



T.R.
ONDOKUZ MAYIS UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION

**EFFECTS OF VERMICOMPOST AND PLANTING ON SOIL
AGGREGATE FORMATION AND ORGANIC CARBON
CONTENT**

Master's Thesis

Dorcas Ebunoluwa OJEADE

Supervisor

Prof. Dr. Coşkun GÜLSER

II. Supervisor

Prof. Dr. Tatiana MINKINA

SAMSUN
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SAMSUN
2022

ACCEPTANCE AND APPROVAL OF THE THESIS

The study entitled “EFFECTS OF VERMICOMPOST AND PLANTING ON SOIL AGGREGATE FORMATION AND ORGANIC CARBON CONTENT” prepared by **Dorcas Ebunoluwa OJEADE**, and supervised by **Prof. Dr. Coşkun GÜLSER** and **Prof. Dr. Tatiana MINKINA**, was found successful and unanimously accepted by committee members as Master thesis, following the examination on the date 6.7.2022 .

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This thesis has been approved by the committee members that already stated above and determined by the Institute Executive Board.

APPOVAL

... / ... / ...

Prof. Dr. Ali BOLAT

Head of Institute of Graduate Studies

DECLARATION OF COMPLIANCE WITH SCIENTIFIC ETHIC

I hereby declare and undertake that I complied with scientific ethics and academic rules in all stages of my Master's Thesis , that I have referred to each quotation that I use directly or indirectly in the study and that the works I have used consist of those shown in the sources, that it was written in accordance with the institute writing guide and that the situations stated in the article 3, section 9 of the Regulation for TÜBİTAK Research and Publication Ethics Board were not violated.

Is Ethics Committee Necessary?

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15 /06/ 2022

Dorcas Ebunoluwa OJEADE

DECLARATION OF THE THESIS STUDY ORIGINALITY REPORT

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ÖZET

VERİMİKOMPOST VE EKİMİN TOPRAK AGREGA OLUŞUMU VE ORGANİK KARBON İÇERİĞİ ÜZERİNE ETKİLERİ

Dorcas Ebunoluwa OJEADE
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Toprak Bilimi ve Bitki Besleme Ana Bilim Dalı
Yüksek Lisans, Temmuz/2022
Danışman: Prof. Dr. Coşkun GÜLSER
II. Danışman: Prof. Dr Tatiana MINKINA.

Vermikompost ve soya fasulyesi ekiminin killi toprağın yapısal parametreleri üzerindeki etkisi, yığın yoğunluğu, gözenek boyutu dağılımı, hidrolik iletkenlik, agrega boyutu dağılımı ve stabilitesi, su tutma ve bitki su tutma kapasitesi ile değerlendirildi. Toprak örneklerinin fizikokimyasal özellikleri de ölçülmüştür.

Dört işlem vardı: kontrollü bir ortamda gözlemlenen toprak (S), toprak+%2 solucan gübresi (SV), toprak+dikim (SP) ve toprak+dikim+%2 solucan gübresi (SPV). Nem içeriği tarla kapasitesi civarında tutulmuş, kap ve silindirler günlük tartıldıktan sonra yağmur suyu ile ıslatılmıştır. Denemenin ilk yarısı başladıktan 24 gün sonra, ikinci yarısı bitkiler vejetatif olgunluğa (72 gün) ulaştığında sona ermiştir.

İstatistiksel testler (SPSS, versiyon 17) kullanılarak yapıldı. Veriler, Duncan kullanılarak ortalamalar ayrılırken, faktör olarak toprak yönetim sistemi ve örnekleme tarihleri ile faktöriyel deney tasarımına göre test edildi. Kuru eleme yöntemiyle elde edilen mekanik olarak kararlı agregalar (MSA), ağırlıklı olarak makro agregalardı ($>0,25$ mm). 24 günde, MWD'nin kontrole göre yüzde artışı SP, SV ve SPV için sırasıyla %10,32, %1,94 ve %9,03 olmuştur. Genel olarak, günlük sulama makroagreganın gevşemesine neden olmuştur. Mikroagrega ($<0,25$ mm), p'de (<0.01) makroagregalardan (>0.25 mm) önemli ölçüde daha yüksek OC içeriği içeriyordu.

İnce partiküller (mikro agregalar) bozulmaya karşı en güçlü olanlardır. Çoğu yapısal parametre uzun bir süre boyunca iyileştirilir. Bununla birlikte, soya fasulyesi ekim işleminin toprakta ölçülen fiziksel ve yapısal özellikler üzerinde tek başına vermikompost uygulamasından daha önemli bir etkisi olmuştur. Vermikompost, geleneksel olarak üretilen ve pazarlanan kompostun dünya çapındaki markalarından "son derece üstün" olarak adlandırılrsa da, tüm kaynakların toprak üzerinde olumlu bir etkisi olmayacağını belirtmekte fayda var.

Anahtar Sözcükler: Agrega Stabilitesi, Toprak Organik Karbonu, Soya Fasulyesi Ekimi, Su Tutma Eğrisi, Vermikompost.

ABSTRACT

EFFECTS OF VERMICOMPOST AND PLANTING ON SOIL AGGREGATE FORMATION AND ORGANIC CARBON CONTENT

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Master, July/2022

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The influence of vermicompost and soybean planting on the structural parameters of clayey soil was evaluated by bulk density, pore size distribution, hydraulic conductivity, aggregate-size distribution and stability, water retention, and plant water holding capacity. Physicochemical properties of soil samples were also measured.

There were four treatments: soil (S), soil+2%vermicompost (SV), soil+planting (SP), and soil+planting+2% vermicompost (SPV) observed in a controlled environment. Moisture content was kept around field capacity, wetting with rainwater after daily weighing the pots and cylinders. The first half of the experiment ended 24 days after it began, while the second half ended when the plants reached vegetative maturity (72 days).

The statistical tests were done using the (SPSS, version 17). Data were tested according to factorial experimental design with soil management system and sampling dates as factors while means were separated using Duncan. Mechanically stable aggregates (MSA) obtained by the dry sieving method were predominantly macroaggregates (>0.25 mm). At 24 days, the percentage increase of MWD over control was 10.32 %, 1.94 % and 9.03 % for SP, SV and SPV respectively. Generally, daily irrigation led to slaking of macroaggregate. Microaggregate (<0.25mm) contained significantly higher OC content than macroaggregates (>0.25 mm) at $p < 0.01$.

Fine particles (microaggregates) are strongest against degradation. Most structural parameters are improved over a long period. However, soybean planting treatment had a more significant effect on soil measured physical and structural properties than the sole application of vermicompost. It is worthy to note that though vermicompost is termed as "exceptionally superior" to worldwide brands of conventionally produced and marketed compost, not all sources will have a positive effect on soil.

Keywords: Aggregate Stability, Soil Organic Carbon, Soybean Planting, Water Retention Curve, Vermicompost.

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“There is no self-made greatness, every greatness is built on a foundation laid by someone else”

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Presenting in an international symposium and publishing an article from this project was indeed an opportunity to face my fears, to take the bull by its horns and to perform the task that has once threatened my emotions. With the focus and mindset to finish well, I have learnt better writing skills and I hope to improve as I write more.

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Dorcas Ebunoluwa OJEADE

CONTENTS

ACCEPTANCE AND APPROVAL OF THE THESIS.....	i
DECLARATION OF COMPLIANCE WITH SCIENTIFIC ETHIC	ii
DECLARATION OF THE THESIS STUDY ORIGINALITY REPORT	ii
ÖZET	iii
ABSTRACT	iv
ACKNOWLEDGEMENT.....	v
CONTENTS.....	vi
ABBREVIATION OF TERMS	vii
FIGURES LEGENDS.....	viii
TABLES LEGENDS.....	
1. INTRODUCTION.....	1
2. LITERATURE REVIEW.....	4
2.1. Unmissable Properties of Clay Soil.....	4
2.2. Aggregate Stability	5
2.2.1. Aggregate Stability Indicators	5
2.2.2. Aggregate Stability Methods	6
2.3. Factors that Influence Soil Aggregation.....	7
2.3.1. Wetting and Drying Process	7
2.3.2. Organic Matter Addition.....	7
2.3.3. Binding Agents	8
2.4. Effect of Legume planting on soil properties	9
2.5. Vermicompost as a Soil Amendment.....	10
2.6. Soil Physical Properties	11
2.6.1. Porosity	12
2.6.2. Bulk density	12
2.6.3. Pore Size Distribution.....	13
2.6.4. Hydraulic conductivity	13
2.7. Soil Water Retention Curve.....	14
2.7.1. Volumetric Water Content.....	15
2.8. Soil Chemical Properties	16
2.8.1. Soil Organic Carbon	16
2.8.2. Soil pH.....	17
2.8.3. Electrical Conductivity	18
3. MATERIALS AND METHODS	19
3.1. Experimental Setup and Soil Sampling.....	19
3.1. Bulk Density.....	20
3.2. Porosity.....	20
3.3. Hydraulic conductivity and Pore Volume	20
3.4. Aggregate Size Distribution	21
3.5. Aggregate stability	21
3.6. Organic Carbon	22
3.7. Exchangeable Cations	22
3.8. Electrical conductivity and pH.....	22
3.9. Pore Size Distribution	23
3.10. Soil Moisture Constant and Retention.....	24
3.11. Plant-available water capacity.....	24
3.12. Statistical Analysis	24
4. RESULTS AND DISCUSSION	25

