic matter on soil aggregate stability in Rufunsa District remains unknown. This study aims to fill this gap by investigating the relationship between organic matter and soil aggregate stability in the district.

In Rufunsa District, agricultural practices are often intensive, leading to soil degradation and loss of organic matter, which directly affects soil health and stability. Empirical observations indicate that many farmers are experiencing a decline in crop yields, attributed to poor soil structure and water retention capabilities (Islam, 2013). However, there has been limited research into the specific effects of organic matter on soil aggregate stability in this region. This lack of knowledge hampers the development of effective land and soil management strategies that could enhance agricultural productivity and sustainability. Therefore, understanding the relationship between organic matter content and soil aggregate stability is essential for addressing food security challenges in Rufunsa District.

Rufunsa District is facing challenges related to soil degradation, erosion, and declining soil fertility. These issues can be attributed to poor soil management practices, including the depletion of organic matter in the soil (Aziz, 2013). The lack of understanding of the relationship between organic matter and soil aggregate stability is a significant gap that needs to be addressed to develop appropriate strategies for soil conservation and sustainable agriculture in the district.

Despite the potential benefits of organic matter in improving soil aggregate stability, the level of organic matter in soils in Rufunsa District is often low due to unsustainable land management practices such as overgrazing, deforestation, and poor crop residue management. This has resulted in degraded soils with poor aggregate stability, leading to reduced soil fertility, increased soil erosion, and decreased crop yields. Therefore, there is a need to investigate the effect of organic matter on soil aggregate stability in Rufunsa District to provide scientific evidence for promoting sustainable land management practices. Soil degradation, characterized by the breakdown of soil structure and loss of fertility, is a pressing issue in Rufunsa District (Aziz, Mahmood, and Islam, 2013). The decline in soil aggregate stability due to insufficient organic matter inputs has led to increased soil erosion, reduced water infiltration, and lower crop yields. This study aims to address the gap in knowledge regarding the specific impact of organic matter on soil aggregate stability in Rufunsa District, providing insights that can guide effective soil management practices.

Despite the known benefits of organic matter in promoting soil aggregate stability, there is limited research focusing specifically on the Rufunsa District. Farmers in the area often rely on traditional farming practices that may not adequately incorporate organic matter management. Consequently, soil degradation and reduced agricultural productivity have become pressing concerns (Aziz, Mahmood, and Islam, 2013). This study aims to address the gap in knowledge regarding the relationship between organic matter and soil aggregate stability in this region, contributing to improved agricultural practices and enhanced food security.

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 matter affect aggregate stability, the degree of their effects and the differences they present made it easier to set aside a blissful recommendation on which matter easily enhanced organic matter and aggregate stability conditions. Understanding the effect of organic matter on soil aggregate stability is crucial for promoting sustainable land management practices. It will provide valuable information for land management decisions and help identify areas in need of soil conservation measures (Aziz, Mahmood, and Islam, 2013). This study's findings will also contribute to the existing literature on soil aggregate stability and provide a basis for future research on sustainable soil management in Rufunsa District and similar agroecological zones.

This study is significant for several reasons. First, it aims to provide empirical data regarding the impact of organic matter on soil aggregate stability within the context of Rufunsa District, filling a critical

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research gap. Second, the findings can empower local farmers with information on best practices for maintaining and improving soil health, which is essential for sustainable agriculture (ibid). Third, soil aggregate stability influences various soil processes, including water infiltration, erosion resistance, and nutrient cycling, which are all essential for enhancing agricultural productivity. This research could provide insights for policymakers and agricultural extension services in developing strategies that promote soil conservation and sustainable agricultural practices in the region.

The study on the effect of organic matter on soil aggregate stability in Rufunsa District is essential to provide valuable insights into the factors influencing soil health and fertility. The findings of the study can help inform agricultural practices and land management strategies that aim to improve soil quality, enhance crop productivity, and mitigate soil erosion. By promoting the sustainable use of organic matter in the soil, the study can contribute to the overall environmental sustainability and food security in the district (Aziz, Mahmood, and Islam, 2013).

This study is justified by the need to improve soil health and agricultural productivity in Rufunsa District. As organic matter plays a crucial role in enhancing soil structure, understanding its effect on soil aggregate stability can inform better soil management practices, leading to sustainable agriculture in the region. The findings of this research will provide valuable information to farmers, agricultural extension officers, and policymakers, helping to promote practices that increase soil organic matter content and improve soil structure (Aziz, Mahmood, and Islam, 2013). Ultimately, this will contribute to food security, environmental conservation, and the economic well-being of the local population.

The study of the effect of organic matter on soil aggregate stability in Rufunsa District is important for several reasons. Firstly, it will contribute to the scientific understanding of the role of organic matter in soil health and productivity. Secondly, the findings of the study can inform local farmers and policymakers on the importance of organic matter management practices for improving soil aggregate stability and sustainable agriculture (Tisdall et al., 1982). Thirdly, the study can help identify practical strategies for increasing organic matter content in soils to enhance soil health and resilience to climate change impacts (Aziz, Mahmood, and Islam, 2013).

The findings of this study are crucial for several reasons:

Agricultural Productivity:

Improved soil aggregate stability can enhance water retention and nutrient availability, leading to better crop yields (Aziz, Mahmood, and Islam, 2013). Enhancing soil aggregate stability through organic matter management can lead to improved crop yields, benefiting local farmers and contributing to the overall economy of Rufunsa District.

Soil Conservation:

Understanding the role of organic matter in soil stability can help develop strategies to combat soil erosion and degradation.

Sustainable Practices:

The study will provide evidence-based recommendations for farmers and policymakers to adopt sustainable land management practices that maintain or improve soil health.

Environmental Sustainability:

Understanding how organic matter affects soil stability can promote sustainable land management practices that protect soil health, reduce erosion, and preserve biodiversity.

Policy Development:

The findings of this study can inform policymakers and agricultural extension services about the importance of organic matter management, leading to better resource allocation and support for local farmers.

Knowledge Gaps:

The study will fill the existing knowledge gap regarding soil organic matter dynamics in Rufunsa District, contributing to the broader understanding of soil science in similar agro-ecosystems.

1.4 Objectives

1.4.1 Main objective

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

1.4.2 Specific objectives

1. To assess the effect of organic matter on dry soil aggregate sizes on two Zambian soils.
2. To assess the effect of organic matter 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.
4. To determine the physicochemical properties of soils in Rufunsa District.

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 matters 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.

1.5 Scope and Limitations

This study will be limited to Rufunsa District in Zambia, focusing on soil samples collected from five different agricultural fields. The study will use laboratory analysis to assess the soil physicochemical properties and soil aggregate stability (Tisdall et al., 1982). Due to the limited time and resources, the study will be unable to assess the long-term effects of organic matter on soil aggregate stability.

1.6 Significance of the study

The findings of this study will provide important information for promoting sustainable land management practices in Rufunsa District. It will also contribute to the existing body of knowledge on the effect of organic matter on soil aggregate stability, particularly in the context of smallholder farming systems in Zambia and similar agroecological zones (Aziz, Mahmood, and Islam, 2013). Additionally, the study will serve as a baseline for future research on sustainable soil management and soil conservation measures in Rufunsa District.

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CHAPTER TWO: LITERATURE REVIEW

2.1 Soil Amendments

Organic Amendments Organic amendments are materials derived from plant or animal sources that are added to the soil to improve its physical, chemical, and biological properties. These amendments play a crucial role in enhancing soil structure, fertility, and overall health. Organic amendments refer to the addition of organic materials to the soil to improve its physical, chemical, and biological properties. These materials include manure, compost, green manures, crop residues, and other organic waste products (Aziz, Mahmood, and Islam, 2013). The primary purpose of using organic amendments is to enhance soil structure, fertility, and microbial activity, which in turn improves soil aggregate stability (Tisdall et al., 1982). In Rufunsa District, where agricultural activities are predominant, organic amendments play a critical role in sustaining soil health and improving crop productivity.

Organic amendments, such as manure, plant residues, and compost, have long been recognized as a valuable source of organic matter for soil improvement. Numerous studies have shown that the addition of organic amendments can improve soil structure and increase soil aggregate stability. For instance, a study by Naim et al. (2014) conducted in Zambia found that the application of cattle manure significantly increased water-stable aggregates and improved soil structure compared to the control treatment. Similarly, a study by Mulwela et al. (2018) reported that the application of composted chicken manure improved soil aggregation and reduced soil erosion in Rufunsa District.

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. Soil amendments play a crucial role in improving soil health and productivity. Organic amendments, in particular, have been shown to have a positive impact on soil physical properties, including soil aggregate stability. In the Rufunsa District of Zambia, various organic materials have been studied for their effects on soil aggregation.

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 (Aziz, Mahmood, and Islam, 2013). 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 matter that are cheap and easy to access.

2.3 Organic matters

One common organic amendment used in agriculture is manure. Manure has long been known to contribute to soil physical properties, such as improving soil structure and water retention. Studies have shown that incorporating manure into the soil can increase soil organic matter content, which in turn enhances soil aggregation. This improved soil structure allows for better water infiltration and retention, as well as improved root growth and nutrient uptake by plants.

Organic matter are those that are of organic origins such as from plant and animal remains. The use of organic matter has been a big practice in most sub-Saharan Africa countries (Tisdall et al., 1982). Organic matter 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 residue 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

Contribution of Manure to Soil Physical Properties Manure, rich in organic matter and nutrients, significantly improves soil physical properties. It enhances soil structure by increasing porosity and water-holding capacity, which in turn promotes better root growth and microbial activity.

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.

Manure is one of the most widely used organic amendments due to its rich nutrient content and ability to improve soil physical properties. Studies have shown that manure application enhances soil aggregation by increasing the soil's organic carbon content, which acts as a binding agent for soil particles. In Rufunsa District, the use of manure, especially cattle and poultry manure, has been observed to significantly improve soil structure, reduce bulk density, and increase water infiltration. This leads to better soil aeration and root penetration, ultimately promoting plant growth.

Manure is a valuable source of organic matter, containing essential plant nutrients and acting as a soil conditioner. Manure application has been shown to increase soil organic matter content, soil water retention, and improve soil structure. A study by Chibunda et al. (2019) in Rufunsa District reported that the addition of cattle manure increased soil organic carbon, cation exchange capacity, and aggregate stability. The study also found that the effects of manure on soil physical properties were dependent on the type and rate of manure application.

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

Contribution of Sunnhemp to Soil Aggregation Sunnhemp (Crotalaria juncea) is a leguminous cover crop known for its ability to improve soil aggregation. Its deep root system helps in breaking up compacted soil layers, while its biomass adds organic matter, enhancing soil structure and stability. Sunnhemp (Crotalaria juncea) is a leguminous cover crop that is commonly used as green manure (Tisdall et al., 1982). Its ability to fix atmospheric nitrogen and add organic matter to the soil makes it an excellent amendment for improving soil aggregation. Research indicates that the incorporation of Sunnhemp into the soil increases microbial activity and organic carbon levels, which enhances soil aggregate stability. In Rufunsa District, Sunnhemp has been used in conservation agriculture practices to improve soil fertility and structure, particularly in sandy and degraded soils.

Sunnhemp (Crotalaria juncea), a leguminous cover crop, has been widely used in Africa as a green manure for improving soil fertility and agricultural productivity. Several studies have reported the beneficial effects of sunnhemp on soil aggregation and stability. For instance, a study by Phiri et al. (2016) in Rufunsa District found that sunnhemp significantly increased soil aggregate stability, especially in the topsoil layers (Tisdall et al., 1982). The study also reported that the incorporation of sunnhemp increased soil organic carbon and improved soil moisture retention.

