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Organic amendments effects on soil dry aggregate stability in Chipata, Zambia

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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 inadequate in Zambia. The study was carried out to assess the effect of organic amendments on soil dry aggregate stability and organic matter on soils from Chipata, Zambia. The specific objectives were to: Assess the effect of organic amendments on soil dry aggregate stability and assess if there is a relationship between soil organic matter and soil aggregate stability on a loamy ferric luvisol soil. Soil aggregates were collected from the top 10 cm of 10 m × 10 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 five treatments: Sunn hemp, *Tephrosia vogelii* alley cropping, pigeon pea alley cropping, animal manure, and conventional treatments on a loamy ferric luvisol. Amending soils with Sunn hemp showed a significantly higher mean weight diameter (MWDd) of 2.393 compared to amending soils with *T. vogelii* alley cropping MWDd 1.767 (P value <0.001). Hence, for a loamy ferric luvisol soil, Sunn hemp and animal manure may be used to improve the condition especially for aeration and aggregate stability.

Key words: *Tephrosia vogeli*, Sunn hemp, animal manure, conventional, loamy ferric luvisol.

INTRODUCTION

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, 2006). 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

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practices during land preparation for crop production (USDA, 2008). 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 (Adebayo et al., 2019) due to the aforementioned attributes. The resultant infertile soils coupled with erratic rainfall and poor management of the natural resource base, lead to declining yields and increased risk of crop failure in much of the smallholder dry land farming sector of southern Africa (Thierfelder and Wall, 2009). Soils from these areas were generally low in nutrients, organic matter, water storage and had unstable soil aggregates (Adebayo et al., 2019; Lal, 1986). For instance, in Zambia's high rainfall region III, the loss of nutrients increased through leaching and deep percolation for nutrients such as nitrogen in nitrate and ammonium forms (Bwembya and Yerokun, 2001). While in Zambia's low rainfall region I, nutrients are mostly lost through runoff due to high rainfall intensity, soil disturbance in farmer's fields and poor soil structure.

Globally, the need to improve soil quality to ensure a build-up of soil nutrients and improved water storage has been of interest. The solution to this problem has involved both chemical and physical methods. Chemical methods involve the inclusion or addition of nutrients in chemical forms to the soil that can easily improve and provide nutrients in available forms.

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 for instance the use of organic waste (poultry manure) to improve organic matter and infiltration rate (Adebayo et al., 2019) and use of cattle manure on soil particle distribution (El-Nagar and Mohamed, 2019). Organic amendment practice is considered important for improving soil quality in agro-ecosystems. Organic amendments are able to increase water retention, soil nutrient availability, soil resilience and substantially increase crop yields in farmer's fields (Jiang et al., 2018). 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 (Rohoskova and Valla, 2014) and is usually associated with water (USDA, 1996).

Aggregation results from the rearrangement of particles through flocculation and cementation. Aggregate stability indicates general information about soil conditions (Rohoskova and Valla, 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). 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).

The null hypotheses for the study was that there was no significant difference in soil dry aggregate stability indices, soil organic matter and relation between soil organic matter and soil dry aggregate stability when different organic amendments are applied to the soil. The alternative hypothesis for the study was that there was at least a significant difference in soil dry aggregate stability indices, soil organic matter and relation between soil organic matter and soil aggregate stability between two or more organic amendments applied to the soil.

METHODOLOGY

Study site location and description

The study was carried out at Msekera Research Station in Eastern province. This station is located along latitude 13° 38′ S and longitude 32° 39′ E with an altitude of 1025 m. The area received an annual rainfall of between 800 and 1000 mm. The soils at Msekera were loamy ferric luvisols according to the FAO/UNESCO classification soil map of the world legend (Figure 1).

Experimental design and description of treatments

The trials were set in a randomized complete block design (RCBD) for a period of three seasons; 2015/2016, 2016/2017 and 2017/2018 farming seasons. The treatments were conventional farming, tephrosia alley cropping, pigeon peas alley cropping, Sunn hemp interplant and animal manure as shown in Table 1.