4.1. Bulk Density	25
4.2. Total Porosity	27
4.3. Pore Size Distribution	28
4.4. Hydraulic Conductivity	29
4.5. Stability and Size Distribution of Soil Aggregates	30
4.5. Mean Weight Diameter	32
4.6. Percentage of Aggregate Destruction	34
4.7. Effect of Vermicompost on Plant Root Growth	35
4.8. Effect of Treatment on EC and pH.....	35
4.9. Impact of Treatment on Soil Organic Carbon Content of Soil Aggregates	37
4.10. Water Retention Curve	39
4.11. Plant Available Water Content.....	40
5. CONCLUSION AND RECCOMENDATION	42
REFERENCES	43
CURRICULUM VITEA.....	50

ABBREVIATION OF TERMS

CO ₂	:Carbon dioxide
N ₂ O	:Nitrous Oxide
CEC	:Cation Exchange Capacity
EC	:Electrical Conductivity
pH	:Power of Hydrogen
K _s	:Saturated hydraulic conductivity
MWD	:Mean Weight Diameter
GMD	:Geometric Mean Diameter
D	:fractal dimension
WSAR	:Water-Stable Aggregates Stability Rate
WSA	:Water Stable Aggregate
DC	:Dispersed Clay
DDL	:Diffuse Double Layer
GHG	:Greenhouse Gases
CC	:Cover Crop
FC	:Field Capacity
PWP	:Permanent Wilting Point
SAW	:Soil Available Water
F	:Porosity
AS	:Aggregate Stability
S	:Soil
SP	:Soil + Planting
SV	:Soil + Vermicompost
SPV	:Soil + Planting + vermicompost
PAWC	:Plant Available Water Capacity
E _{sd}	:equivalent spherical diameter
PAD	:Percentage of Aggregate Destruction

FIGURES LEGENDS

Figure 2.1. Typical Soil Water Retention Curve for different Soil Textures.....	14
Figure 2.2. Soil Water Status.....	16
Figure 4.1. Interaction and Mean Values of Soil bulk densities during the studied period under different management systems.....	25
Figure 4.2. Interaction and Mean Values of Total Porosity during the studied period under different management systems.....	27
Figure 4.3. Treatment Effect on Pores and pore size distribution.....	28
Figure 4.4. Interaction and Mean Values of Hydraulic Conductivity during different sampling days under the management systems	29
Figure 4.5. Distribution of Mechanical stability aggregate Size fractions (Percentage) under different treatment and time.....	31
Figure 4.6. Mean Weight Diameter at 24 days and 72 days.....	33
Figure 4.7. Rate of Aggregate Destruction %.....	34
Figure 4.8. Root Fresh weight of treatments SP and SPV.....	35
Figure 4.9. Electrical Conductivity of treatment at 72 days.....	36
Figure 4.10. pH at 24 and 72 days.....	36
Figure 4.11. Percentage of organic carbon in different aggregate sizes and time.....	37
Figure 4.12. Percentage of organic C in different aggregate sizes.....	37
Figure 4.13. Soil Water Retention at (A) 24 days (B) 72 days.....	39
Figure 4.14. Interaction and Mean Values of Field Capacity during different sampling days under the management systems.....	40
Figure 4.15. Interaction and Mean Values of Available Water Capacity during different sampling days under the management systems.....	40
Figure 4.16. Effects of planting (A) and vermicomposting (B) treatments on water retention curves.....	41

TABLES LEGENDS

Table 3.1. Some properties of Vermicompost used in the Study.....	20
Table 4.1. Aggregate Stability across various treatments and time.....	32

1. INTRODUCTION

Many soil processes such as water holding capacity, infiltration, organic matter content, root growth, and aggregate stability are controlled by soil structure (Martens 2000; Lal and Shukla, 2013; Trivedi et al., 2013; Rabot et al., 2018). Being a dynamic soil property, changes in soil management practices have a significant impact on soil structure, making it prone to destructive acts of wetting, raindrop impact, and intensive cultivation (Wu et al., 2014). Maintaining good-structured soil, often expressed by the presence of stable soil aggregates is the most desirable requisite for soil sustainability, productivity, and crop yield (Zhang et al., 2016; Almendro-Candel et al 2018).

Aggregates are composed of sand, silt, clay, and organic particles compacted together. (Cambardella, 2006; Xie et al., 2015), however, high-clay and organic-matter soils tend to be well structured than those containing mostly sand and or silt (Finch et al., 2014). The fact that soils high in clay content ($> 40\%$) are problematic, annuls its efficiency in maintaining good soil structure because its high preponderance of micropores makes it easily waterlogged and this slows down plant growth, as root penetration is inhibited due to lack of oxygen. Thus, appropriate management of organic matter is the most important for increasing aggregate stability (Ayoubi, et al., 2020). Moreover, soil minerals and organic materials must interact to produce aggregates (Six, et al., 2004). Other than organic matter, organic binding agents including, roots, microbial by-products, and humic substances (Lal and Shukla, 2013), inorganic binding agents such as metal cations, carbonates, aluminium and iron oxides (Six, et al., 2004), and external factors such as dry-wet cycle influence soil aggregate stability.

Tisdall and Oades (1982) proposed that the essential factors for aggregate formation varied based on aggregate sizes. Long-term binding agents, such as humified SOC interactions with clay particles, hold microaggregates together, whereas macroaggregates are held together by temporary and transient binding agents such as roots, fungal hyphae and plant-derived polysaccharides. In their studies, Six et al., (2004) reported that root development had a significant impact on the fraction of macroaggregates in the soil, as well as on root exudation, root biomass and soil water regime because the stability of macroaggregates is dependent on some important mechanisms. Research also shows that soil's physical and structural

properties are better improved within the short term through the influence of leguminous crops' roots than grasses (Adetunji et al., 2020). It has been reported that legume cropping increases carbon sequestration (Kumer et al., 2019, 2020), maintains soil fertility while improving soil physical quality (Gulser, 2004; Sogut and Ozturk, 2017; Arslan et al., 2018; Demir et al., 2019) and controls soil erosion (Garcia Estringana et al., 2013). Demir (2019) reported the substantial impact on the soil's physicochemical qualities, hence an indirect effect on hydraulic properties. Soybean, the world's most significant crop, has risen to become one of the most traded products with diverse uses (GAIN, 2021). It has the potential to alleviate world hunger and lessen the environmental impact of excessive chemical fertilizer use since the soybean plants and Rhizobium bacteria work together to turn nitrogen into ammonia, which is essential for healthy plant growth and seed production.

Profoundly, many researchers (Hüttermann et al., 1999; Laird and Lentz, 2010; Chang et al., 2015; Inbar and Sekharan, 2015; Lentz, 2015, and Sepaskhah and Shahabizad, 2010) consider soil conditioners as one of the best practices for improving porosity, aeration, drainage and soil water retention. Interestingly, vermicompost - the finely divided, and mature peat-like substance formed when earthworms ingest organic wastes has been termed as "exceptionally superior" to major global compost brands that are conventionally produced and marketed because it is at least seven times richer in nutrients and growth-promoting qualities than traditional compost (Thakur et al., 2021).

In this era of climate change, intermittent rainfall accompanied by dry spells has had a tolling effect on agricultural soils, thereby, food production. Aggregate stability and other structural qualities may be affected by these environmental changes. (Cosentino et al. 2006; Ma et al. 2015). Many researchers (Brazo Garza et al., 2009, Hu et al., 2015, Xu et al., 2017, Xu et al., 2021) found that the percentage of water-stable aggregates decreases as a result of wetting-drying cycles while few (Pillai and McGarry, 1999) suggested that wetting-drying cycles could enhance soil structure. However, Kaiser et al. (2015) recorded inconsistent results within a single study and attributed their findings to the many techniques of determining aggregate stability and the basic physical condition of aggregates. FAO (2017) reported that apart from climate change, another major challenge in agriculture is the declining

plant available water capacity (PAWC). PAWC is a vital physical feature of soil that regulates plants' ability to absorb water and nutrients.

Plants suffer from oxygen deficiency more frequently in clays, despite their larger porosity, since clays have many small disconnected pores and absorb water more readily than coarser-grained soils (sands).

Soil aggregate stability affects soil organic carbon (SOC) sequestration. Many studies have shown a positive effect of SOC, the major constituent of SOM on soil aggregation and soil properties (Bronick and Lal, 2005, Gülser, et al, 2015, Jensen, et al., 2019, Józefowska, et al., 2021), nevertheless, there are few contradicting studies (Inelmo et al., 1998; Guerrero et al., 2002; Mahboub-Khoman et al., 2021) reporting that the chemical composition of some sources of organic matter such as cattle manure, peat, bark, and sewage sludge can negatively affect soil properties.

Even though a variety of factors influence aggregate stability, few researchers have investigated how they interact to influence aggregation and SOM alterations (Six et al., 2004). Predicting changes in soil C storage and examining the impact of soil structural indicators over different management system and sampling time is especially important.