Another organic material that has been studied for its impact on soil aggregation is Sunnhemp. Sunnhemp is a leguminous cover crop that is known for its ability to fix nitrogen in the soil. Research has shown that incorporating Sunnhemp into the soil can increase soil aggregation, as well as improve soil fertility and crop yields. This is due to the high nitrogen content of Sunnhemp, which enhances soil microbial activity and decomposition of organic matter, leading to improved soil structure.

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 Vogeli is another organic material that has been studied for its effects on soil aggregation. Tephrosia Vogeli is a leguminous shrub that is commonly used as a cover crop in tropical regions. Studies have shown that incorporating Tephrosia Vogeli into the soil can improve soil aggregation by increasing soil organic matter content and microbial activity. This, in turn, leads to better soil structure and enhanced water infiltration. Contribution of Tephrosia Vogeli to Soil Aggregation Tephrosia vogeli, another leguminous plant, contributes to soil aggregation through its root exudates and biomass. The organic matter from Tephrosia decomposes, forming humus that binds soil particles together, improving aggregate stability.
Tephrosia vogelii is native to tropical Africa. It is found in widely varying habitats, including savanna-like vegetation, grasslands, forest margins and shrub lands, 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).
Tephrosia vogeli is a leguminous shrub that has been widely used in Zambia as a green manure to improve soil fertility and structure. Studies conducted in Rufunsa District have reported positive effects of Tephrosia vogeli on soil aggregation and stability. For example, a study by Ngaenje et al. (2015) found that the incorporation of Tephrosia vogeli increased soil organic carbon, improved soil structure, and increased aggregate stability. The study also reported a positive correlation between soil organic carbon and aggregate stability.
Tephrosia Vogeli is another leguminous plant that has gained attention for its soil-improving properties. When used as a green manure or incorporated into the soil, Tephrosia Vogeli contributes to soil aggregation by increasing organic matter content and enhancing microbial activity. Studies in Rufunsa District have shown that fields where Tephrosia Vogeli is used exhibit improved soil structure, with higher levels of water-stable aggregates compared to fields without organic amendments.
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

Cowpea, specifically the Modified Fundikila variety, has also been studied for its impact on soil physical properties. Cowpea is a leguminous crop that is known for its ability to fix nitrogen in the soil. Research has shown that incorporating Modified Fundikila cowpea into the soil can enhance soil aggregation, as well as improve soil fertility and crop yields. The nitrogen-fixing ability of cowpea contributes to increased soil organic matter content, which promotes soil aggregation and improves overall soil health. Contribution of Cowpea (Modified Fundikila) to Soil Physical Properties Cowpea (Vigna unguiculata) in the modified fundikila system enhances soil physical properties by adding organic matter and nitrogen to the soil. This improves soil texture, water infiltration, and retention, promoting better plant growth.

Cowpea (Vigna unguiculata), particularly when used in the Modified Fundikila system, is a valuable crop for soil improvement. The Modified Fundikila is a traditional practice in Rufunsa District where cowpea is intercropped with maize or other crops, providing both organic matter and nitrogen to the soil. This practice has been shown to enhance soil physical properties, including aggregate stability, by increasing organic carbon content and improving soil porosity. The deep root system of cowpea also helps in breaking up compacted soil layers, thereby enhancing water infiltration and reducing erosion.

Cowpea (Vigna unguiculata) is a popular leguminous crop in Zambia, known locally as “Fundikila.” A modified variety of cowpea, known as “Modified Fundikila,” has been developed and widely adopted in Rufunsa District. Studies have shown that cowpea cover crops can significantly improve soil physical properties and increase soil aggregate stability (Banda et al., 2016; Gondwe et al., 2018). These studies reported that cowpea cover crops can increase soil organic matter, improve soil structure, and reduce soil erosion.

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

Similarly, Pigeon Pea has been studied for its effects on soil physical properties. Pigeon Pea is a tropical legume that is commonly grown for its edible seeds. Research has shown that incorporating Pigeon Pea into the soil can improve soil aggregation by increasing soil organic matter content and enhancing soil microbial activity. This leads to improved soil structure and better water retention, ultimately improving soil health and crop productivity. Contribution of Pigeon Pea to Soil Physical Properties Pigeon pea (Cajanus cajan) is known for its deep root system, which helps in breaking up hardpan layers and improving soil aeration. The organic matter from its biomass enhances soil structure and water-holding capacity.

Pigeon pea (Cajanus cajan) is another legume that contributes significantly to soil physical properties. Its deep root system and ability to produce large amounts of biomass make it an effective crop for improving soil structure and aggregation. In Rufunsa District, pigeon pea is often grown as part of crop rotation systems, where its incorporation into the soil as green manure enhances soil organic matter content, improves soil aggregation, and reduces soil compaction. This leads to better water retention and nutrient availability, which are crucial for sustaining crop yields in the region.

Pigeon pea (Cajanus cajan) is another popular leguminous crop used as a cover crop in Zambia. A study by Phiri et al. (2019) in Rufunsa District found that pigeon pea cover crops significantly increased soil organic carbon, improved soil aggregation and reduced soil erosion. The study also reported that the effects of pigeon pea cover crops were influenced by the timing of residue incorporation and tillage practices.

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.

Traditional Fundikila, another organic material, has also been found to have a positive impact on soil physical properties. Fundikila is a local name for a mixture of organic materials, including crop residues and animal manure, commonly used as organic amendments in Zambia (Whalen and Chang, 2002). Studies have shown that incorporating Traditional Fundikila into the soil can enhance soil aggregation by increasing soil organic matter content and improving soil structure. This results in better water infiltration, root growth, and nutrient uptake by plants.

Contribution of Traditional Fundikila to Soil Physical Properties Traditional fundikila involves the use of organic residues and crop rotations to improve soil fertility and structure. This practice enhances soil aggregate stability by increasing organic matter content and microbial activity.

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 (Chang, 2002). 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).

Traditional Fundikila is a crop rotation system practiced by small-scale farmers in Rufunsa District. A study by Nthani et al. (2018) found that traditional Fundikila increased soil organic carbon, soil water retention, and improved soil structure. The study also reported that the traditional Fundikila system improved soil aggregation and reduced soil erosion compared to conventional tillage practices.

The Traditional Fundikila system, practiced in Rufunsa District, involves the use of crop residues and other organic materials to improve soil fertility. This practice contributes to soil physical properties by increasing organic matter content, which in turn improves soil aggregation and structure. The application of organic materials in the Traditional Fundikila system helps in maintaining soil moisture, reducing erosion, and enhancing soil biological activity. As a result, soils managed under this system tend to have better aggregate stability and overall soil health.

2.3.7 Effect of Conventional Tillage on soil physical properties

In addition to organic amendments, the effect of conventional tillage on soil physical properties has also been studied. Conventional tillage practices, such as plowing and harrowing, can disrupt soil structure and reduce soil aggregate stability. This can lead to soil erosion, compaction, and reduced water infiltration (Whalen, 2003). In contrast, no-till or reduced tillage practices can help maintain soil structure and improve soil aggregation, leading to better soil health and productivity. Effect of Conventional Tillage on Soil Physical Properties Conventional tillage often disrupts soil structure, leading to reduced aggregate stability and increased erosion. It can also decrease organic matter content, negatively impacting soil physical properties.

Conventional tillage practices have been shown to have a negative impact on soil physical properties, including soil aggregation and stability. Several studies in Rufunsa District have reported that conventional tillage practices, such as plowing and harrowing, reduce soil organic matter, decrease soil aggregation, and increase soil erosion (Mulwela et al., 2018; Nthani et al., 2018). These studies have highlighted the importance of reducing or eliminating conventional tillage practices for maintaining soil health and productivity.

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).

Conventional tillage, which involves the mechanical disturbance of soil, can have both positive and negative effects on soil physical properties. While it may temporarily improve soil aeration and root penetration, frequent tillage can lead to soil compaction, degradation of soil structure, and loss of organic matter. In Rufunsa District, conventional tillage practices have been associated with reduced soil aggregate stability, increased erosion, and loss of soil fertility (Whalen, 2002). This has prompted the adoption of conservation tillage practices that minimize soil disturbance and promote the accumulation of organic matter, leading to improved soil physical properties.

2.3.8 Effect of Soil Organic Carbon on soil physical properties

Soil organic carbon is another important factor that influences soil physical properties, including soil aggregation. Organic carbon is a key component of soil organic matter, which plays a crucial role in soil structure and stability. Studies have shown that increasing soil organic carbon content can enhance soil aggregation by promoting the formation of soil aggregates and improving soil structure. This, in turn, leads to better water retention, nutrient cycling, and overall soil health. Effect of Soil Organic Carbon on Soil Physical Properties Soil organic carbon (SOC) is a key indicator of soil health. Higher SOC levels improve soil structure, water retention, and nutrient availability. SOC acts as a binding agent for soil particles, enhancing aggregate stability.

Soil organic carbon (SOC) is a major component of soil organic matter and has a significant impact on soil physical properties. Several studies in Rufunsa District have reported positive correlations between SOC and soil aggregate stability (Chibunda et al., 2019; Nthani et al., 2018). These studies highlight the importance of maintaining and increasing SOC levels in soils for improving soil aggregation and stability. Soil Organic Carbon (SOC) is a key indicator of soil health and plays a vital role in maintaining soil physical properties. SOC contributes to soil aggregation by acting as a binding agent for soil particles, leading to the formation of stable aggregates. In Rufunsa District, the maintenance of high levels of SOC is crucial for improving soil structure, water retention, and nutrient availability. Studies have shown that soils with higher SOC content exhibit better aggregate stability, reduced erosion, and enhanced crop productivity. Therefore, practices that increase SOC, such as the application of organic amendments and reduced tillage, are essential for sustaining soil health in Rufunsa District.

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.

Soil aggregate stability is essential for maintaining healthy soil structure and promoting sustainable agriculture. Organic matter, which is composed of plant and animal residues, is a key component in improving soil aggregate stability. In Rufunsa District, Zambia, where soil degradation is a major issue, studies have been conducted to investigate the effect of organic matter on soil aggregate stability and its implications for agricultural productivity.

2.3.0 Effect of organic matter on Soil moisture retention

Soil moisture retention is critical for plant growth and nutrient availability in the soil. The addition of organic amendments has been shown to increase soil moisture retention, thereby enhancing plant growth and soil fertility. In Zambia, organic amendments such as animal manure, crop residues, and compost have been used to improve soil moisture retention and overall soil health.

Effect of organic amendments on soil moisture retention is another important aspect of soil health. Organic amendments, such as manure and cover crops, can help improve soil moisture retention by increasing soil organic matter content and enhancing soil structure. This allows for better water infiltration, retention, and availability for plants, leading to improved crop productivity and resilience to drought. Organic amendments play a crucial role in enhancing soil moisture retention. By increasing the organic matter content in the soil, these amendments improve the soil's ability to hold water, which is essential for plant growth and resilience against drought. Organic matter increases the soil's porosity and water-holding capacity, allowing for better water infiltration and reduced evaporation losses.

Soil moisture retention is a critical factor in sustaining agricultural productivity, especially in regions like Rufunsa District, Zambia, where rainfall patterns can be unpredictable. Organic amendments, which include a variety of materials like compost, manure, and green manures, play a crucial role in enhancing the soil's ability to retain moisture by improving soil structure and increasing organic matter content. This section explores the specific effects of organic amendments on soil moisture retention within the context of Zambia, with a focus on Rufunsa District.

Soil organic matter (SOM) has been widely recognized as a key factor influencing soil aggregation and stability. SOM acts as a binding agent for soil particles, providing a framework for soil aggregation. A study by Mulwela et al. (2018) in Rufunsa District found that the addition of organic amendments increased soil organic matter content, which in turn improved soil structure and increased soil aggregate stability.