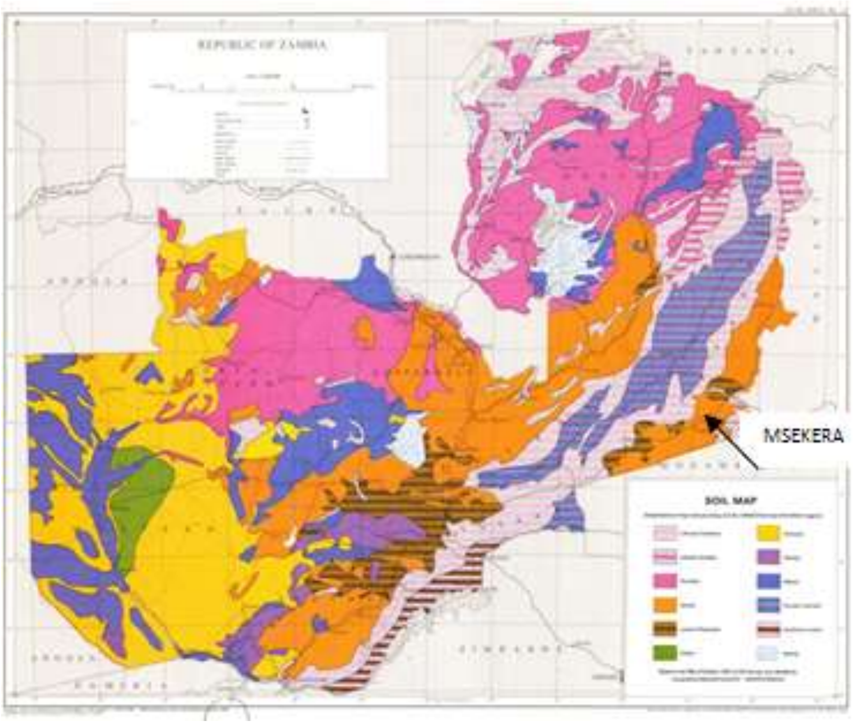

Figure 1. Soil Map of Zambia.
Source: Soil Survey (1983).

Soil sampling

Sampling of soils was done 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 10×10 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. 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.

Soil characterization

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, electrical conductivity (EC) and soil texture using the hydrometer method.

Mean weight diameter dry (MWDD)

Mean-weight diameter of dry aggregates (MWDD) was measured using the method described by Kemper and Chepil (1965). Instead of 250 g soil aggregates, 100 g of dry soil aggregates initially sieved through a 9.5 mm 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 0.5 mm 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 5 min. The mean weight diameter of dry aggregate (MWDD) was then computed using Equation 1 described by Kemper and Chepil (1965).

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

where MWDD is mean weight diameter of dry aggregates, $\bar{X}i$ is the mean diameter between the two sieves (mm); and *Wi* is the weight fraction of aggregates remaining on the sieve (%).

RESULTS AND DISCUSSION

Characterization of soils before and after application of organic amendments

The selected soil chemical and physical properties at study site are presented in Table 2. The analysis of soils indicates that the soils were acidic with a pH of less than 4.50 in 0.01 M $CaCl_2$ at Msekera. The soil textural class was sandy clay loam and organic matter content after application of organic amendments was higher than the baseline organic matter. There was a general decline in nutrient composition after three farming seasons and use of organic amendments compared to baseline samples as indicated in Table 2.

Table 1. Treatments used for study site.

Study site	Treatments	Replicates
Chipata	Conventional farming + recommended rate of fertilizer (200 kg/ha)	5
	Animal manure(10 tons/ha) + ½ rate of fertilizer(100 kg/ha)	5
	Pigeon peas alley cropping + ½ rate of fertilizer (100 kg/ha)	5
	Tephrosia vogelii alley cropping + ½ rate of fertilizer (100 kg/ha)	5
	Sunn hemp interplant + ½ rate of fertilizer (100 kg/ha)	5

Table 2. Soil characterization for Msekera before and after project intervention.