The objectives of the present study are;

To investigate the effect of vermicompost and soybean planting on aggregation, stability, and organic carbon contents of different aggregate size fractions

To evaluate the relationship between some soil structural parameters

To understand how management influences the water holding capacity of clay soil

To compare the rate of deterioration of soil structure after alternate wetting and drying process for 2 months

2. LITERATURE REVIEW

Soil aggregation is an essential part of overall soil health, especially in SOC storage. It is a useful indicator of the structure of the soil, and it is created as a result of the reorganization of the particles, flocculation, and cementation. (Six et al., 2000, Gülser, 2006, Gülser et al., 2016). Strong aggregation reduces the erodibility of soil particles caused by water or wind (Netherlands, 2004).

2.1. Unmissable Properties of Clay Soil

Most studies on clay are usually on the mineralogy, the colloidal and physico-chemical aspects are usually glossed over if not ignored. In many publications and symposiums, clay is often referred to as a microporous solid or multilayered substance. However, particle size is the key parameter in all definitions of clay. While sedimentologists use 4 μ m and colloid chemists use 1 μ m for clay particle size, soil scientists and geologists use particle size < 2 μ m in equivalent spherical diameter (e.s.d) (Bergaya et al., 2006)

Soil with a high percentage of clay (> 40 %) is the most challenging soil to work with due to its high micropore content, which causes poor drainage and poor root growth. They are often dense, stiff, and sticky when wet; hard when dry, and frequently poorly aerated, necessitating a great deal of effort to manipulate in both wet and dry situations. Hence termed, problematic soils. However, they contribute immensely to soil fertility because they have a very high capacity for retaining water and nutrients for crop use. Finch et al. (2014) reported that these soils tend to be more structured than those containing mostly sand and or silt.

The movement of water in heavy clay soil is often dominated by flow in large pores (macropores) because the fine porous matrix is usually very poorly permeable, thus soil with high clay content has a low to very low saturated hydraulic conductivity. This accounts for the most drainage problems encountered by them.

Additionally, the presence of clay has been suggested as a binding agent (Shainberg et al., 1992a; Brubaker et al., 1992; Curtian et al., 1994a; Le Bissonnais, 1996a). Finch et al. (2014) reported that soils with high clay or organic matter content tend to be well-structured than those containing mostly sand and or silt. However, Ternan et al. (1996) found that these soils had a lower aggregate stability

2.2. Aggregate Stability

Aggregate stability can refer to either macro or micro-aggregate stability, depending on the context. While others focus on the stability of macro-aggregates. As an example, macro-aggregate stability tests are commonly referred to as "aggregate stability tests," but micro-aggregate stability tests are commonly referred to as "dispersion tests."

2.2.1. Aggregate Stability Indicators

Many authors who have worked on aggregate stability have used at least two or more of these indicators; Soil Mean Weight Diameter (MWD), fractal dimension (D), Geometric Mean Diameter (GMD), Percentage of Aggregates Destruction (PAD), Water Resistance Index (WRI) and Water-Stable Aggregates stability Rate (WSAR). The different stability data expressions have complicated the comparison among them.

Folly (1995) reported that the use of MWD to determine erodibility may not be appropriate in tropical soils with oxyhydroxides mineralogy and a relatively stable microgranular structure. There is no such record with temperate soils. As a result of the fact that many aggregate stability indices are produced utilizing all aggregate-size classes, such indices can provide information regarding the overall soil stability. The mean weight diameter (MWD) of aggregates is a common example and arguably the most extensively utilised of such metrics. The MWD is frequently used as a measure of macroaggregate stability. In this study, the MWD is referred to

The chemical composition of the water used to perform the measurement has a significant impact on aggregate stability testing. Clay dispersion has been proven to be possible using distilled water. Despite this, it has been the most widely utilized liquid in wet-sieving techniques. However, tap water is preferred. Roth and Eggert (1994) devised a method for calculating aggregate stability based on raindrop-induced breakdown. This methodology is derived from a process that was outlined by Young (1984). The level of aggregate stability was measured in terms of the percentage of stable aggregates that were still present on the sieves after an application of rainfall, which was interpreted as the rate of aggregate breakdown.

The typical parameter derived from the traditional single-sieve procedure is the water-stable aggregate percentage (WSA) (Kemper and Rosenau, 1986). Multiple-sieve approaches convey the stability data through the particle size distribution (PSD) in several distinct classes, or a number of different indices, such as Mean Weight Diameter (MWD) and Geometric Mean Diameter (GMD) (Kemper and Rosenau, 1986).

When talking about the stability of macro-aggregates, the terms "water-stable" and "wet-aggregate stability" are frequently employed. However, Six et al., 2000b stated that to provide more accurate assessments of aggregate stability, it is necessary to examine distinct aggregate distributions. This is because varied quantities of energy are imposed on the soil.

2.2.2. Aggregate Stability Methods

Wet or dry analysis can be used to determine aggregate stability. The most popular method for studying water effects at the scale of soil macroaggregate is determining the size distribution of wet aggregates. It entails wetting the sample and then sieving it through a series of sieves while being submerged in water to separate aggregates into specific sizes. Because this approach uses a disruptive force (wetting), it can be used to examine the aggregates' water stability. Because of this, the size distribution of water-stable aggregates is essentially a measure of macro-aggregate stability. This is because the aggregates that were able to pass through the various sieves must have been able to maintain their stability throughout the wetting and sieving process. (Jastrow and Miller, 1991). Yoder (1936), Williams et al. (1966), Kemper and Koch (1966), and Kemper and Rosenau (1966) all used basic approaches.

In literature, there are numerous disagreements on the optimum size border between macro and micro aggregates. Oades and Waters' categorization method (Oades and Waters, 1991) will be employed, which specifies 0.25 millimetres as the boundary between macro and micro aggregates, which is compatible with the use of 0.25 millimetres as the boundary between water-stable and water-unstable aggregates in aggregate stability experiments. Pseudo-sands are a frequent manifestation of the stable microgranular structure. They are composed of clay particles that are securely cemented together by iron oxides (Igwe, 2005).

2.3. Factors that Influence Soil Aggregation

Aggregates can be formed by alternating wetting and drying processes; adding organic matter; and binding agents (Six, et al., 2004, Lal and Shukla, 2013).

2.3.1. Wetting and Drying Process

Hu et al. (2015) proposed that two (repulsive and attractive) forces are involved during the wetting-drying process. During wetting, water molecules are drawn in between the particles by osmosis, forcing them apart - Because of surface hydration forces, also known as the repulsive force, soil particles in aggregates are capable of separating to a distance of 1.2–1.4 nm between two neighbouring particle surfaces. Clay soil will continue to swell until the forces of repulsion are balanced by forces of attraction between the negatively charged surfaces and positively charged cations held between the layers. When the forces of repulsion are higher than the forces of attraction, there is a breakdown in the aggregate, which might take the form of an explosion or a dispersion. Moreover, dispersed clay is readily transported by water and is likely to clog macro-pores reducing infiltration and rendering the soil impermeable but during drying out, dispersed clay may be re-aggregated.

Structural stability is a function of the rate of wetting. Rapid wetting may produce a rapid breakdown of macro-aggregates and result in surface sealing which reduces infiltration and enhances soil erosion. During drying, clay soil shrinks, and cracks begin to form on the surface which sometimes extends deeper as the soil dries out.

Aldood, et al. (2014) and Hoy et al. (2017) explained that expansion and contraction during respective hydration and dehydration affect the contact between soil particles, causing changes like contact and particle cohesion. These changes are caused by the expansion and contraction of soil particles. Repeated wetting and drying cycles have the potential to cause irreversible damage to the soil (Wan et al., 2015; Estabragh et al., 2015).

2.3.2. Organic Matter Addition

As far as aggregate stability is concerned, the role of soil organic matter (SOM) remains unclear. This apparent contradiction can be attributed to the comparison of SOM with stability parameters such as Water Stable Aggregate (WSA) and Dispersed Clay (DC) (Amézqueta,1999). For instance, an increased WSA means

increased aggregate stability and an increased clay dispersion decreases aggregate stability, considering these parameters differently will give different views of aggregate stability. According to the findings of this study, the paradox can be partially comprehended if we divide the stability of aggregates into two distinct categories: macro-aggregate stability and micro-aggregate stability

2.3.2.1. Effect of Organic Matter Addition to Soil Health

Major practices by organic farmers to improve soil health and promote long-term sustainability include cover cropping, organic amendments, rotational cropping, and weed management strategies (Tully and McAskill, 2020). It is no discovery that cover cropping affects soil health (Pieters 1927), however, the extra effect of increasing soil Nitrogen by legume makes it more valued than grass cover cropping. Tully and McAskill (2020) reported that it will be easier for organic farmers to improve the physical, chemical, and biological indicators of soil health and to improve the supply of agroecosystem services if they use a variety of manures and composts (without applying too much of either).

2.3.3. Binding Agents

They can be organic or inorganic. Depending on how old and degraded the organic matter is, these binding agents are divided into three categories: transient, temporary, and persistent. (Tisdall and Oades, 1982). Microbial and plant-derived polysaccharides are examples of transient binding agents; they are so-called due to their quick breakdown by microbes. Persistent binding agents consist of resistant aromatic humic material connected with polyvalent metal cations, and strongly adsorbed polymers (Tisdall and Oades, 1982) and are formed from the resistant pieces of roots, hyphae, bacterium cells, and colonies.