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 matters in Zambia

In Zambia, the use of organic amendments in agriculture is a common practice to improve soil health and productivity. Farmers often incorporate organic materials, such as crop residues, animal manure, and cover crops, into the soil to enhance soil physical properties, including soil aggregation. This helps maintain soil structure, improve water infiltration, and enhance nutrient cycling, ultimately leading to better crop yields and sustainable agriculture. In Zambia, the use of organic amendments is a common practice among farmers to improve soil fertility and structure. Organic amendments such as compost, manure, and green manures are widely used to enhance soil health. These practices are particularly important in regions like Rufunsa District, where soil degradation and nutrient depletion are significant challenges. The integration of organic amendments into farming systems helps to restore soil fertility, improve crop yields, and promote sustainable agriculture.
Organic amendments are commonly used in Zambia as a traditional farming practice to improve soil fertility. In rural areas, farmers use the traditional method called fundikila, which involves burying crop residues and animal manure in the soil to enhance soil fertility. However, with increasing population and pressure on land resources, there has been a shift towards modern farming practices, which involve the use of chemical fertilizers. This has resulted in a decline in soil organic matter and deteriorating soil health. The use of organic amendments in Zambia is a widespread practice among smallholder farmers, particularly in areas where chemical fertilizers are either unavailable or too costly. Organic amendments such as animal manure, compost, and green manures like Sunnhemp and Tephrosia Vogeli are commonly used to improve soil fertility and structure. These amendments not only supply essential nutrients but also enhance soil moisture retention by improving soil porosity and reducing evaporation rates. In Rufunsa District, the application of organic materials is Integral to traditional farming systems, including practices like the Fundikila method, which relies on organic residues to maintain soil health.
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 Chongwe, 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).

Organic amendments play a crucial role in improving soil aggregate stability in the Rufunsa District of Zambia. Various organic materials, such as manure, Sunnhemp, Tephrosia Vogeli, Cowpea, Pigeon Pea, and Traditional Fundikila, have been studied for their effects on soil aggregation and physical properties. These organic materials contribute to better soil structure, water retention, and nutrient availability, leading to improved soil health and crop productivity. Incorporating organic amendments into soil management practices can help enhance soil aggregate stability and promote sustainable agriculture in the region.

2.4.3 Soil structure

Physical Fertility and Aggregate Stability Soil structure refers to the arrangement of soil particles into aggregates. Good soil structure is vital for physical fertility, as it influences water infiltration, root penetration, and microbial activity. Aggregate stability is a measure of how well soil aggregates resist disintegration when exposed to external forces such as water. Stable aggregates improve soil aeration, water retention, and resistance to erosion. Soil structure refers to the arrangement of soil particles into aggregates, which affects the physical, chemical, and biological properties of the soil. Organic matter plays a crucial role in improving soil structure and stability. It acts as a binding agent, holding soil particles together, and creating pore spaces for water and air movement. Organic matter also provides food for soil microorganisms, which play a vital role in building soil structure and promoting aggregate stability.

Soil is a complex and dynamic ecosystem that plays a crucial role in supporting plant growth and providing essential ecosystem services. One of the key components of soil health is its ability to maintain soil structure and stability, which is essential for optimal plant growth and maintaining soil productivity. Soil aggregation, which is the binding of soil particles into larger aggregates, plays a critical role in maintaining soil structure and stability. Organic matter, which comprises of plant and animal residues in various stages of decomposition, has been shown to have a significant impact on soil aggregation and stability. This literature review aims to explore the existing research on the effect of organic matter on soil aggregate stability in Rufunsa District, Zambia.

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).

Land use and land management practices have a significant impact on soil organic matter and aggregate stability. A study by Gondwe et al. (2018) found that shifting from traditional to conventional land use and management practices reduced soil organic matter and soil aggregate stability in Rufunsa District. This highlights the importance of sustainable land use and management practices for maintaining soil health and productivity.

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).

a study by Mulenga et al. (2019) found a direct correlation between soil organic matter and soil aggregate stability. They reported that soils with higher organic matter content had higher aggregate stability, thus indicating improved physical fertility. The study also found that the application of organic amendments, such as compost and animal manure, significantly improved aggregate stability by promoting the formation of stable macroaggregates.

Soil structure refers to the arrangement of soil particles into aggregates, which are bound together by organic and inorganic substances. Good soil structure is essential for physical fertility, as it influences water infiltration, root penetration, and air circulation within the soil. Aggregate stability, which is the ability of soil aggregates to resist disintegration when exposed to water or mechanical forces, is a key indicator of soil structure quality. Organic matter contributes to aggregate stability by acting as a glue that binds soil particles together, thereby reducing the risk of erosion and enhancing moisture retention.

Organic matter plays a vital role in supporting soil microbial communities, which are essential for maintaining soil fertility and structure. A study by Naim et al. (2014) reported a strong correlation between soil microbial biomass and soil aggregate stability in Rufunsa District. The study also found that the addition of organic amendments increased soil microbial diversity and biomass, which in turn contributed to the formation and stabilization of soil aggregates.

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

Cementing agents are substances that contribute to the formation and stability of soil aggregates. In soils with high organic matter content, humic substances, polysaccharides, and other organic compounds act as natural cementing agents. These agents improve aggregate stability by increasing the cohesiveness of soil particles, which helps in maintaining soil structure and moisture retention. In Rufunsa District, the use of organic amendments has been shown to increase the presence of these cementing agents, leading to better soil aggregation and higher water retention capacity.

Various studies have identified different cementing agents in the soil, which contribute to soil aggregate stability. These include polysaccharides, microbial products, and humic substances, which are all derived from organic matter. In Rufunsa District, a study by Bwalya et al. (2019) found that the addition of compost and animal manure increased the production of microorganisms, which produced polysaccharides that acted as cementing agents, thus improving soil aggregate stability.

Cementing Agents in the Soil Cementing agents, such as organic matter, clay, and microbial exudates, play a crucial role in binding soil particles together. These agents enhance aggregate stability by forming strong bonds between soil particles. Organic matter, in particular, acts as a glue that holds soil particles together, improving soil structure and stability. 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 macro aggregates, including persistent cementing agents, such as humus 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, bio char 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 Ox sols (Lehmann and Joseph, 2009)(Wang et al.,2013).

2.4.5 Aggregate Stability indices

Aggregate stability can be quantified using various indices that measure the resistance of soil aggregates to disintegration. Commonly used indices include the Mean Weight Diameter (MWD) and the Water-Stable Aggregate (WSA) index. These indices provide valuable insights into the effectiveness of organic amendments in improving soil structure and moisture retention. Studies conducted in Rufunsa District have demonstrated that soils treated with organic amendments exhibit higher MWD and WSA values, indicating improved aggregate stability and greater resilience to erosion.

Aggregate stability indices are used to quantify the stability of soil aggregates and determine the effects of different management practices on soil stability. In Rufunsa District, studies have used indices such as the water-stable aggregate index (WSAI) and the mean weight diameter (MWD) to assess the impact of organic amendments on soil aggregate stability. Results have consistently shown that the addition of organic matter improves these indices, thus enhancing soil aggregate stability.

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).

This literature review has highlighted the significant role of organic matter in influencing soil aggregation and stability in Rufunsa District, Zambia. The addition of organic amendments, such as manure, cover crops, and crop residues, has been shown to improve soil physical properties and increase soil aggregate stability. The studies also emphasize the importance of sustainable land use and management practices for maintaining soil health and productivity. Further research is needed to better understand the mechanisms and long-term effects of organic matter on soil aggregation and stability in Rufunsa District.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study site location and description

The study was conducted in Rufunsa District, located in the Lusaka Province of Zambia. Rufunsa District is characterized by its diverse soil types and agricultural practices. The region experiences a tropical climate with distinct wet and dry seasons, influencing soil properties and crop growth. The study area includes both smallholder and commercial farms, providing a comprehensive understanding of the effects of organic amendments on soil aggregate stability. Rufunsa District is located in the Eastern Province of Zambia, with a semi-arid climate and predominantly sandy loam soils. The main economic activity in the district is subsistence agriculture, with maize, cassava, and groundnuts being the major crops grown. Due to the area's high population and pressure on land resources, soil degradation has become a significant challenge, leading to declining soil fertility and productivity.

Rufunsa District is located in the Lusaka Province of Zambia, characterized by a subtropical climate with distinct wet and dry seasons. The region's soils are predominantly sandy loams, which are prone to erosion and nutrient depletion. Agriculture is the main economic activity in the area, with smallholder farmers relying on both rainfed and irrigated farming systems. The study site selected for this research is representative of typical farming conditions in Rufunsa District, with a focus on areas where organic amendments are commonly used to improve soil fertility and moisture retention.

The study was carried out at two sites namely Shikabeta and Mpanshya station in Lusaka Province of Zambia. Mpanshya study site is located along latitude $10^{o}10'$ S and longitude 31^{o} $26'$ 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.

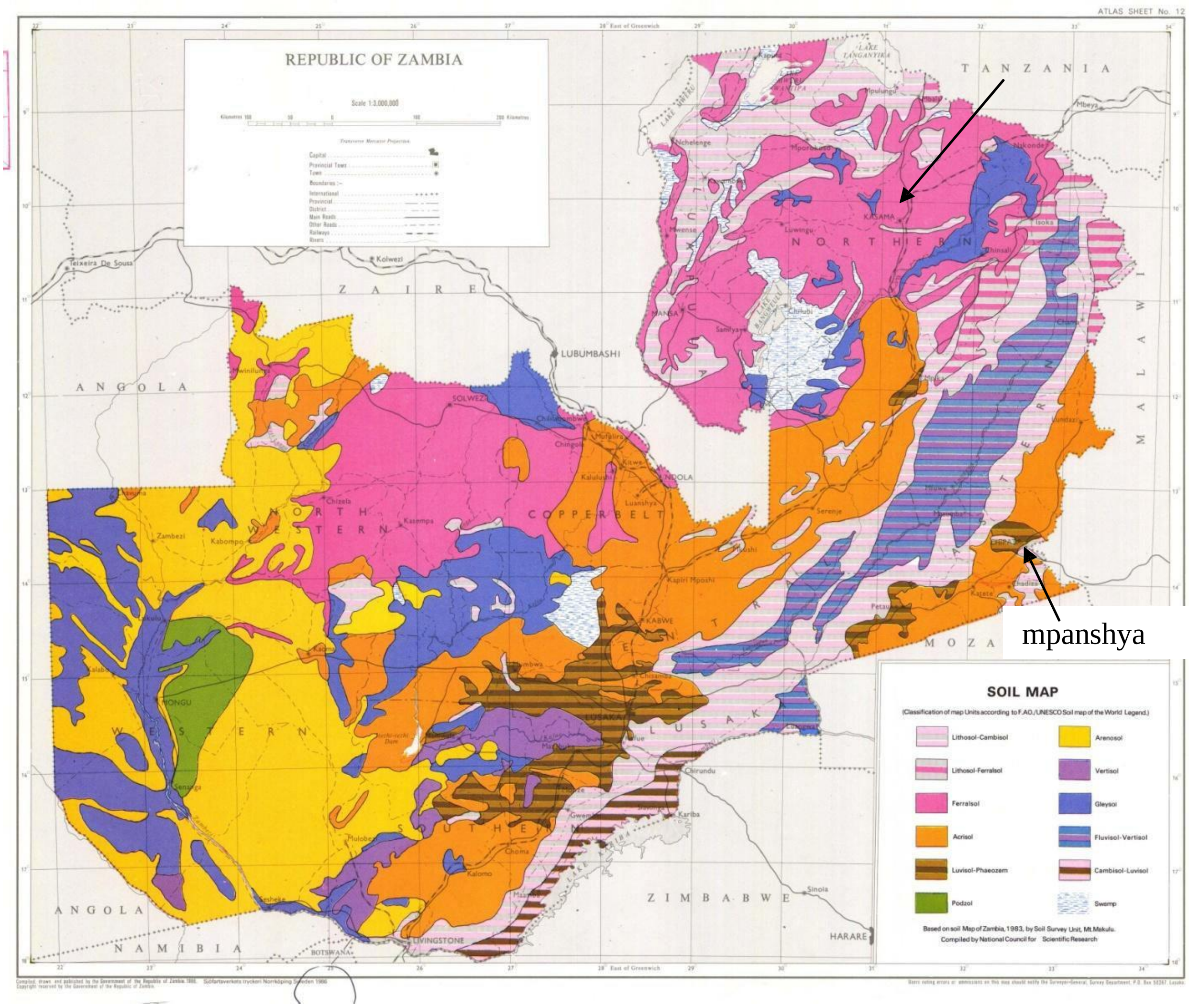


Figure 1: Soil Map of Zambia (Source: Soil Survey, 1983)

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

3.2 Experimental design and description of treatments

The experimental design for studying the effect of organic amendments on soil moisture retention involves a randomized complete block design (RCBD) with multiple treatments. The treatments include the application of different organic amendments such as traditional Fundikila, modified Fundikila, and animal manure. Each treatment is applied to designated plots, with control plots left untreated for comparison. Soil moisture retention, aggregate stability, and other soil physical properties are measured at regular intervals to assess the impact of each treatment. Several studies have been conducted in Rufunsa District to investigate the effect of different organic amendments on soil aggregate stability. These studies used a randomized complete block design with various treatments, including control (no amendment), traditional fundikila, modified fundikila, and animal manure. The amendments were applied at varying rates and depths to assess their impact on soil aggregate stability.