Sample ID	pH	OM	N	P	K	Ca	Mg	Na	Acidity	Al^{3+}	H+
	$CaCl_2$	%		mg/kg	cmol/kg						
Msekera	4.225	2.32	0.175	6.295	0.45	1.73	1.75	0.71	0.3	0.24	0.06
Msekera Base line	4.28	2.08	0.28	8.91	0.63	3.83	2.58	0.78	0.28	0.16	0.12

	ECEC	Sand	Clay	Silt	Textural class USDA
	cmol/kg	%			
Msekera	4.95	64	24.4	11.6	Sandy Clay Loam
Msekera Base line	8.1	60	29.4	10.6	Sandy Clay Loam

Effect of organic amendments on dry aggregate stability

After three farming seasons of applying organic amendments on a loamy ferric luvisol, mean weight diameter dry (MWDd) of soils amended with Sunn hemp was found to be 2.393 and pigeon pea 2.125 which were very highly significantly different from loamy ferric luvisol soils amended with tephrosia alley cropping with a MWDd of 1.767 (P <0.001) at 95% confidence interval as illustrated in Figure 2a. 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 Sunn hemp 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.

For MWDd under Sunn hemp treatment, the reason could be due to a dense root growth in the soil profile which favors particle aggregation and so the remediation of degraded or compacted soils which was also reported by Castro et al. (2011). The effect of cover crops on soil physical properties was reported by Nascente and Ston (2018) to have shown improvement. The beneficial influence of grasses on the structure and stability of soil aggregates is attributed to the high root density, which promotes the aggregation of the particles (Tisdall and Oades, 1979; Silva and Mielniczuk, 1997; Rilling et al., 2002), which could be the reason in the case of Sunn hemp interplant with significantly stable aggregates.

Effect of organic amendments on dry aggregate stability fractions

Loamy ferric luvisol soils amended with Sunn hemp, and pigeon pea alley cropping presented a larger amount of retained aggregates in the 8-9.5 mm 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.

In the 6.35-8.0 mm aggregate distribution, Sunn hemp 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.

In the 2.8-4.75 mm aggregate distribution (Figure 3a), Sunn hemp indicated very highly significantly stable aggregates compared to animal manure, conventional, tephrosia and baseline aggregates while not significantly different from that of pigeon pea with a P value of <0.001*** at 95% confidence interval.