2.3.3.1. Organic binding agents

Plant roots, microbial by-products, and humic substances significantly influence aggregation more than inorganic cementing agents (Tisdall and Oades, 1982). Roots exudation, continual deaths of roots, and particularly root hairs promote microbial activities which result in the production of humic cement. Moreso, when root proliferates the soil for water uptake as vegetative growth occurs, there is differential dehydration, shrinkage, and opening of numerous cracks (Hillel, 2004).

The protein, glomalin, symbiotically along the aggressive taproots of legumes serves as a “glue” that binds soil together into stable aggregates. (Yuvaraj, et al., 2020).

2.3.3.2. Inorganic Binding Agents

Iron and aluminium oxides, carbonates, and metal cations are examples of inorganic binding agents. They appear to be physically sheltered within aggregates of clay and silt-sized particles, which allows them to survive in the soil for an extended period (Skjemstad et al., 1993). However, the valence of metal cation, size of cation, the hydrated radius of cation, and concentration of soil solution determine soil stability. Ca^{2+} , Mg^{2+} , K^{+} , and Na^{+} are the main salt cations in soil solution. When cations with higher valencies such as Al^{3+} , Fe^{3+} , Ca^{2+} , and Mg^{2+} are dominant in the soil, an equilibrium often establishes itself, reducing the zeta potential to its critical limits so that there is more stability than when Na^{+} is dominant.

There is a relationship between zeta potential and ionic size. Small ions are characterised by a large hydrated radius and are thus less stable than large ions. High salt concentration normally tends to compress Diffuse Double Layer (DDL) resulting in a reduction of distance between micelle surface and cation. Clay dispersion and swelling are the results of high SAR values combined with low electrolyte concentrations, which ultimately leads to a loss of soil structural effects. (Shainberg and Singer, 1990; Rengasamy and Olsson, 1991; Amézketa and Aragüés, 1995b).

Electric Double Layer or Diffuse Double Layer is the layer formed as a result of two opposing forces (Brownian and Columbial) in an electrolytic solution of clay micelle. The Brownian is kinetic in nature and moves cations away from a clay micelle while collumbial electrostatic force attracts cations to the clay micelle.

2.4. Effect of Legume planting on soil properties

It is estimated that soybeans could end world hunger because they are the world's most widely grown commodity (GAIN, 2021) and are now one of the most widely traded commodities. It belongs to the Fabaceae (or Leguminosae) family. Research shows that soil's physical and structural properties are better improved within the short term through the influence of leguminous crops' roots than grasses (Adetunji et al., 2020). The protein, glomalin, symbiotically along the aggressive taproots of legumes serves as a “glue” that binds soil together into stable aggregates.

(Yuvaraj, et al., 2020). Rhizobium bacteria in the roots of legumes enable them to fix atmospheric nitrogen in the soil. This naturally causes an increase in SOM (Teodoro et al., 2011, Demir et al., 2019a) and improves soil physical quality, thus, having indirect effects on hydraulic properties and structural stability (Gulser, 2004; Sogut and Ozturk, 2017; Arslan et al., 2018; Demir et al., 2019).

It is interesting to note that the proton release from legume roots results in a lower pH level in the soil. According to the findings of Yan et al., 1996, the cultivation of field beans for 45 days resulted in a considerable decrease in the pH of the soil, which reduced from 6.00 to 5.64. Gulser, 2004 noted a similar trend in planting different legume crop species. However, the high concentration of H⁺ and Al³⁺ ions in the soil solution is detrimental to the growth of leguminous plants. because it inhibits nodule development (Brett et al., 2013). Zavalin et al., 2019 reported an increase in Al toxicity, decrease in Mg absorption, repression of sugar transport to nodules, and stoppage of N fixation as other effects. Nodules maintain a symbiotic life with soil-dwelling bacteria called rhizobia to ensure that nitrogen fixation occurs. Nodule formation can be inhibited by soil pH as well as effectively regulated by the plant. Most known legume crops can be grown in low soil pH levels.

Legumes also have the capacity of increasing soil carbon sequestration (Abberton, 2010, Kumer et al., 2019, 2020) lowering the emission of greenhouse gases (GHG) such as carbon dioxide (CO₂) and nitrous oxide (N₂O) (Siamabele, 2021), and when included in crop rotation, SOC content increases exponentially (Shah et al., 2003, 2011; Ghimire et al., 2017; Rajpoot et al., 2021).

According to a study Çerçioğlu et al., (2019) after five years of cover crop (CC) growth, CC management improved water retention and K_s for the -2.5 kPa pressure. In comparison to no cover crop management, cover crop enhanced macropores by 24% (Haruna et al., 2018b) and water infiltration metrics by 22% (Haruna et al., 2018).

2.5. Vermicompost as a Soil Amendment

Vermicompost is an important organic amendment that restores soil fertility and promotes plant growth. Generally, composts have a positive impact on overall soil quality; increasing soil pH, CEC, and EC promoting carbon storage, mitigating nutrient loss, and improving soil structure by increasing aggregate stability

(Candemir and Gulser 2011; Gulser et al., 2015; Gulser 2006; Al-Omran et al., 2021). It is produced when earthworms consume organic waste and change it into a finely divided, mature peat-like substance that possesses desirable qualities such as high porosity, aeration, drainage, water-holding capacity, and microbial activity. (Xu and Mou, 2016; Biouin et al., 2019).

According to Roberts (1997), soil texture has an impact on water storage capacity. Smaller particles with a bigger surface area make up heavy-textured soils, whereas larger sand particles with a smaller surface area make up light-textured soils. Heavy-textured soils may hold more water than light-textured soils because they have a bigger surface area that allows them to hold more water. As a result, soils maintained under an organic-fertilizer-added agricultural system hold more water than soils managed under a traditional farming system.

When compared to worldwide brands of compost that are manufactured and sold using conventional methods, vermicompost is "exceptionally excellent." It is at least four times more nutritious than conventional compost, which is often produced from cow dung, and it is seven times richer in nutrients and characteristics that promote growth compared to conventional compost (Thakur et al., 2021). This is because earthworms are so efficient at producing humus in large quantities (Canellas et al., 2002).

2.6. Soil Physical Properties

Soil physical properties are not just significant indicators for soil physical quality, determining the suitability and sustainability of soil for agricultural purposes (Regelink et al. 2015; Rabot et al. 2018 Almendro Candel et al 2018); they form the foundation of several chemical and biological processes (Jat et al., 2018). When it comes to optimal plant growth, the soil must create a favourable physical environment for root development to meet the plant's needs for nutrients, water and anchorage.

Parameters like porosity (micro and macropores) pore size distribution, bulk density, hydraulic conductivity, aggregate size distribution, permeability, and infiltration are major indicators of soil structural stability and productivity (Almendro Candel et al 2018).

2.6.1. Porosity

Porosity is regarded as one of the most significant factors influencing soil quality, as more porosity correlates to greater productivity (Rodrigue and Burger, 2004). The portion of the bulk volume that is not occupied by mineral or organic materials but is instead an open area that may be occupied by air or water is referred to as the porous space. Pore space should account for approximately half of the entire volume of the soil, if at all possible. Airspace is needed to provide oxygen to organisms that break down organic matter, humus, and plant roots. This interstitial space also stores water and dissolved nutrients. The rate of air and water entry into the soil is determined by porosity and pore-size distribution (Boyle et al., 1989).

Porosity is determined by the overall moisture content of the soil, clay dispersion, compaction and crusting. It is determined by various elements, including packing density, particle size distribution, particle form, and cementing.

2.6.1.1. Functions of soil macropores and micropores

Large soil pores promote high infiltration rates, good tilth, and appropriate aeration for plant growth. Most soils have an abundance of these large pores right after cultivation. After heavy rain or excessive irrigation, macroporosity (non-capillary porosity, aeration porosity) is critical for quick drainage of excess water from the soil. Rapid drainage of this water permits air to return to the soil, which is necessary for root function.

Microporosity (capillary porosity) helps plants retain the water they need to flourish. As the plant takes the water from these microscopic pores, it also fills with air. Gravitational forces do not cause the water in these pores to evaporate. However, the smaller the pores, the harder it is for plants to extract water.

2.6.2. Bulk density

The bulk density of soil is one of the primary soil quality indicators, productivity, compaction, porosity, and structure. A well-structured soil has low bulk density values while a poorly structured soil has high bulk density values. This property is dynamic and can be altered by vegetation, soil biota, trampling by livestock, farm machinery, weather and the season of the year, etc. (Hu et al., 2012). The high bulk density affects the available water capacity, root growth, and the movement of air and water through the soil. High bulk density is an indicator of low

porosity and soil compaction. Compaction increases bulk density and reduces yields and plant cover available to protect the soil from erosion. Dal Ferro et al., 2014 reported that root growth (length, density, diameter, and mass) decreased with increasing BD. Gusler 2015 reported that compost reduced bulk density by 20%.