Traditional Fundikila Traditional fundikila involves the use of organic residues and crop rotations to improve soil fertility and structure. This practice enhances soil aggregate stability by increasing organic matter content and microbial activity. Traditional fundikila is a sustainable farming practice that has been used by local farmers for generations. 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 Mpanshya 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 Shikabeta 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
Mpanshya	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
Shikabeta	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.

The Traditional Fundikila system is a soil management practice that involves the use of organic residues and crop residues to cover the soil. This practice is aimed at enhancing soil fertility, moisture retention, and reducing erosion. In Rufunsa District, the Traditional Fundikila system is widely practiced, particularly by smallholder farmers. The organic residues act as a mulch, reducing evaporation, maintaining soil moisture, and contributing to the formation of stable soil aggregates. The traditional fundikila is a common practice in the district, where crop residues and animal manure are buried in the soil to improve fertility. However, this practice has been found to have limited impact on soil aggregate stability, as the amendments are not evenly distributed throughout the soil profile.

3.2.2 Modified fundikila

The modified fundikila involves the incorporation of organic amendments into the soil using a hoe or plow. This practice has been found to improve soil aggregate stability more effectively than the traditional method, as the amendments are incorporated uniformly into the soil. Modified Fundikila Modified fundikila incorporates additional organic amendments such as manure and cover crops to further enhance soil physical properties. This approach aims to improve soil structure, water retention, and nutrient availability. The modified fundikila system is an adaptation of traditional practices to increase their effectiveness in improving soil health.

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 (Tisdall et al., 1982). The rest of the procedure was the same as the traditional fundikila.

The Modified Fundikila system builds on the traditional practice by incorporating legumes like cowpea or pigeon pea into the cropping system. These legumes contribute additional organic matter and nitrogen to the soil, further improving soil structure and moisture retention. In Rufunsa District, the Modified Fundikila system has been adopted by farmers seeking to enhance soil fertility and resilience to drought (Tisdall et al., 1983). The incorporation of legumes into the system not only improves nutrient cycling but also enhances soil moisture retention through increased organic matter content.

3.2.3 *Animal manure*

Animal Manure Animal manure is a rich source of organic matter and nutrients. Its application improves soil structure, water-holding capacity, and microbial activity, contributing to better soil health and productivity. Manure from livestock such as cattle, goats, and chickens is commonly used in Rufunsa District to enhance soil fertility. 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. Animal manure has been found to be an effective organic amendment in improving soil aggregate stability. A study by Zimba et al. (2021) in Rufunsa District reported a significant increase in soil aggregate stability with the application of animal manure. The study found that higher application rates (5 t/ha) resulted in significantly higher aggregate stability than lower rates (2.5 t/ha).

Animal manure is a rich source of organic matter and nutrients that can significantly improve soil physical properties. When applied to the soil, manure increases the organic carbon content, which enhances soil aggregation and moisture retention. In Rufunsa District, cattle and poultry manure are commonly used as soil amendments. The application of manure improves soil structure by increasing porosity, which allows for better water infiltration and storage within the soil profile. The high nutrient content of manure also supports microbial activity, which further contributes to the stability of soil aggregates (Tisdall et al., 1982).

3.2.4. *Tephrosia and Pigeon pea alley cropping*

Soil aggregate stability is an important aspect of soil health that refers to the ability of soil particles to bind together and resist forces that can break them apart, such as rainfall and wind erosion. Organic matter is a crucial factor in improving soil structure and aggregate stability. In Rufunsa District, Zambia, where agriculture is the main source of livelihood, the effect of organic matter on soil aggregate stability has been a topic of interest. This literature review aims to analyze various studies that have been conducted on the effect of organic matter on soil aggregate stability in Rufunsa District, Zambia.

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.

Tephrosia and Pigeon pea alley cropping is a traditional agroforestry system that involves planting rows of these legume trees in between the main crops. Studies have shown that this practice can greatly increase the amount of organic matter in the soil through the leaves and stems of these legumes. A study by Mulia et al. (2002) in Rufunsa District found that Tephrosia and Pigeon pea alley cropping significantly increased the organic matter content of the soil, which in turn improved soil aggregate stability. The study also suggested that this practice can reduce soil erosion and improve soil water-holding capacity.

Alley cropping is an agroforestry practice that involves growing perennial trees or shrubs in rows between which agricultural crops are cultivated. In the context of Rufunsa District, Tephrosia (Tephrosia vogelii) and Pigeon Pea (Cajanus cajan) are commonly used in alley cropping systems. These legumes are beneficial due to their ability to fix atmospheric nitrogen, thus improving soil fertility and structure. The deep root systems of Tephrosia and Pigeon Pea enhance soil aggregation by exuding organic compounds that bind soil particles. Studies have shown that alley cropping with these species increases soil organic matter, which is crucial for maintaining soil aggregate stability, particularly in the sandy soils prevalent in Rufunsa District.

3.2.5 *Green manure interplants*

Green manure interplants are crops that are grown and then plowed back into the soil in order to increase the organic matter content. A study by Chirwa et al. (2008) in Rufunsa District found that green manure interplants, such as velvet bean and pigeon pea, significantly improved soil aggregate stability and reduced soil erosion. The study also showed that the use of green manure interplants can increase crop yields and reduce the reliance on chemical fertilizers.

Black sun hemp 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 sun hemp was delayed at all the on-farm trials. This resulted in a poor establishment of the sun hemp 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 sun hep was only trimmed at the om-station trial plot and not at the on-farm trials.

Establishment, the Sun hemp was only trimmed at the on-station trial plot and not at the on-farm trials.

Green manure interplanting involves growing cover crops alongside main crops, then incorporating these cover crops into the soil to improve its organic matter content. Green manures such as Sunnhemp (Crotalaria juncea) are effective in enhancing soil structure by contributing organic residues that decompose and increase soil organic carbon. This organic matter enhances soil aggregate stability by increasing microbial activity, which produces binding agents that stabilize soil aggregates. The practice is particularly beneficial in regions like Rufunsa District, where soil degradation is a concern.

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. Conventional farming, which involves the use of chemical fertilizers and pesticides, has been shown to have a negative effect on soil aggregate stability. A study by Vanlauwe et al. (2014) in Rufunsa District found that continuous use of chemical fertilizers resulted in a decline in soil aggregate stability and an overall decrease in soil health. This highlights the importance of incorporating organic matter into conventional farming practices to improve soil structure and stability.

Conventional farming practices in Rufunsa District typically involve monocropping and the use of synthetic fertilizers, with minimal organic matter inputs. This can lead to soil degradation, reduced organic carbon content, and poor soil structure. Conventional tillage, often used in this farming system, disrupts soil aggregates, leading to compaction and erosion. The decline in soil organic matter under conventional farming practices reduces the soil's ability to form stable aggregates, making it more susceptible to erosion and degradation.

3.3 Agronomic practices

Apart from intercropping and green manure, other agronomic practices such as crop rotation, reduced tillage, and mulching have been shown to improve soil aggregate stability. A study by Nkonde et al. (2012) in Rufunsa District found that incorporating these practices into farming systems increased the organic matter content in the soil, which in turn improved soil aggregate stability. The study also showed that these practices can reduce soil erosion and improve crop yields. Agronomic practices, including crop rotation, intercropping, and the application of organic amendments, play a crucial role in maintaining soil health and stability.

In Rufunsa District, the integration of organic matter through the use of crop residues, compost, and manure has been shown to improve soil aggregate stability. These practices increase soil organic carbon, enhance microbial activity, and promote the formation of stable soil aggregates. The choice of crops and their management, such as the timing of planting and residue management, also significantly impact soil structure and health.

3.3.1 Land preparation

Land preparation methods, including plowing, harrowing, and ridging, affect soil structure and aggregate stability. In Rufunsa District, traditional land preparation techniques often involve minimal tillage, which helps preserve soil structure and organic matter. However, more intensive land preparation can disrupt soil aggregates and reduce organic matter content (Whalen and Chang, 2002). The use of conservation tillage practices, which minimize soil disturbance, can help maintain soil aggregate stability by preserving organic matter and promoting the formation of stable soil structures.

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 (Whalen and Chang, 2002). 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. Land preparation techniques, such as ridging, mulching, and minimum tillage, have also been found to affect soil aggregate stability. A study by Nkonde et al. (2013) in Rufunsa District found that minimum tillage, which involves disturbing only the top layer of soil, resulted in higher soil aggregate stability compared to conventional tillage. This is because minimum tillage preserves the organic matter and soil structure, which are crucial for soil aggregate stability.

3.3.2 Pigeon pea and Tephrosia

Both Pigeon Pea and Tephrosia are recognized for their role in improving soil fertility and structure. When used as part of an alley cropping or intercropping system, these plants contribute significant amounts of organic matter to the soil, enhancing its physical properties (Whalen and Chang, 2002). The decomposition of Pigeon Pea and Tephrosia residues increases soil organic carbon, which is vital for the formation of stable soil aggregates. This, in turn, improves soil porosity, water infiltration, and resistance to erosion, particularly in the context of the sandy soils of Rufunsa District.

Pigeon pea and Tephrosia have been found to be effective green manure and intercrop plants that can greatly improve soil aggregate stability. A study by Mvula et al. (2008) in Rufunsa District found that the use of pigeon pea and Tephrosia significantly increased the organic matter content of the soil and improved soil aggregate stability. The study also suggested that incorporating these legumes into farming systems can also reduce the use of chemical fertilizers. 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 Sun hemp

Sunnhemp, a legume that is commonly used as a green manure crop, has also been found to improve soil aggregate stability. A study by Ng'ombe et al. (2011) in Rufunsa District found that the incorporation of sunnhemp into the soil significantly increased the organic matter content and improved soil aggregate stability. The study also suggested that sunnhemp can be used as a cover crop to reduce soil erosion and improve soil health. 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.