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

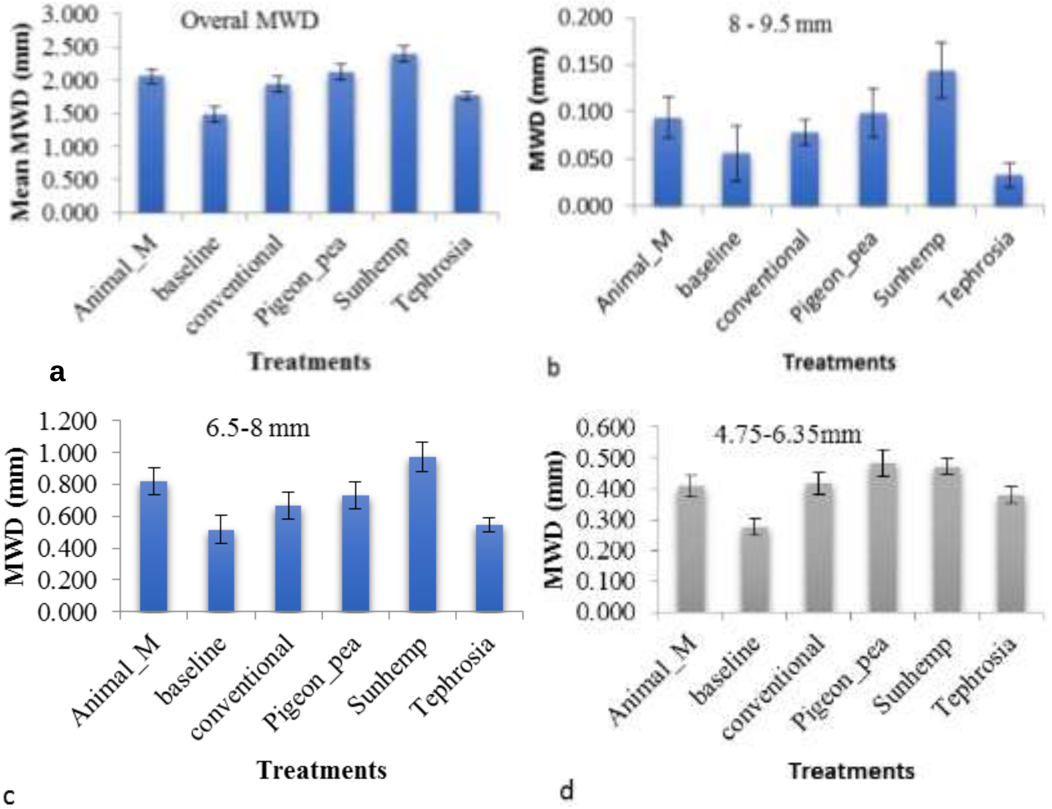

Figure 2. Effect of treatment on MWD for selected soil aggregates at Msekera.

Sunn hemp while not significantly different from tephrosia and conventional with a 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 Sunn hemp, 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 Sunn hemp. Baseline was also very highly significantly different from Sunn hemp, tephrosia, conventional, pigeon pea and animal manure with a P value of <0.001*** at a 95% confidence interval.

Amount of aggregates retained on a sieve indicates how stable a soil is against agents of weathering such as wind and water. The stability increases towards the larger sieve distribution. In this case, a soil is more stable when more is retained on a larger sieve distribution than that of smaller sieves. The 0.05-0.25-mm size range dominates water sediments from high sand soils, and aggregates ranging in size from 0.02 to 0.20 mm are most erodible from high silt and clay soils (Young, 1980). The larger amount of soil retained in the smaller sieve size indicate how easily the soil disintegrates when exposed to mechanical shaking like in the case of baseline and tephrosia treatments as indicated by Skidmore and Powers (1982); Chepil (1958) says aggregates between 0.05 and 0.50 mm in diameter are most easily transported by wind. Henc, baseline and tephrosia presented a larger amount of aggregates susceptible to wind erosion. The other aggregates were retained on sieves above 0.5 mm and were less susceptible to wind erosion (Skidmore and Powers, 1982; Chepil, 1958). The larger quantities of aggregate size distribution for Sunn hemp, animal manure and pigeon pea were above 0.84 mm; thus resistant to wind erosion (Skidmore and Powers, 1982; Chepil, 1958). Francesc et al. (2016) found that adding organic matter significantly increases the number of small and medium sized pores and enhances a better structure and plant growth. El-Nagar and Mohamed (2019) show that different particle sizes of cattle manure significantly affected bulk density, total porosity, pore size distribution, and available water in sandy soil with decreasing particle size.

These results are consistent with other findings that show addition of organic manure to reduce bulk density