2.6.3. Pore Size Distribution

It is the ratio of pore in a given soil sample. The ratio of the large pore to the small pore. The large pore which is otherwise the non-capillary pore holds air while the micropore otherwise called the capillary pore holds water. Under normal conditions, the ratio of macro-pore to micro-pore should be 1:1 so that adequate air and water are given to the crop. Pore size is a function of the capillary rise equation

The amount of water retained at low suction (less than 1 bar) is principally determined by the capillarity and pore-size distribution and is thus greatly influenced by soil structure. At high suction, water retention is caused by surface adsorption and mostly influenced by texture

The pore size distribution of soil is important because it has a dynamic and significant relationship with certain other soil properties. It provides significantly more information about structure complexity than just porosity. The concept of aggregates, for example, is based on the pore size distribution of different portions of the soil. Pore size, according to some definitions, can help distinguish micropores from macropores (and mesopores) in turn, affecting the movement and distribution of water and air in the soil, both of which are important factors in the growth of crops. It also has a significant influence in predicting hydraulic properties. Nimmo (2004) reported that in the study of soil, new pore size concepts, measurement techniques, and relationships to transport processes are anticipated to remain a major focus.

2.6.4. Hydraulic conductivity

It refers to the movement of water through the soil in both a vertical and a horizontal direction, and it can occur whether the soil is saturated with moisture or not. Under saturated conditions, the movement is mostly horizontal, whereas, under unsaturated conditions, the flow is mostly vertical. This is because the large pores are filled with air under saturated conditions. The saturated hydraulic conductivity, abbreviated as K_{sat} , is a property that is dependent on the soil structure, the

settlement of soil particles, the clay content, the organic matter content, the soil aggregation, bioturbation, swelling, and the overall structure of the soil. The key physical properties that help predict complex water movement and retention pathways through the soil profile are also widely used as a measure of the overall quality of the soil's physical state (Lim et al., 2016). It is commonly known as Darcy's law, and it is a law that describes the flow of fluid through saturated porous media.

2.7. Soil Water Retention Curve

The relationship between soil moisture condition and soil matric potential is explained by the soil moisture retention curve, otherwise called ‘soil moisture release curve’, ‘soil moisture desorption curve’, or ‘soil moisture characteristics curve’. It is the capacity of soil to store water, describing the ability of soil to hold water against the influence of gravity. It is important because it tells how much water will be available for plants. It is a function of varying environmental factors such as temperature, humidity, and soil properties such as organic matter content, texture, and structure. It is mostly related to the water content after drainage, evapotranspiration, and surface flow had occurred.

As a result, the retention curve explains the stage of plant stress (depending on soil moisture). Water movement can also be described by understanding the soil moisture status and the retention curve of soil (at various depths). This is not within the scope of this study.

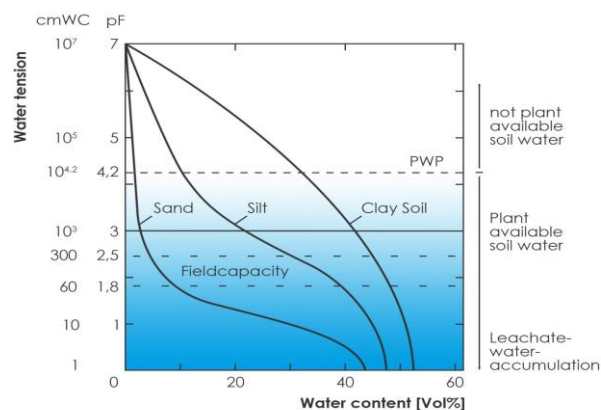


Figure 2.1. Typical Soil Water Retention Curve for different Soil Textures

2.7.1. Volumetric Water Content

The volumetric water content (v_w) of soil is measured in terms of the amount of water present in the soil's volume only undisturbed soil samples with known volumes can be used to determine this parameter. The most acceptable method is to use thin-walled metal cylinders of known volume (Lowery, et al., 1996).

2.7.2. Soil Moisture Constants

They are the parameters used in describing different stages of moisture in the soil at different potentials. These include Saturation Capacity, Field Capacity (FC), Permanent Wilting Point (PWP), Hygroscopic Coefficient (HC), and Soil Available Water (SAW). Saturation Capacity, otherwise called the maximum water holding capacity is defined as when all pores are filled with water. This is an undesirable situation on the field because the air pores are completely expelled. This occurs when soil matric potential is at zero.

The upper limit of SAW is represented by FC. It is the maximum amount of water a saturated soil can hold against the influence of gravity. The large pores are emptied of water at a matric potential range of 0.1 bar to 0.3 bar. While sandy soils dispel water within 2-3 days, it takes clay soil between 4-8 days to be well-drained. Permanent Wilting Point is the percentage of water remaining in a soil when soil can no longer supply water to the plant roots at a sufficiently fast rate to prevent the soil from wilting permanently. Moisture is present as a thin film around soil particles in the micro-pores. Matric potential ranges from -10 bars to -20 bars. It represents the lower limit of SAW. SAW is the maximum amount of water that the soil can hold for the use of crops. Soils with a fine texture will have more soil available water than soils with a coarse texture

Soybean (or any other crop) yields will suffer greatly if the soil is allowed to deteriorate to the point where it is permanently wilted. To meet the crop's water requirement for optimum growth and development, the soil water table may need to be raised to the root level, which may necessitate the use of organic matter and irrigation activities.

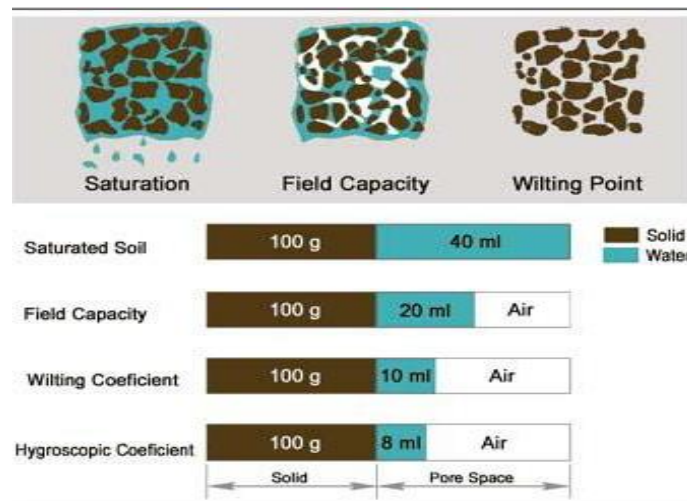


Figure 2.2. Soil Water Status

However, the presence of a shallow water table or a nearby obstructing horizon causes the redistribution process to continue with a significant flow rate for an extended period in such soils. In layered soils, redistribution following infiltration can result in successive water content profiles of such complexity that it is futile to calculate field capacity. For field water capacity to be a useful metric, the soil profile must be sufficiently saturated to a depth that exceeds the root zone depth.

2.8. Soil Chemical Properties

2.8.1. Soil Organic Carbon

The decomposition of plant and animal residues, root exudates, living and dead microorganisms, and soil biota contributes to the formation of soil organic carbon (SOC) (Edwards et al., 1999). Soil microorganisms get their energy primarily from carbon stored in organic matter. The SOM fraction in which SOC is located has an effect on the ease and speed with which it becomes available. SOM can be converted to OC using a factor of 1.72 because it contains about 58% carbon. (Brady et al., 2007; Edwards et al., 1999).

Many researchers have reported that macro-aggregates are made up of organic binding agents (Yu et al., 2015; Penget al., 2015; Kalhoro et al., 2017, Zhou et al., 2020), allowing them to have a better SOC protection mechanism than micro-aggregates (Hurrso et al., 2013). On the contrary, Christensen (1986); De Jonge et al. (1999); and Li et al. (2006) found that as organic carbon concentration increased, aggregate particle size decreased, and organic carbon was predominantly dispersed in microaggregates (< 0.25 mm).

2.8.2. Soil pH

In moderately acidic soils, Brady (1974) claims that aluminium and hydrogen compounds are responsible for the presence of hydrogen ions in the soil solution. There is a slight increase in pH and percentage saturation of the base in these soils. Hydrogen adsorption in moderately acidic soils also contributes to the hydrogen in the soil solution. Permanent charge exchange sites in clay and humus hold hydrogen that is easily interchangeable.

It is also important to understand the soil's ability to buffer pH variations. Brady et al. (2007) claim that soil organic matter found in humus-rich lands, such as organic farms, is critical for soil buffering. This is because the surface area of stable humus content is 30 times that of a common mineral. colloid. They went on to say that buffering is crucial in terms of maintaining soil pH stability. A significant change in pH signals a significant change in the soil environment, particularly in terms of plant nutrient availability. If this environment varies too much, higher plants and microbes will surely suffer severe consequences before they can make necessary changes. They would be influenced not only directly by the change in H ion concentration, but also indirectly by nutritional elements, which may be extremely undesirable. Buffering the soil's pH appears to be the best way to avoid these problems.

Compost addition also aids in the adsorption of hydrogen ions, raising soil pH levels (Pocknee and Sumner 1997). This is also in line with the findings of (Ouédraogo, Mando, and Zombré 2001), who found that compost treatments increased soil pH levels.

2.8.3. Electrical Conductivity

In terms of crop production, soil electrical conductivity (EC) is a measurement that correlates with soil properties, such as soil texture, drainage conditions, organic matter level, salinity, sub-soil characteristics, and most importantly, cation exchange capacity (CEC). Simply put, the ability of a material to transmit or conduct an electrical current is measured in milliSiemens per metre or milliSiemens per centimetre.