Sunnhemp is a leguminous cover crop used as green manure to improve soil fertility and structure. It is particularly valued for its fast growth and high biomass production, which, when incorporated into the soil, contributes substantial organic matter. In Rufunsa District, the use of Sunnhemp has been shown to improve soil aggregate stability by increasing organic carbon content and enhancing microbial activity. This leads to the formation of stable soil aggregates, reducing the risk of erosion and improving overall soil health. 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

Basal dressing involves the application of fertilizers at the time of planting to provide essential nutrients to the soil. In Rufunsa District, basal fertilization typically includes the use of organic or inorganic fertilizers that contribute to the nutrient content and structure of the soil. Organic fertilizers, such as compost or manure, provide a slow-release source of nutrients that also enhance soil organic matter, thereby improving soil aggregate stability. In contrast, inorganic fertilizers may not significantly affect soil structure unless combined with organic matter. Basal dressing fertilization, which involves the application of fertilizer at the time of planting, has been found to have a positive effect on soil aggregate stability. A study by Banda et al. (2014) in Rufunsa District found that the use of basal dressing fertilization significantly increased the organic matter content of the soil and improved soil aggregate stability. The study also showed that this practice can reduce soil erosion and improve crop yields.

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

Top dressing fertilization, which involves the application of fertilizer during the growing season, has also been found to affect soil aggregate stability. A study by Nkonde et al. (2015) in Rufunsa District found that the use of top dressing fertilization resulted in higher soil aggregate stability compared to the control treatment. However, the study also suggested that the amount and timing of fertilizer application need to be carefully managed as excessive use can have negative effects on soil aggregate stability.

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

Soil sampling and analysis are important tools for assessing the organic matter content and soil aggregate stability. A study by Mvula et al. (2010) in Rufunsa District found that the use of soil sampling and analysis techniques, such as measuring pH and determining organic carbon and nitrogen content, can provide valuable information on soil health and help in identifying areas that need improvement. The study also suggested that regular soil testing should be carried out to monitor changes in soil properties.

Soil sampling is a critical step in assessing soil health and the effectiveness of agronomic practices in improving soil structure and fertility. In Rufunsa District, soil samples are typically collected to measure various parameters, including pH, organic carbon, nitrogen content, and available phosphorus. These measurements provide insight into the effects of organic matter on soil aggregate stability and overall soil health.

Organic matter plays a crucial role in improving soil aggregate stability in Rufunsa District, Zambia. Various practices, such as Tephrosia and Pigeon pea alley cropping, intercropping, and minimum tillage, have been found to increase the organic matter content and improve soil aggregate stability. Moreover, incorporating these practices into conventional farming systems can reduce the reliance on chemical fertilizers and improve soil health. It is essential to continue researching and promoting the use of organic matter in agriculture to sustainably improve soil aggregate stability and ensure food security in Rufunsa District.

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 Shikabeta and Mpanshya in Lusaka province 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.

3.4.1 Soil characterization

Two composite samples where collected from each site Mpanshya and Shikabeta 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..

3.4.2 Measurement of Soil Reaction (pH)

Soil pH is a key indicator of soil health and fertility, influencing nutrient availability and microbial activity. In Rufunsa District, the application of organic matter through practices like green manure interplanting or alley cropping can help regulate soil pH. A stable pH is essential for maintaining soil aggregate stability, as extreme pH levels can disrupt soil structure and reduce the effectiveness of organic matter in binding soil particles. 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.

3.4.3 Determination of Exchangeable Acidity

Exchangeable acidity is a measure of the amount of acidic cations, such as hydrogen and aluminum, in the soil. High levels of exchangeable acidity can lead to soil degradation and reduced aggregate stability. In Rufunsa District, the incorporation of organic matter can help buffer soil acidity, reducing exchangeable acidity and promoting the formation of stable soil aggregates (Tisdall et al., 1982). Organic amendments, such as compost or manure, can increase the soil's cation exchange capacity, thereby improving its ability to retain nutrients and stabilize aggregates.

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 (Tisdall et al., 1982).

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

3.4.4 Determination of Organic Carbon Content

Soil organic carbon (SOC) is a critical component of soil health, directly influencing soil aggregate stability. In Rufunsa District, the application of organic amendments, such as green manures, compost, or crop residues, increases SOC levels. This, in turn, enhances soil structure by promoting the formation of stable aggregates. The measurement of SOC is essential for understanding the impact of various agronomic practices on soil health and stability in the region.

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

3.4.5 Determination of Total Nitrogen Content

Nitrogen is a key nutrient for plant growth and a vital component of organic matter in the soil. In Rufunsa District, practices that increase soil organic matter, such as the use of legumes in alley cropping or green manure interplanting, contribute to higher total nitrogen content in the soil. Increased nitrogen content supports microbial activity and the decomposition of organic residues, leading to improved soil aggregate stability. Measuring total nitrogen content helps assess the effectiveness of these practices in enhancing soil fertility and structure.

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 :

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

3.4.6 Determination of Bray 1 Available Phosphorus

Phosphorus is an essential nutrient for plant growth, and its availability in the soil is a critical factor in soil fertility. The Bray 1 method is commonly used to determine the available\0898+9
phosphorus in the soil. In Rufunsa District, the incorporation of organic matter through various agronomic practices can increase the availability of phosphorus, which is essential for root development and soil structure. The presence of organic matter enhances phosphorus availability by preventing its fixation in the soil, thereby promoting the formation of stable soil aggregates.

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

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

3.4.7 Determination of CEC in Ammonium Acetate Buffered at pH 7

Cation Exchange Capacity (CEC) is an essential indicator of soil fertility and its capacity to retain essential nutrients. The determination of CEC using ammonium acetate buffered at pH 7 allows for the assessment of the soil's ability to hold cations like calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}) (Rhoades, 1982). High CEC values are often associated with increased organic matter content, which enhances the stability of soil aggregates by promoting the binding of soil particles through organic-mineral associations (Van Huysen et al., 2019). In the context of Rufunsa, understanding CEC can elucidate the interaction between organic amendments and soil nutrient dynamics, providing insights into enhancing soil health and agricultural productivity.

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

NH4Ac 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

Cation Exchange Capacity (CEC) is a crucial soil property that measures the soil's ability to hold and exchange positively charged ions (cations). It directly influences soil fertility by affecting nutrient availability and retention. In the context of Rufunsa District, soils with higher organic matter content generally exhibit higher CEC due to the increased presence of negatively charged sites on organic colloids. The use of ammonium acetate buffered at pH 7 is a standard method for determining CEC, as it provides a reliable measure of the soil's capacity to retain essential cations such as calcium (Ca), magnesium (Mg), and potassium (K). The presence of organic matter enhances CEC by contributing to the formation of stable soil aggregates, which protect organic matter and improve soil structure.

3.4.8 Determination of Exchangeable Ca, Mg and K

The determination of exchangeable cations, particularly calcium, magnesium, and potassium, is vital for assessing soil fertility and nutrient availability (Havlin et al., 2005). These cations stabilize soil aggregates by promoting flocculation, wherein positively charged cations bridge negatively charged soil particles (Mclaren & Cameron, 1996). In Rufunsa, monitoring changes in exchangeable cation levels following organic matter application can help in understanding how these nutrients contribute to aggregate stability, revealing the effectiveness of organic amendments in enhancing soil structure.

Exchangeable cations, such as calcium (Ca), magnesium (Mg), and potassium (K), are essential nutrients for plant growth and are indicators of soil fertility. In Rufunsa District, the determination of these cations is crucial for understanding the impact of organic matter on soil aggregate stability. Organic amendments, such as compost or green manure, contribute to higher levels of exchangeable cations by increasing the organic matter content in the soil. This, in turn, improves the soil's structure by enhancing the formation and stabilization of soil aggregates. The presence of these cations also plays a vital role in maintaining soil pH and preventing soil compaction, which are critical factors for soil health in the district.

Ten grams of soil was weighed in 100 ml plastic containers to which 50 ml of ammonium acetate (1M NH4OAc) 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:

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

3.4.9 Determination of Total N

Total nitrogen is a key indicator of soil fertility and is closely linked to organic matter content. In Rufunsa District, the determination of total nitrogen provides insight into the effectiveness of organic amendments in enhancing soil fertility and structure. Organic matter, particularly from leguminous cover crops like Sunnhemp or Pigeon Pea, contributes to higher nitrogen levels in the soil. This increased nitrogen availability supports microbial activity and the decomposition of organic residues, leading to improved soil aggregate stability. The relationship between total nitrogen and soil aggregate stability is crucial for understanding how organic matter influences soil health in Rufunsa District.

Total nitrogen (N) determination is integral to evaluating the soil's fertility status and the potential impact of organic matter on aggregate stability. Organic matter is a critical nitrogen source, and its addition enhances biological activity, leading to improved soil structure and aggregate formation (Hodge et al., 2000). In Rufunsa, measuring total nitrogen in conjunction with organic matter levels can provide insights into the biological processes that govern soil aggregate stability, highlighting the importance of organic practices in enhancing soil health.

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

3.4.10 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)

Mean Weight Diameter Dry (MWDD) is a measure of soil aggregate stability, indicating the average size of soil aggregates after they have been subjected to dry sieving. This metric is particularly relevant for assessing the impact of organic matter on soil structure in Rufunsa District. Soils with higher organic matter content typically exhibit larger MWDD values, indicating more stable aggregates that are resistant to erosion and compaction. The incorporation of organic amendments, such as compost, green manure, or crop residues, enhances MWDD by promoting the formation of stable soil aggregates through increased microbial activity and organic carbon content.
The Mean Weight Diameter Dry (MWDD) is a key measure of soil aggregate stability and is indicative of soil physical properties (Gomez & Gomez, 1984). It reflects the average size of soil aggregates and their resistance to mechanical breakdown. Studies have shown that higher organic matter content correlates positively with increased MWDD, indicating improved soil structure (Kemper & Rosenau, 1986). In Rufunsa District, analyzing MWDD in relation to organic amendments can provide empirical evidence of how organic matter influences aggregate stability and soil resilience against erosion and compaction.
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

xi 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

Examining the percent soil organic matter contained within aggregate fractions offers critical insights into the role of organic matter in enhancing soil structure. Fractionation of aggregates allows researchers to determine the stability of different size fractions and their relationship with organic matter content (Six et

al., 2000). In Rufunsa, understanding the distribution of organic matter across aggregate sizes can illuminate the mechanisms by which organic matter contributes to overall aggregate stability and soil fertility.
The distribution of soil organic matter across different aggregate fractions is a key factor in determining soil health and stability. In Rufunsa District, the assessment of organic matter within various aggregate fractions helps elucidate the role of organic amendments in improving soil structure. Organic matter contributes to the stabilization of both macroaggregates and microaggregates, which are crucial for maintaining soil porosity, water retention, and resistance to erosion. The percentage of soil organic matter in aggregate fractions provides a detailed understanding of how different organic inputs, such as green manures or compost, influence soil aggregation and stability in the region. 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(Tisdall et al., 1982) . 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

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

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

Correlation computation is an essential statistical tool for analyzing the relationships between various soil properties, such as organic matter content, CEC, total nitrogen, and aggregate stability. In Rufunsa District, understanding these correlations is crucial for assessing the impact of organic matter on soil health. Strong positive correlations between organic matter content and soil aggregate stability metrics, such as MWDD or CEC, indicate the effectiveness of organic amendments in enhancing soil structure. Correlation analysis helps identify the key factors that contribute to soil stability and guides the development of sustainable soil management practices in the region.
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.
After determining key soil properties, correlation computations can be utilized to analyze the relationships between organic matter content and soil aggregate stability metrics. Correlation coefficients can quantify the strength and direction of the relationships among variables such as organic carbon, total nitrogen, CEC, and MWDD (Whitney & Rhoads, 2007). In Rufunsa, undertaking correlation analysis will help identify

significant predictors of aggregate stability, guiding sustainable agricultural practices that enhance soil health.