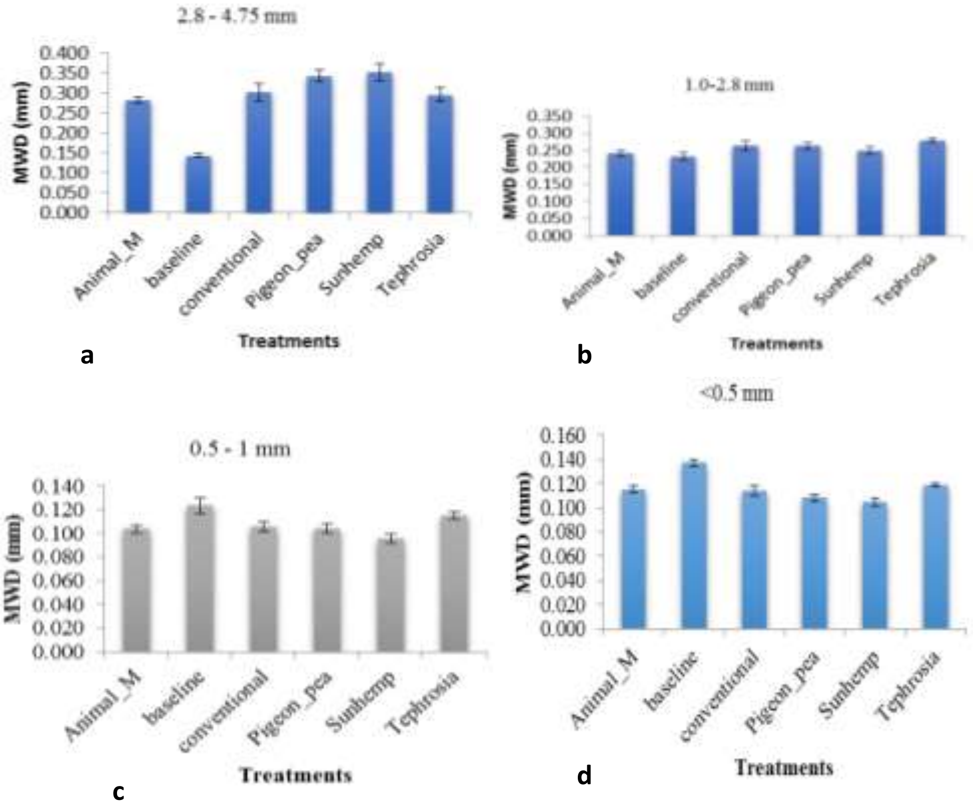

Figure 3. Effect of treatment on MWD for the selected smaller aggregates at Msekera.

and enhance aggregate stability improvement which increases yields significantly as indicated by Mbah and Onweremadu (2009) on improved maize yield to increased SOM on ultisol in south-eastern Nigeria. Smaling et al. (2002) also reported significant increases in the maize yield biomass and other yield components with the addition of organic manure.

The influence of four (4) organic amendments on the dry soil aggregates of this research indicates that they are varying and are similar to the influences of three different organic sources on aggregate formation and stability in soil conducted by Zeki and Erdem (2009). After a seven-month incubation period, aggregate formation and their stability were determined and their correlation to different C sources was developed. The effect of KHumate on aggregate formation was significant for 2-1 mm aggregates ($P<0.05$) and 0.5-0.25 mm aggregates ($P<0.01$). The effect of CPE on aggregate formation was significant for 0.5-0.25 aggregates ($P<0.05$), while the Molasses had no significant effect on aggregate formation in any aggregate size. The effect of K-Humate on aggregate stability was significant for 8-4 mm and 1-0.5 mm aggregates. Thus, it is not all organic amendments that are capable of enhancing significant aggregation like the case of tephrosia and Molasses in the two studies.

Effect of organic amendment on the correlation of MWD and OM

The mean values of soils treated with different organic amendments showed a general significant positive Pearson correlation for loamy ferric luvisol soil at Msekera as indicated in Figure 4, and the correlation in the 8.75 mm was significant as indicated in Figure 5; though the other soil distributions did not show any significant correlation. The findings for loamy ferric luvisols at Msekera are similar with a research carried out by Chaney and Swift (1984) on some British soils in which the stability of aggregates from 26 soils selected from agricultural areas was measured by wet-sieving and the results correlated with sand, silt, clay, nitrogen, organic matter and iron contents and with cation exchange capacity. The results Indicated a highly significant correlations that were obtained for the relationships between aggregate stability and organic matter. The relationships between aggregate stability and organic matter content plus some of its component fractions were examined in more detail using 120 soils.