EC is a direct measure of soil salinity, indicating the total concentration of the soluble salts. It has been reported that EC values in soil increased continuously with the addition of organic matter.

3. MATERIALS AND METHODS

3.1. Experimental Setup and Soil Sampling

The experiment was carried out in the greenhouse of the Agricultural Faculty of Ondokuz Mayıs University between August 9 and October 5, 2021; under a temperature range of 18.1 and 37 and average humidity of 44%. The temperature and humidity graph is given in Figure 3.1. Glass cylinders and pots with a diameter size of 550 mm and 1200 mm respectively were used as soil carriers.

Soil from the Faculty's experimental field was allowed to air-dry in the laboratory before being sieved through 4mm screens size. The hydrometer technique was used to determine particle size distribution (Day, 1965), soil reaction (pH, 1:1 (w:v) soil: water suspension) was measured using a pH metre, and electrical conductivity at 25°C was measured with an EC metre in the same soil suspension, while the organic carbon by Walkley Black Method. Vermicompost made from cow dung and composted for 3 months in the greenhouse was mixed in some parts of bulk soil using a hand trowel with a 2% of dry weight basis. Table 1 outlines the characteristics of both the vermicompost and the soil that were used in the experiment. Soybean seeds, obtained from the Department of Agricultural Biotechnology, Ondokuz Mayıs University were planted two seeds in each cylinder for treatments involving planting and were later thinned to one seedling. Vermicompost was slightly alkaline and non-saline, whereas the soil was clay-textured, slightly acidic, non-saline, and rich in organic matter (Soil Survey Staff, 1993).

There were four treatments in 10 cm soil depths of cylinders: soil (S), soil+2%vermicompost (SV), soil+planting (SP), and soil+planting+2%vermicompost (SPV). Initial soil was used as a control. Pot samples had two replications with the following dimensions: depth, 35.56 cm; and diameter, 6.35 cm. Moisture content was kept around field capacity, wetting with rainwater after daily weighing the pots and cylinders. The first part of the experiment was discontinued 24 days after it began, whereas the second half was terminated after vegetative maturity (72 days). At the conclusion of each period. Soils were tested for aggregate stability, water retention, and physicochemical properties, inclusive of bulk density, hydraulic conductivity,

Electrical Conductivity, organic carbon content, pH, porosity, and exchangeable cations.

Table 3:1: Some properties of soil and vermicompost used in the study

	Sand, %	Silt, %	Clay, %	pH	EC, dS/m	OC, %	N, %	C/N
Vermicompost	-	-	-	8.15	.600	22.7	1.9	11.92
Soil	21.24	2.24	56.38	6.28	0.625	2.01		

3.1. Bulk Density

Bulk density (Bd) was calculated by the core method (Blake, 1965), using the sample dry weight and the equivalent volume of the core.

$$\text{Bulk Density} = \frac{\text{mass of oven dried sample (g)}}{\text{volume of cylinder (cm}^3\text{)}} \quad (3.1)$$

3.2. Porosity

Total porosity (F) was from the equation below. The data for bulk and particle density are required for the calculation of soil porosity (Blake and Hartge, 1986).

$$F = \frac{\text{soil bulk density (g/cm}^3\text{)}}{2.65 (\text{soil particle density})(\text{g/cm}^3)} \quad (3.2)$$

3.3. Hydraulic conductivity and Pore Volume

Using a Mariotte bottle and the constant-head method, the saturated hydraulic conductivity (Ks) values of the soil samples were determined. In order to calculate saturated hydraulic conductivity, the Darcy equation was used to outflow volumes measured at the bottom of soil columns (Ks, cm).

$$K_S = \frac{Q}{At} \left(\frac{S}{S+H} \right) \quad (3.3)$$

Where, Q is outflow volume (cm³), A is cross-sectional area of soil column (cm²), t is time (minutes), S is length of soil column (cm), H is height of pounded water at the top of soil column (cm). At different time intervals, pore volumes were taken from each treatment.

3.4. Aggregate Size Distribution

In order to determine the MWD, dry sieving was used (Kemper and Rosenau, 1986). At room temperature, the damp soil samples were let to air dry.. Using a nest of sieves with mesh sizes ranging from 2.00 mm to 0.25 mm and a shaking time of one minute, 200 g of air-dry soil sample was sieved for one minute. The weight of soil in each class was compared to the overall weight of the soil sample to estimate the aggregate size distribution.

Mean Weight Diameter (MWD) was derived from the size range of air-dry aggregates.

$$\text{MWD} = \sum_{i=1}^n (\bar{X}_i \cdot W_i) \quad (3.4)$$

Where X_i is the mean diameter of the i^{th} aggregates and W_i is the mass percent content of the i^{th} aggregates is the proportion of the total dry sample weight.

3.5. Aggregate stability

The proportion of water-stable aggregate (WSA) and the percentage of each size fraction were used to determine the stability of soil aggregates (PSA). Except for 0.25 mm, aggregates from each size opening were placed on a sieve with a 0.25 mm size. The soil sample was allowed to moisten by capillary for 3 minutes after the sieve was lowered to the water surface. The Yoder device had a vertical stroke of 45 mm and was run at a pace of 37 cycles per minute for 3 minutes.

The wet sieving method was used to evaluate aggregate stability. The fractions that remained on the sieve after sieving were oven-dried to a consistent mass at 105°C. The aggregate stability (AS) of the sieved samples was calculated as a percentage of the total sieved samples. After the fractions were chemically dispersed, correction for sand content in formula was done.

$$\text{AS \%} = \frac{\text{stable aggregate} - (\text{sand correction for } 0.25 \text{ mm})}{\text{oven dry sample} - \text{sand correction}} * 100 \quad (3.5)$$

Percentage of aggregates destruction (PAD %) was calculated as seen in Equation 5

$$\text{PAD} = \frac{M_d - M_w}{M_d} \times 100\% \quad (3.6)$$

where M_d and M_w are the aggregate mass fractions of the dry sieve and the wet sieve, respectively, for particle sizes > 0.25 millimetres

3.6. Organic Carbon

Under the same conditions, the samples representing the various soil aggregate size classes were subjected to treatment with sulphuric acid potassium dichromate. The heat generated by the reaction increases the temperature to a point where oxidation can take place. During the interaction with the soil, the amount of reduced dichromate produced is proportional to the amount of oxidizable organic carbon that is present in the sample. Following this, an estimate of the amount of organic carbon is obtained by determining the quantity of unreduced dichromate that is still present, then performing a back-titration with ferrous sulphate while making use of a diphenylamine indicator.

The SOC is reported as a percentage of carbon for every 100 grammes of soil. Multiplying the percentage of soil organic carbon by 1.72 gave the SOM percentage of the soil samples.

3.7. Exchangeable Cations

For the extraction of soil exchangeable cations, the ammonium acetate extraction method was used (Kacar 1994)

3.8. Electrical conductivity and pH

Using a pH and EC metre, the pH and EC values of a 1:1 (w:v) soil:water suspension were determined.

20 g of air-dried soil sample was mixed with 20 ml of distilled water in a graduated 50 ml plastic test tube with a cover. Mixture was mechanically shaken for around 30 minutes to facilitate the dissolution of anions and cations. By inserting the

conductivity metre, the electrical conductivity of the soil was recorded in uS/cm while the pH meter was used to measure the pH

3.9. Pore Size Distribution

Using the capillary equation, pore size distribution was calculated from the water retention data. Four pore sizes were used; Micropores (< 10 µm), fine mesopores (10 to 60 µm), coarse mesopores (60 to 1000 µm) and macropores (>1000 µm) respectively represented by the following soil water pressures 0.0 to –0.5 kPa, –0.5 to –5.0 kPa, –5.0 to –33 kPa, and –33 kPa.

From the water retention data, the pore size distribution was determined using the capillary equation. Four pore sizes were utilised: micropores (< 10 µm), fine mesopores (10 to 60 µm), coarse mesopores (60 to 1000 µm), and macropores (>1000 µm), which were represented by soil water pressures ranging from 0.0 to –0.5 kPa, –0.5 to –5.0 kPa, –5.0 to –33 kPa, and > –33 kPa, respectively.

The total pore volume of the soil samples was calculated as the volume of the total pores capable of storing water when the pressure is at its maximum (0 kPa);

$$\text{Total pore volume} = \frac{M_s - M_d}{V_t} \times \frac{1}{e_w} \quad (3.7)$$

Where: M_s = mass of saturated soil, M_d = bulk of oven-dried soil, and e_w = density of water at 20°C (0.998 g/cm³),

The equivalent pore diameter (EPD) of a particular matric potential was calculated utilising the capillary rise equation (Warrick, 2002), which connects the suction applied to a water column to the capillary radii.

$$EPD = \frac{4\gamma \cos \alpha}{\rho W g h} \approx \frac{2980}{h} \quad (3.8)$$

Where: γ = pore water surface tension (972.8 g/s²)

ρW = is water density (0.998 g/cm³)

g = gravitational acceleration (980 cm/s²)

$\alpha \approx 0$, the water-pore contact angle

h = the smallest pore (mm) drained at a matric potential of h (kPa).

The pore size distribution was expressed as a percentage of the total porosity's pore volume occurring within a certain matrix potential range.