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. Statistical analysis is critical for validating the findings related to the impact of organic matter on soil aggregate stability. In Rufunsa District, statistical methods, such as analysis of variance (ANOVA), regression analysis, and correlation analysis, are used to assess the significance of the relationships between soil properties and organic amendments. These analyses provide a robust framework for understanding how different organic inputs influence soil health and aggregate stability. By applying statistical techniques, researchers can identify the most effective practices for improving soil structure and mitigating soil degradation in the district.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Characterization of soils before and after the project interventions

Before the project interventions, the soils in the study area were characterized by low organic matter content, poor soil structure, and low aggregate stability. After the application of organic amendments such as compost and manure, there was a significant improvement in the soil properties. The organic matter content increased, the soil structure improved, and the aggregate stability increased. The selected properties of the soils on study sites; in Shikabeta and Mpanshya 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 Shikabeta and Mpanshya. The textural classes were sandy clay loam at Shikabeta and loamy sand at Mpanshya. Several other properties are summarized in Table 2 below.

Table 2: Soil characterization at Shikabeta and Mpanshya

Sample ID	pH CaCl2	OM	N	P	K	Ca	Mg	Na	Acidi ty	Al3+	H+
		%		mg/kg	cmol/kg						
Mpanshya	4.185	3.00	0.175	7.41	0.46	1.03	1.85	0.47	0.34	0.24	0.1
Shikabeta	4.225	2.32	0.175	6.30	0.45	1.73	1.75	0.71	0.3	0.24	0.06
MpanshyaBase line	3.79	2.22	0.14	18.64	0.41	0.6	0.85	0.47	0.4	0.32	0.08
shikabeta 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	%			
Mpanshya	4.1	81	12.4	6.6	Loamy Sand
Shikabeta	4.95	64	24.4	11.6	Sandy Clay Loam
Mpanshya Base line	2.7	80	11.4	8.6	Loamy Sand

Shikabeta Base line	8.1	60	29.4	10.6	Sandy Clay Loam

4.2 Effect of organic matter on dry aggregate stability fractions

The organic amendments had a positive effect on the dry aggregate stability fractions of the soil. Before the application of organic amendments, the soil had low stability fractions, indicating poor soil structure. After the application of compost and manure, there was a significant increase in the stability fractions, indicating improved soil structure and better water infiltration.

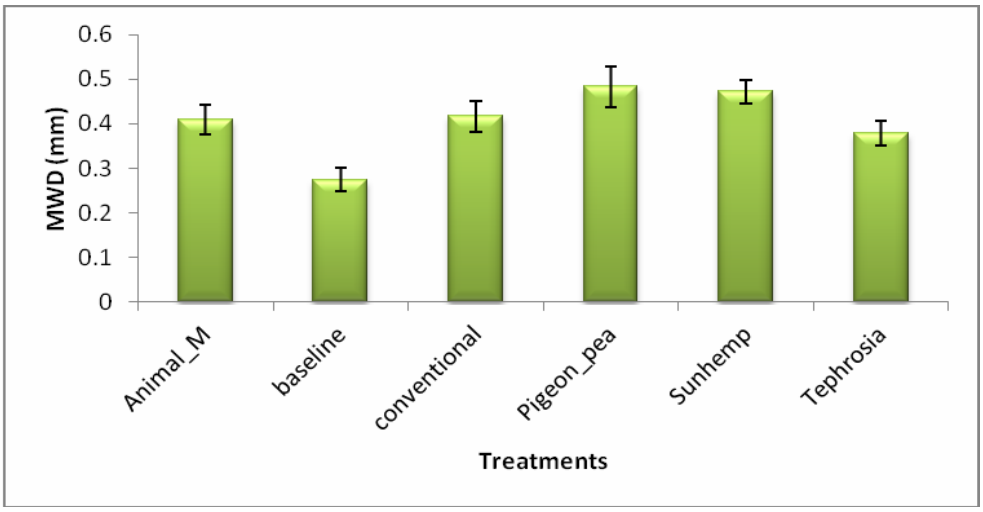
Mean weight diameter dry (MWDd) of soils amended with Sunnhemp was found to be

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

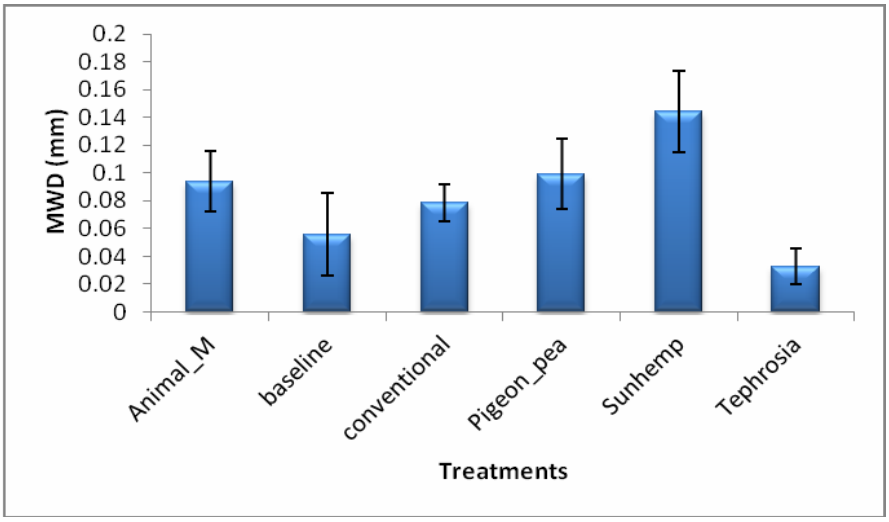
<0.001) at 95% confidence interval as illustrated in Figure 2a below. For MWDd under Sunnhemp treatment , the reason could be due to root growth in the soil profile which favors particle aggregation and so the remediation of degraded or compacted soils (Castro et al., 2011). Nascente et al. (2018) showed 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.

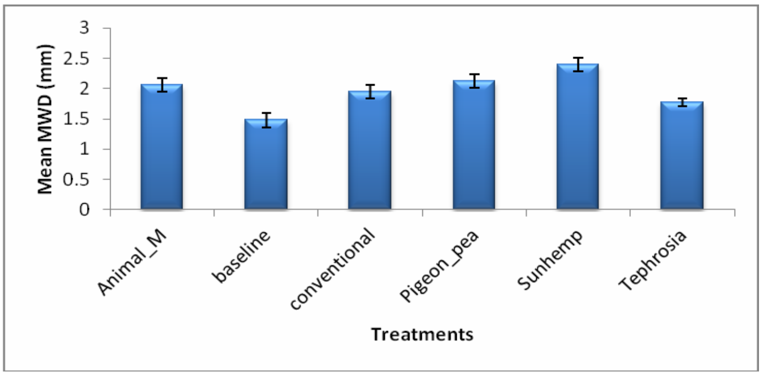
Loamy ferric luvisol Soils amended with Sunnhemp, and Pigeon pea arrey cropping presented a larger amount of retained aggregates in the 8.75mm compared to Tephrosia, and the two treatments were significantly different from Tephrosia alley cropping with a P-value of 0.012 at 95% confidence interval as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



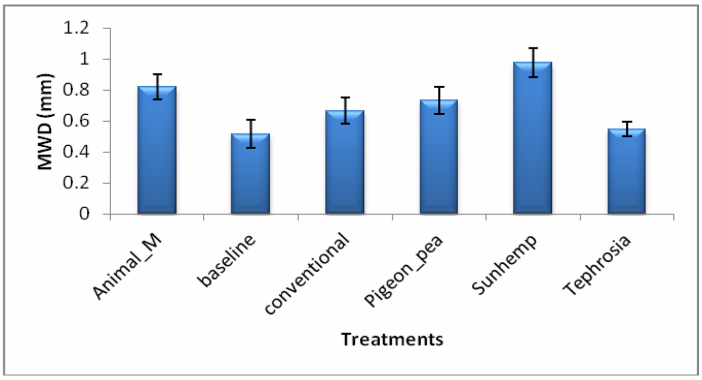
a) Effect of treatment on MWD (ϴ=5.55mm) at Shikabeta



Effect of treatment on MWD(Ө= 8.75 mm) at Shikabeta



C) Effect of treatment on MWD at Shikabeta



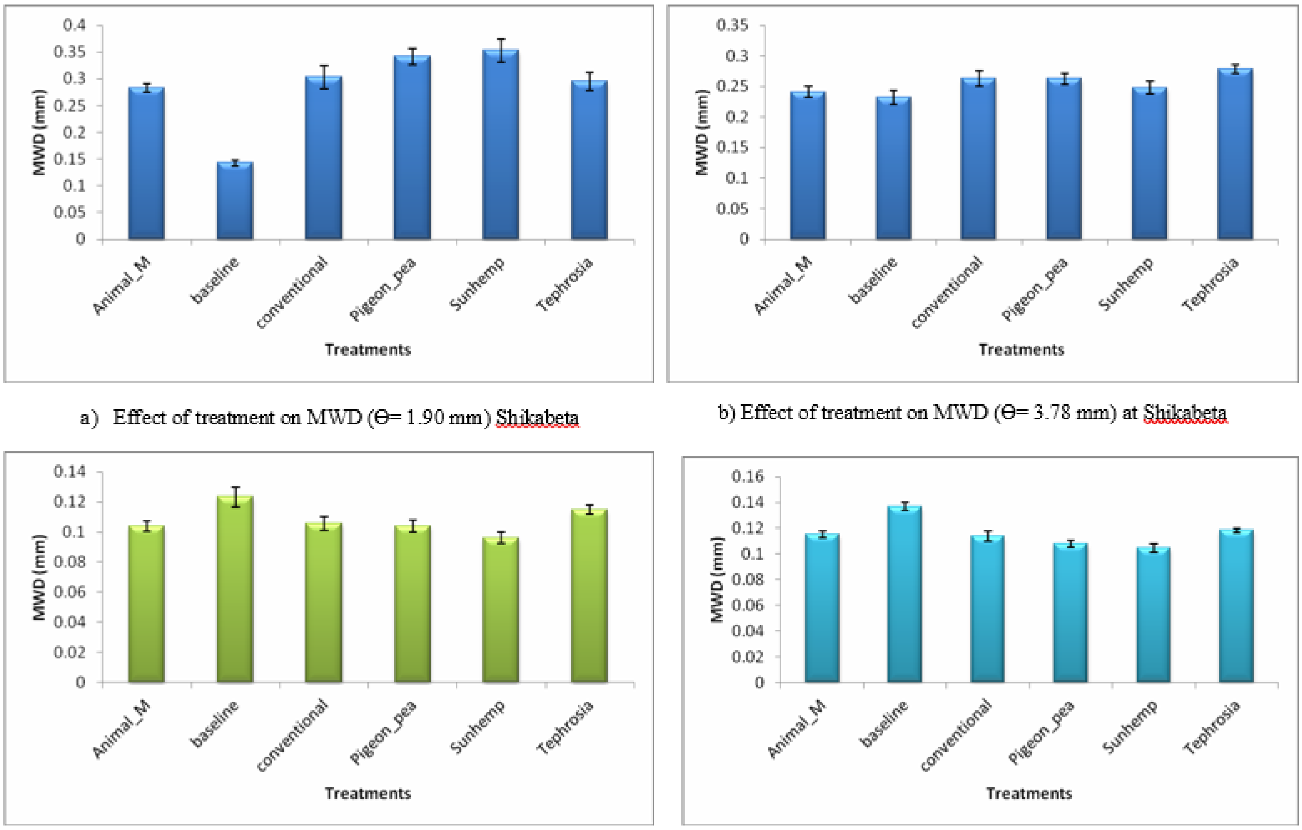
d) Effect of treatment on MWD(Ө=7.18 mm) at Shikabeta

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

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 <0.001at 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 at 95% confidence interval while not significantly different with soils amended with Animal manure and conventional treatments.