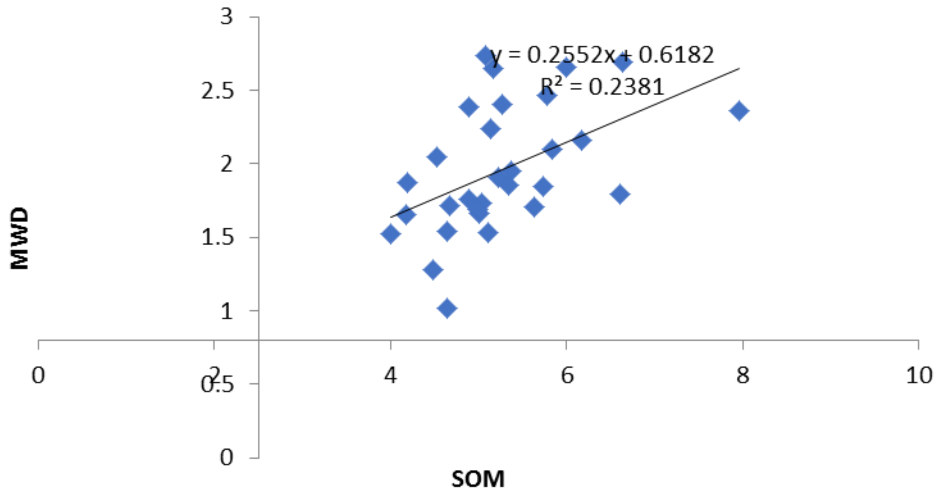

Figure 4. Relationship of the overall MWD and SOM at Msekera.

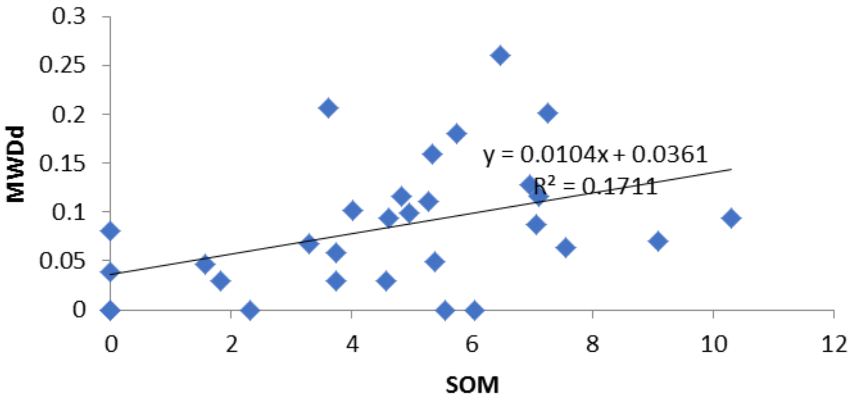

Figure 5. Relationship between MWDd (8-9.5 mm) and SOM at Msekera.

Total organic matter, total carbohydrate and humic material extracted by various reagents each gave highly or very highly significant correlations with aggregate stability. The other fractions that did not show any correlation aligns with Tisdall and Oades (1982) and Mercedes et al. (2006) 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.

The organic matter from the five treatments did not show any significant difference despite having some minor differences from each other.

Conclusion

The main objective was to determine the effect of organic amendments on aggregate stability indices. The results showed a significant effect on the different amendments added to the soil. Sunn hemp, animal manure, and pigeon pea showed a highly significant difference from tephrosia inter plants. Hence, for loamy ferric luvisol, Sunn hemp, and animal manure may be used to improve the condition especially aeration and aggregate stability. There was a general significant correlation for the loamy ferric luvisols at Msekera and the correlation in the 8-9.5 mm while no significant correlation for the other soil size distributions. Thus, we reject the null hypotheses and accept the alternatives that at least there is a significant difference between each pair of items.

Recommendations

The various organic amendments presented significantly different soil dry aggregate stability. More research should be conducted to determine the contributing organic matter constituents enhancing the aggregate stability.

Future work

A follow up and comprehensive research on the various organic amendments will be conducted after five farming seasons to indicate stability and instability indices and water retention.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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