3.10. Soil Moisture Constant and Retention

Using the sandbox and pressure plate apparatus the water content was measured at various suction pressures (Klute, 1986). In a plastic cylinder with a 5 cm diameter and 5 cm height, respectively, soil samples from each treatment were filled in replicates; placed in a flat-bottomed bowl of water until fully saturated. Soil moisture retention characteristics were determined on the core soil samples using eighteen matric potentials (-0.25, -0.5, -0.75, -1.0, 1.75, -3.15, -4.0, -5.0, -6.3, -9.84, -33, -70, -100, -300, -600, -900, -1200 and - 1500 kPa)

3.11. Plant-available water capacity

The plant-available water capacity, also known as PAWC (cm^3/cm^3), measures the capacity of the soil to both store and supply water that is accessible to the plant roots (White, 2006). The amount of water that is accessible to plants was determined by determining the difference in moisture content between the field capacity and the permanent wilting point.

$$\text{PAWC} = \theta_{\text{FC}} - \theta_{\text{PWP}}; 0 \leq \text{PAWC} \leq \theta_{\text{FC}} \quad (3.10)$$

Where: θ_{PWP} (cm^3/cm^3) denotes the water content at the permanent wilting point while θ_{FC} refers to water content at Field Capacity

3.12. Statistical Analysis

The statistical tests were done using the statistical package for the social science software (SPSS, 17). Data were tested according to factorial experimental design (soil management system at four levels, and sampling date at two levels) with ANOVA in order to determine main and interaction effects while Duncan tests were used to differentiate the significance of treatment means.

4. RESULTS AND DISCUSSION

4.1. Bulk Density

Results of bulk density are in the range of 0.92 to 0.99 g/cm³, less than the ideal value (1.10 g/cm³) for root growth in clay soil (Soil Quality Staff, 1999). There was no difference between the control soil (S) at both sampling dates, however, there were significant differences for treatments SP, SV and SPV ($p > 0.01$). Mean values of BD were 0.99, 0.94, 0.97 and 0.95 g cm³ for S, SP, SV and SPV respectively. S and SV management showed higher BD as compared to SP and SPV management during the whole studied period.

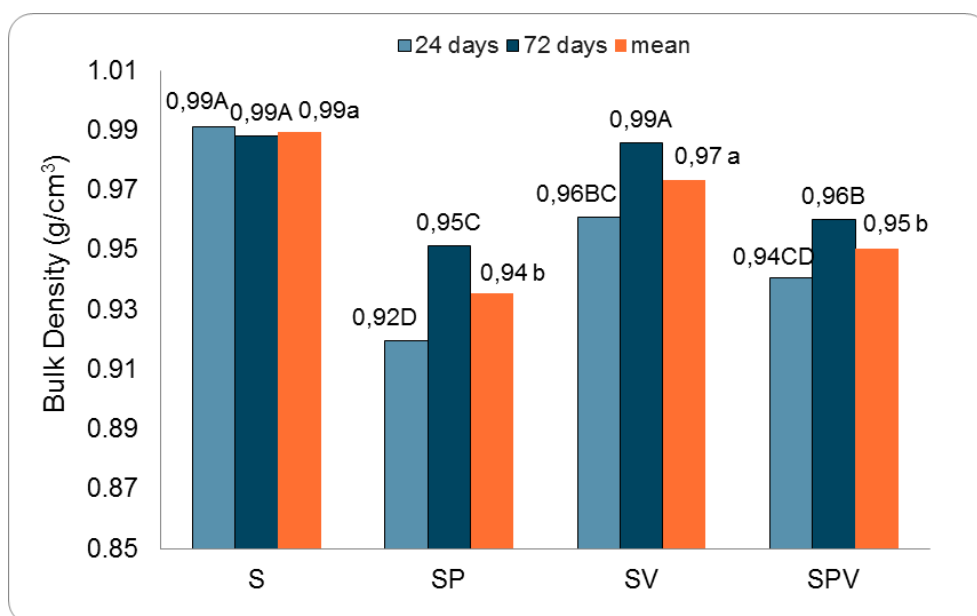


Figure 4.1. Interaction and Mean Values of Soil bulk densities during the studied period under different management systems (control Soil, S; Soil with Soybean planting, SP; Soil with vermicompost addition, SV; Soil with Soybeanplants and vermicompost, SPV). Upper case indicates interaction among factors ($p < 0.05$), lower case represents mean difference ($P < 0.01$)

In comparison with the control, bulk density values were reduced by 7.07%, 3.03%, and 5.05% for treatments SP, SV, and SPV respectively at 24 days (Fig 4.1). This is concurrent with the fact that organically amended soils have lower bulk density than mineral soils. However, the rate of reduction depends on the potency of organic matter added. The result revealed that the highest reduction was found at SP treatment at 24 days, this is not significantly different from SPV at 24 days; an indication that plant root had the greatest impact on clay soil within the shortest time.

SPV certainly has luxurious nutrients because of the presence of extra organic matter from vermicompost. Thus, plant roots do not have to reach deeply into the soil, otherwise, more pores would have been created by plant roots. Plant roots in SP penetrate deeply in the soil column so that more pores are formed.

When porosity increases, there is a decrease in bulk density. This is the reason for the lowest bulk density value at 24 days for SP treatment at 24 days. Moreover, the presence of vermicompost in SPV has altered the natural characteristics of clayey soil that is found in SP.

In their findings, Keisuke Sato *et al.* (2015) reported the higher the clay content, the greater the rate of penetration. because higher clay content results in higher friction and cohesion among the soil particles, causing the increase in penetration rates, invariably downward root growth (Tormena *et al.*, 2008).

It is often reported that higher bulk density over some time is the result of compaction. This is not the case for this greenhouse experiment where at 72 days, values were relatively higher and significantly different from those at 24 days. It should be understood that in nature, the continual wetting process of soil causes volume change, large deformation, rapid settlement and decrease in void ratio (Laloui and Ferrari 2013). This is the reason for the higher bulk density values recorded at 72 days for treatments SP, SV and SPV.

High bulk density values in control soil is attributed to its exposure to the daily temperature change, leading to its vulnerability to form the characteristic crack patterns that occur in clay soils during wetting and drying processes. While other treatments had a measure of covering, the control soil was left bare to the high-temperature effect. Wetting and drying cycles have been reported to be accompanied by continuous reconstruction of soil structure, resulting in a decrease in bulk density. (Tang *et al.*, 2016).

Generally, any management practice that leads to an increase in organic matter in soil will decrease soil bulk density values, increase porosity and increase soil's granular structure (Shaver *et al.*, 2003; Candemir and Gülser, 2011). Such should be the effect of vermicompost in SV treatment. However, the result reveals that SV treatment is not different from control soil. This is a negative omen, thus, it can be

deduced that the impact of soybean plant roots are superior to the vermicompost made from cow dung.

4.2. Total Porosity

When bulk density increased, the total porosity values decreased. Results of total porosity values at 72days are relatively lower compared to the values obtained after 24 days and are significantly different from each other in all management systems the control (Fig 4.2). The mean values ranged from 0.63 to 0.65, with SP and SPV having the highest values and not significantly different from each other but significantly different from S and SV. However SP 72 days sampling the effect on porosity

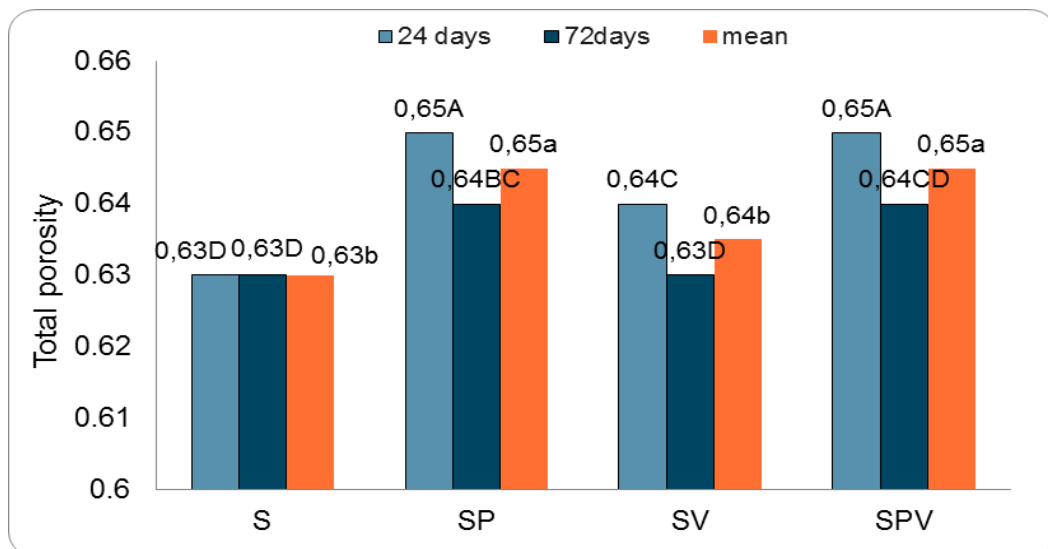


Figure 4.2: Interaction and Mean Values of Total Porosity during the studied period under different management systems (control Soil, S; Soil with Soybean planting, SP; Soil with vermicompost addition, SV; Soil with Soybean plants and vermicompost, SPV). Upper case indicates interaction among factors ($p < 0.05$), lower case represents mean difference ($P < 0.01$)

It must be noted that total porosity is not a true index of soil structure because total porosity fails to quantify the ratio of macropores to micropores. In a review of soil physical properties, Phogat (2015) reported that the more important for plant growth than total porosity is the distribution of different pore sizes. Since porosity depends on several factors such as packing density, a breath of particle density, shape of particle and cementing; it is worthy to note that the variation in these factors affect total porosity. Thus, the focus is on pore size distribution.