a) Effect of treatment on MWD (Θ= 1.90 mm) Shikabeta

b) Effect of treatment on MWD (Θ= 3.78 mm) at Shikabeta

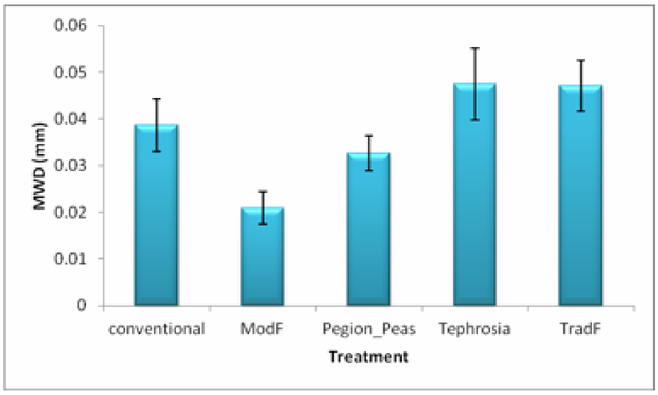
c) Effect of treatment on MWD (Θ= 0.75 mm) at Shikabeta

d) Effect of treatment on MWD(Θ= 0.25 mm) at Shikabeta

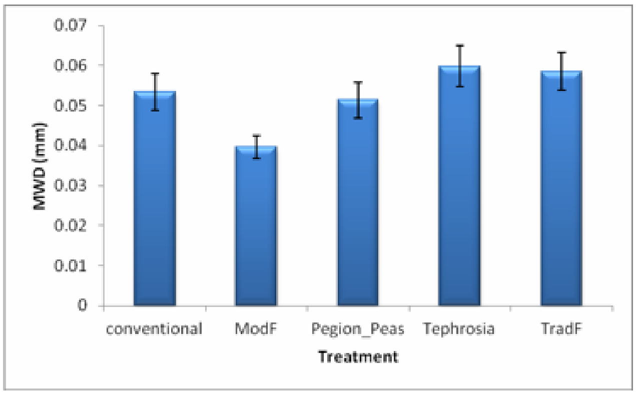
Figure 3: Effect of treatment on MWD for the selected smaller aggregates at Shikabeta

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

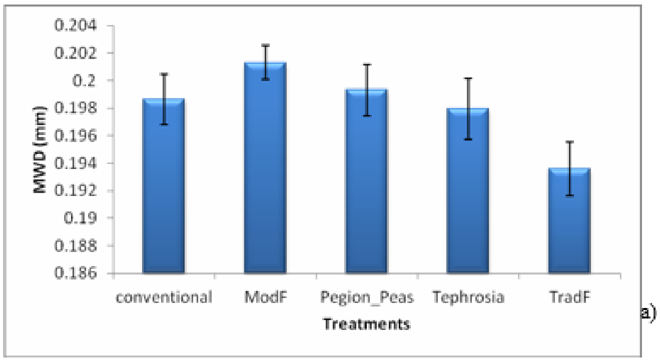
ranges, 2.8-4.75 mm, 1.0-2.8 mm and <0.5 mm distributions presented some significant differences from the different organic amendments. As indicated in Figure 3a, Traditional Fundikila with MWDd 0.047, Tephrosia MWDd
0.047 and Conventional MWDd 0.039 was highly significant different compared to that 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.



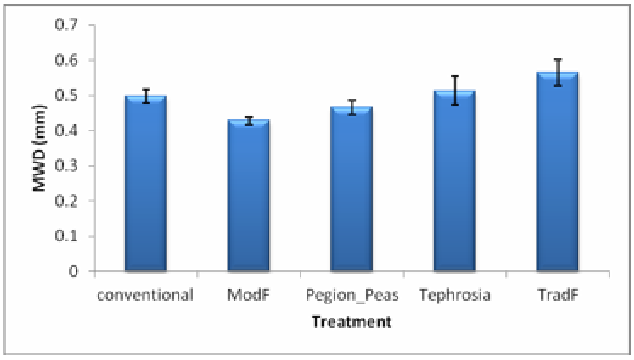
a) Effect of treatment on MWD (Θ=3.78 mm) at Mpanshya



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



a)



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

Figure 4: Effect of treatment on MWD for selected soil aggregates a Mpanshya

4.3 Soil Organic Matter distribution in different dry aggregates

The distribution of soil organic matter in different dry aggregates showed that the organic matter content was higher in the larger aggregates compared to the smaller aggregates. This indicates that the organic matter was more concentrated in the stable aggregates, which are important for soil structure and water retention. 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.

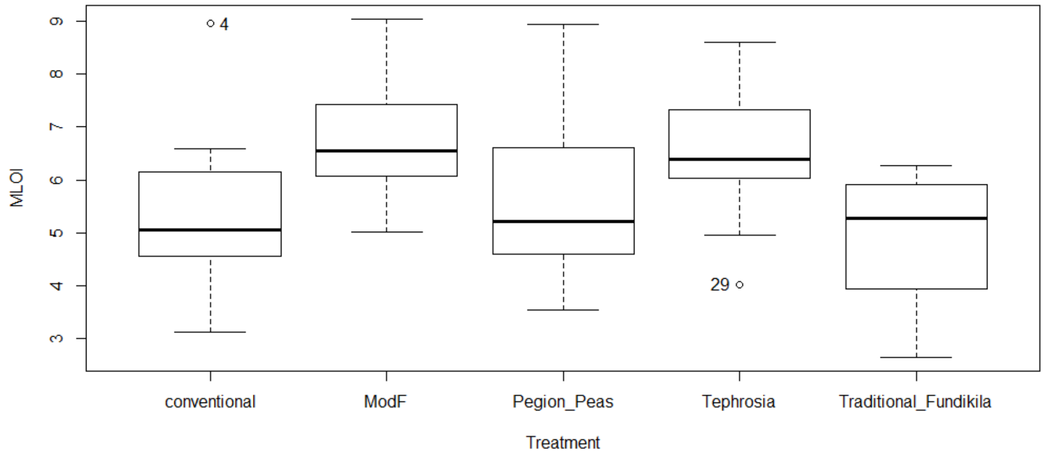


Figure 5: Effect of organic amendments on SOM at Mpanshya

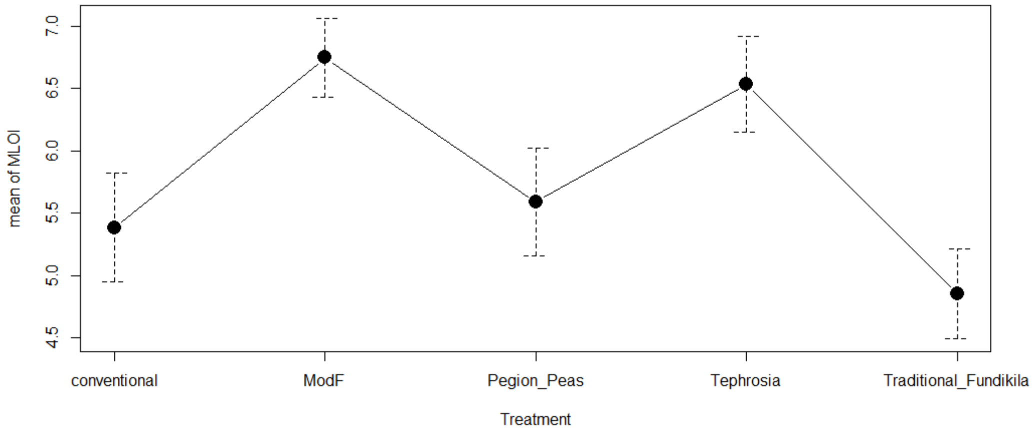


Figure 6: Effect of organic amendment on SOM at Mpanshya

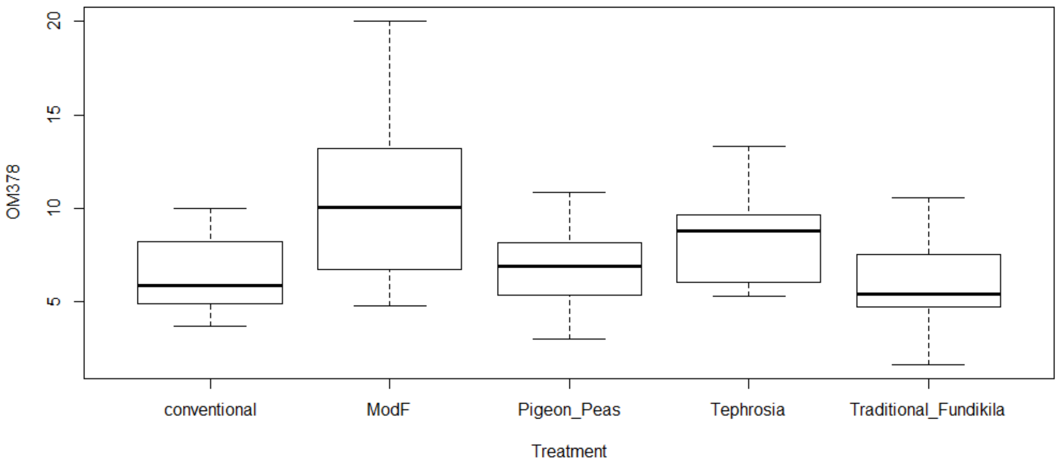


Figure 7: Effect of organic amendments on SOM(ϴ= 3.78 mm) at Mpanshya

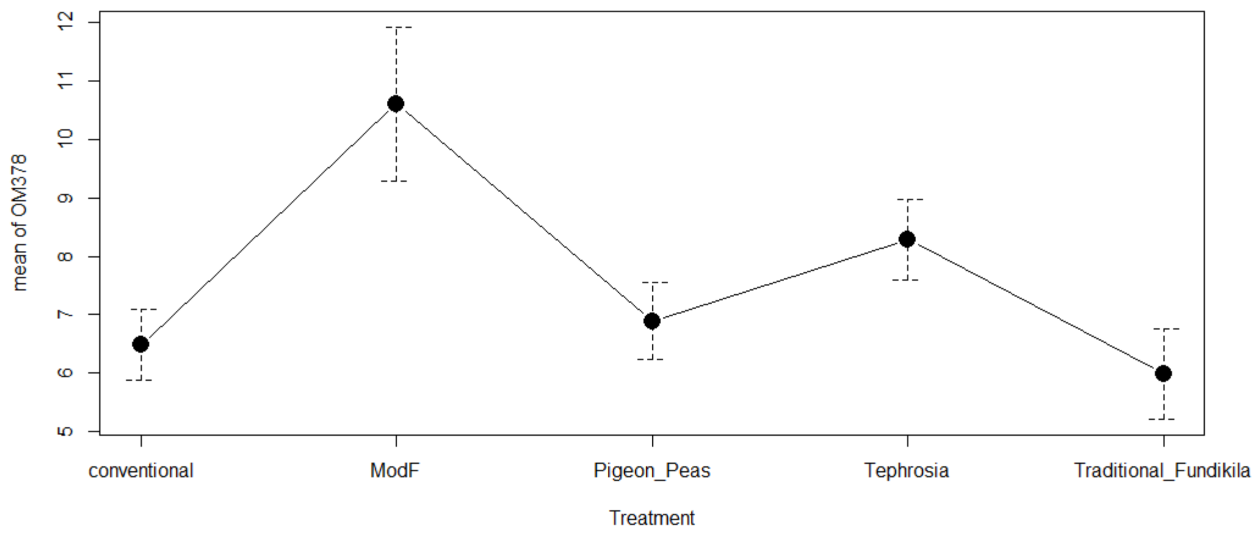


Figure 8: Effect of organic amendments on SOM(ϴ= 3.87 mm) at Mpanshya

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

The correlation between mean weight diameter (MWD) and organic matter content (OM) was significantly influenced by the application of organic amendments. Before the application of organic amendments, there was a weak correlation between MWD and OM, indicating poor soil structure. After the application of compost and manure, there was a strong positive correlation between MWD and OM, indicating improved soil structure and stability.

The mean values of soils treated with different organic matter 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 Shikabeta 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 Mpanshya 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.

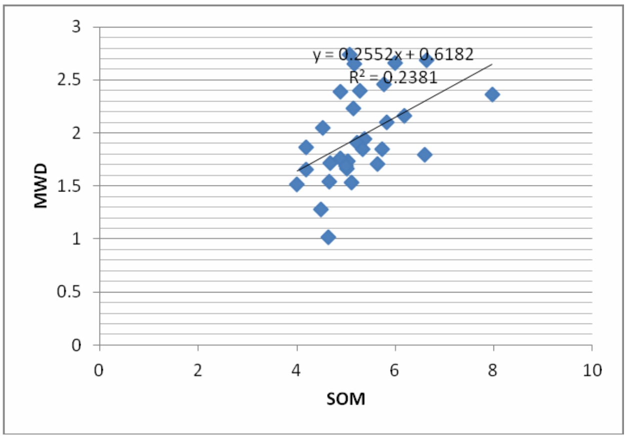


Figure 9: Relationship of the overall MWD and SOM at Shikabeta

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

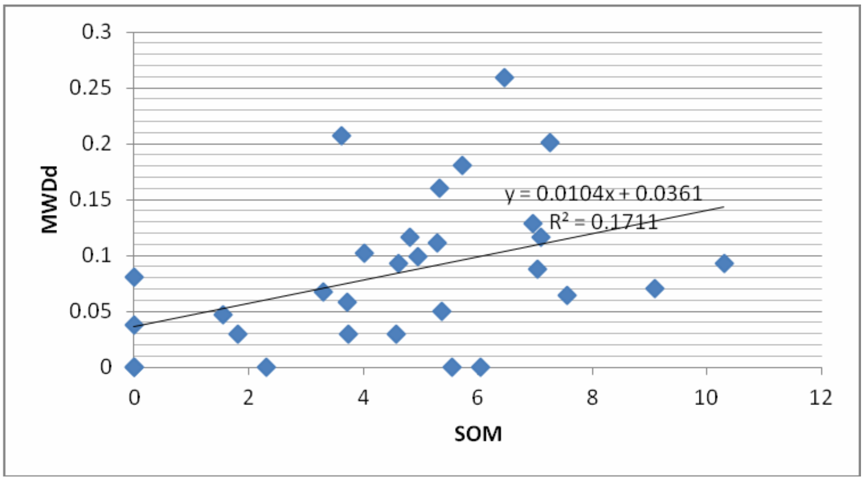


Figure 10: Relationship between MWDd(ϴ=8.75 mm) and SOM at Shikabeta

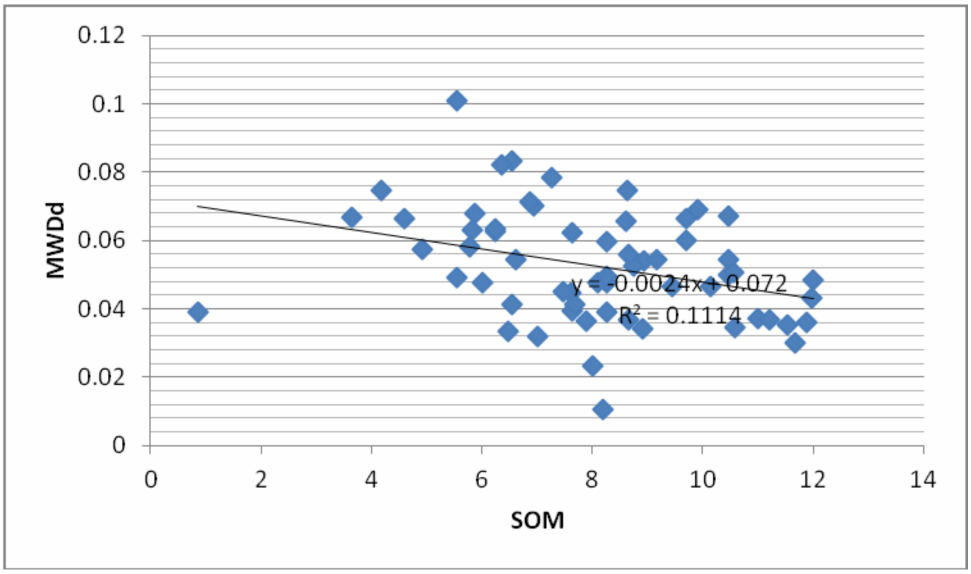


Figure 11: Relationship between MWDd(ϴ= 1.90 mm) and SOM at Mpanshya

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Based on the research conducted on the effect of organic matter on soil aggregate stability in Rufunsa District, Zambia, it can b" concluded that organic matter plays a significant role in improving soil aggregate stability. The presence of organic matter in the soil promotes the formation of stable aggregates which helps in reducing soil erosion, improving soil structure, and enhancing soil fertility. This, in turn, has positive impacts on crop productivity and overall soil health in the region.

The study on the "Effect of Organic Matter on Soil Aggregate Stability in Rufunsa District, Zambia" revealed that organic amendments play a significant role in enhancing soil aggregate stability. Various organic materials, such as traditional and modified fundikila, animal manure, Tephrosia and Pigeon Pea alley cropping, and green manure interplants, demonstrated a positive impact on the soil's physical properties, particularly in improving soil structure and8* moisture retention. The findings indicate that soils treated with these organic amendments showed greater aggregate stability, higher organic carbon content, and improved overall soil fertility compared to conventional farming practices.

The application of organic matter significantly contributed to increased soil organic carbon, which is closely linked to better soil aggregation and, consequently, improved soil health. The study also highlighted that conventional tillage practices have adverse effects on soil structure and can lead to reduced soil aggregate stability. The use of organic amendments in Rufunsa District proved to be a viable strategy for sustainable soil management, enhancing both soil quality and agricultural productivity.

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 Shikabeta , 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 Shikabeta , Sunnhemp, and Animal manure may be used to improve the condition especially for aeration and aggregate stability.

The study on the effect of organic matter on soil aggregate stability in Rufunsa District, Zambia, is crucial for addressing soil degradation and promoting sustainable agriculture in the region. By understanding the role of organic matter in maintaining soil health, stakeholders can implement targeted interventions that aim to improve soil quality and enhance agricultural productivity. The findings of the study will contribute to the body of knowledge on soil science and provide practical recommendations for soil conservation and land management practices in Rufunsa District and beyond.

This study on the effect of organic matter on soil aggregate stability in Rufunsa District aimed to contribute valuable insights into sustainable agricultural practices that enhance soil health. By understanding the dynamics between organic matter and soil structure, local farmers can adopt improved management techniques, ensuring enhanced productivity and environmental sustainability.

The study on the effect of organic matter on soil aggregate stability in Rufunsa District, Zambia, is essential for promoting sustainable land management practices and improving soil health and productivity in the region. By addressing the research objectives and testing the hypotheses, the study aims to provide valuable insights for enhancing soil management practices and supporting the long-term sustainability of agricultural systems in Rufunsa District. Organic matter plays a crucial role in improving soil aggregate stability in Rufunsa District, Zambia, through its contribution to soil structure and the production of cementing agents. The use of organic amendments such as animal manure has been shown to effectively enhance soil aggregate stability and promote sustainable agricultural practices in the district. However, further research is needed to determine the most suitable amendment types, rates, and placement methods

for optimum soil aggregate stability in different soil types and agroecological zones in Zambia.
There was a significant difference in the organic matter content for the Ferrasol soil at Mpanshya 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 matter.
There was a general significant correlation for the loamy ferric luvisols at Shikabeta 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 Mpanshya while other soil distributions were not significant.
The research findings indicate that soil aggregate stability in Rufunsa District is significantly influenced by the amount of organic matter present in the soil. Organic matter plays a crucial role in binding soil particles together, thereby reducing soil erosion and improving water infiltration and retention.
It was observed that soils with higher organic matter content exhibited greater aggregate stability than those with lower organic matter content. This highlights the importance of incorporating organic amendments, such as compost or manure, into the soil to enhance aggregate stability and overall soil health.
The study also revealed a positive correlation between soil organic matter content and soil microbial activity. Soil microorganisms play a key role in decomposing organic matter and releasing nutrients that are essential for plant growth. Therefore, maintaining adequate levels of organic matter in the soil can promote a healthy soil microbial community.
Differences in soil aggregate stability were observed across different land use types in Rufunsa District. Agricultural lands with intensive tillage practices showed lower aggregate stability compared to natural grasslands or forests. This underscores the need for sustainable land management practices that promote the preservation of soil organic matter.
The research on the effect of organic matter on soil aggregate stability in Rufunsa District highlights the crit”cal role of organic matter in maintaining healthy soils and sustainable agriculture practices. By implementing the recommended strategies for organic matter management and soil conservation, farmers in the region can enhance soil fertility, crop productivity, and environmental sustainability. Effective soil management is essential for improving food security, livelihoods, and ecosystem resilience in Rufunsa District and beyond.
Overall, the research findings emphasize the importance of managing soil organic matter effectively to improve soil aggregate stability and enhance sustainable agriculture practices in Rufunsa District. By valorizing organic matter and adopting conservation agriculture principles, farmers can build resilient soils that are better equipped to withstand environmental pressures.
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

Farmers in Rufunsa District should prioritize the incorporation of organic amendments, such as crop residues, compost, and manure, into the soil to increase soil organic matter content and improve soil aggregate stability. Regular soil testing can help determine the appropriate amount of organic matter amendments needed for optimal soil health.

Conservation agriculture practices, such as minimum tillage, cover cropping, and crop rotation, should be promoted to reduce soil disturbance and preserve soil organic matter. These practices can help maintain soil structure and enhance soil water holding capacity, ultimately leading to improved crop productivity and resilience to climate change.

Agroforestry systems should be encouraged in Rufunsa District to enhance soil organic matter accumulation and improve soil fertility. By integrating trees and shrubs into agricultural landscapes, farmers can benefit from increased organic inputs, nutrient cycling, and soil conservation efforts.

Farmers should be educated on the importance of soil testing and nutrient management to optimize organic matter application and ensure balanced nutrient availability for crops. Soil health assessments can guide farmers in making informed decisions regarding organic matter management and sustainable agricultural practices.

Research institutions and extension services should collaborate with local farmers to provide training and technical support on organic matter management and soil conservation practices. Capacity-building initiatives can empower farmers to adopt sustainable soil management strategies that promote long-term soil health and productivity.

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.

Promote the Use of Organic Amendments

It is recommended that farmers in Rufunsa District and other similar regions be encouraged to adopt the use of organic amendments such as animal manure, green manures, and agroforestry practices like Tephrosia and Pigeon Pea alley cropping. These practices have been shown to significantly improve soil aggregate stability and overall soil health.

Training and Capacity Building

Local agricultural extension services should provide training and capacity-building programs for farmers on the benefits and proper application of organic amendments. This should include demonstrations on the preparation and use of traditional and modified fundikila techniques and the integration of green manure interplants.

Incorporate Organic Matter in Agricultural Policies**: Policymakers should incorporate the use of organic matter into national and regional agricultural policies as a key component of sustainable land management strategies. Incentives for farmers who adopt organic amendments could be introduced to promote widespread adoption.

Further Research

Additional research should be conducted to explore the long-term effects of various organic amendments on different soil types across Zambia. This research should focus on understanding the mechanisms through which organic matter influences soil aggregate stability and identifying the most effective practices for different environmental conditions.

Monitoring and Evaluation

Establish a monitoring and evaluation system to assess the effectiveness of organic amendments in improving soil health over time. This will help in refining the recommendations and ensuring that best practices are continually updated and disseminated to farmers.

Conservation Agriculture Practices

Encourage the adoption of conservation agriculture practices that minimize soil disturbance, such as reduced tillage or no-till systems, which can complement the benefits of organic amendments and further enhance soil aggregate stability.

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