4.3. Pore Size Distribution

There is a preponderance of micropores to macropores (Fig 4.3 E, B) approximately 1:10 for macropores and micropores respectively as expected in clay soils. Generally, clay soils have poor drainage and poor root growth because of this reason. While the ratio of macropores to micropores in SP and SPV is 1:8; 1:9 and 1:7; 1:8 at 24 days and 72 days respectively. There is more preponderance of micropores in SPV. This partly explains why the rate of flow is lower at 72 days for all management systems (Fig 4.4). Apparently, SP and SPV increased macropores in soil, this is reflected in Hydraulic conductivity.

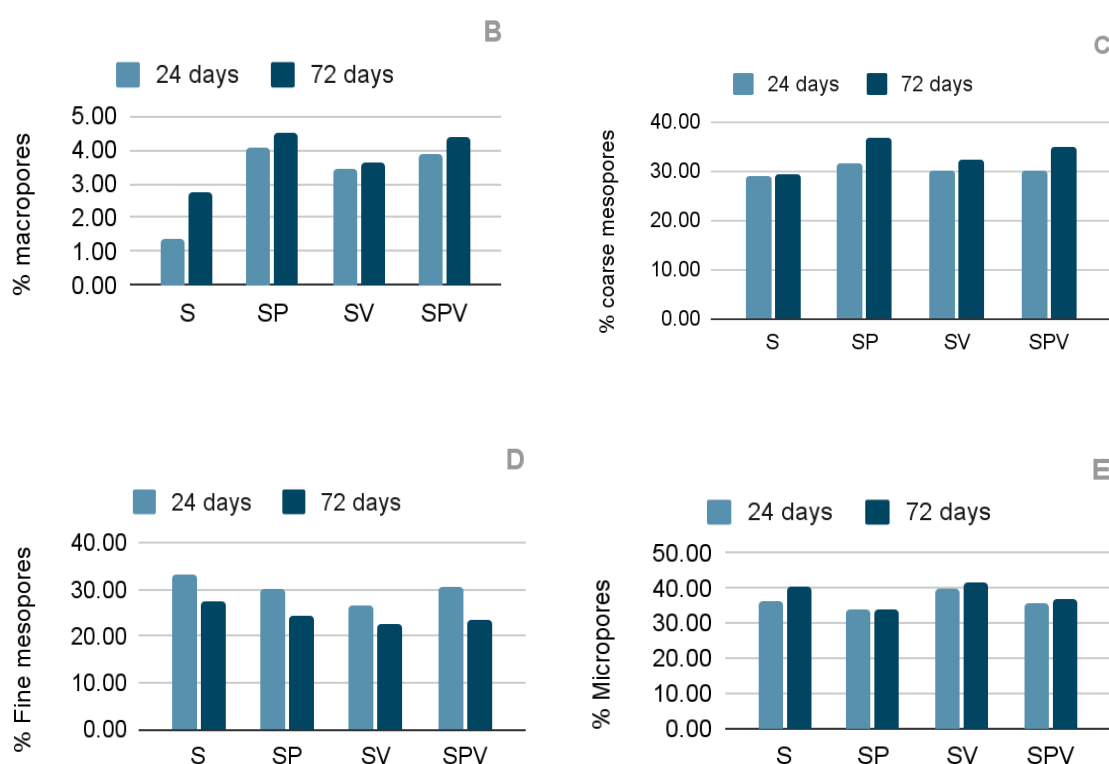


Figure 4.3. Treatment Effect on Pores and pore size distribution (A) porosity at 24 and 72 days, (B) macropores ($>1000 \mu\text{m}$), (C) coarse mesopores ($60\text{--}100 \mu\text{m}$), (D) fine mesopores ($10\text{--}60 \mu\text{m}$), (E) micropores ($< 10 \mu\text{m}$) as influenced by time

For plant growth, macropore promotes a high infiltration rate, good tilth, and enough aeration. Thus, the increased infiltration in SP and SPV (macropores $\approx 4\%$) when compared to S and SV. It is consequently critical to have a better understanding and quantification of infiltration and water movement in macroporous soil.

The increase in micropores (< 10 µm) induced by soybean taproot systems is associated with an improvement in soil physical characteristics as well as the dimensions of the pore space in cultivated soils. At 24 days, there is an increased flow rate in SP and SPV treatment compared to other treatments because of the preponderance of micropores in those treatments.

4.4. Hydraulic Conductivity

There is an interrelationship between bulk density, porosity and hydraulic conductivity (Hillel, 2003; Fuentes *et al.*, 2004; Horn and Smucker, 2005; Buczko *et al.*, 2006; Dec *et al.*, 2008).

From the results obtained (Fig 4.4), the two-way ANOVA revealed that there was no significant interaction between the management system and days of sampling. Simple main effect showed that the rate of flow at 24 days for all management systems was significantly higher than the flow rate at 72 days. Chandrasekhar *et al.*, 2018 reported similar findings, stating that soil hydraulic characteristics are extremely time-variable, even at the seasonal scale.

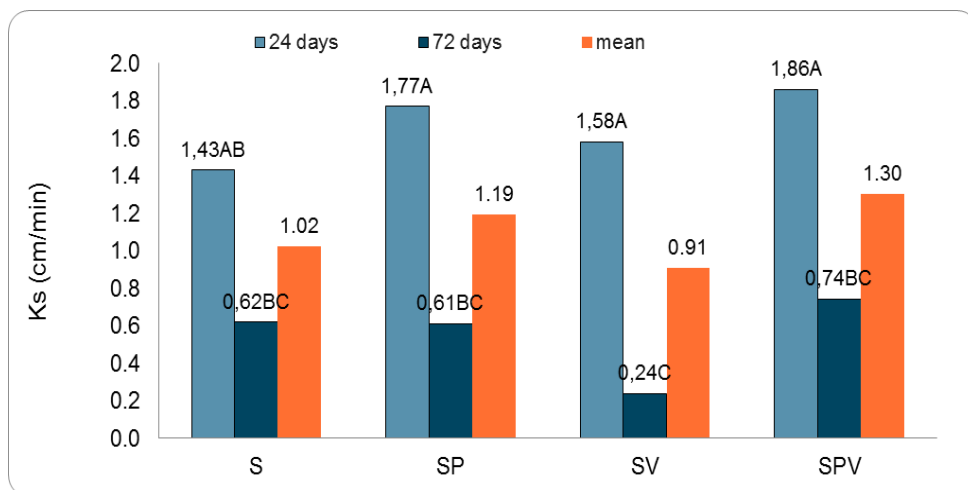


Figure 4.4: Interaction and Mean Values of Hydraulic Conductivity during different sampling days under the management systems (control Soil, S; Soil with Soybean planting, SP; Soil with vermicompost addition, SV; Soil with Soybean plants and vermicompost, SPV). Upper case indicates interaction among factors ($p < 0.01$)

Ksat is an important soil characteristic for understanding drainage, soil water flow and solute movement (Mallants *et al.*, 1997). Soil management has a major

influence on this property (Rachman *et al.*, 2005; Udawatta *et al.*, 2008; Fuentes *et al.*, 2004; Horn and Smucker, 2005; Buczko *et al.*, 2006; Dec *et al.*, 2008) . The hydraulic qualities of soil have been shown to be affected by cover cropping in previous studies. As Demir and Isik (2019) reported, cover crops significantly improved the hydraulic properties of a persimmon orchard's clay soils. The physical properties of clay soil in an apricot orchard were improved by a leguminous crop.

Keisling *et al.*, 1994 and Çerçioğlu *et al.*, 2019 reported that noticeable changes in hydraulic properties were observed several years of cultivation on clay soils. In this experiment, hydraulic quality decreased with time. Perhaps, if sampling time was in years there may be improvement. Thus, the reason there is no significant difference among the management systems at 72 days. However, the reduction was more severe in SV than other management systems at 72 days.

Apart from the effect of consolidation of soil particles as a result of the prolonged wetting process, water permeability can also be affected by various biological and chemical processes (Hillel, 1982). For instance, high EC in sodic soil solution decreased flow rate (Candemir and Gulser, 2012). The impact of exchangeable sodium and salt concentration cannot be underestimated in the study of hydraulic conductivity. Bohn *et al.*, 1985; Sparks, 2003; Candemir and Gulser, 2012 reported that high amounts of sodium and low level of electrolyte concentration cause permeability problems in fine-textured soils. This may be the reason for a very low flow rate recorded by SV at 72 days.

4.5. Stability and Size Distribution of Soil Aggregates

The stability and size distribution of soil aggregates are vital in determining the aggregates' vulnerability to erosion by water and wind respectively. The result (Fig 4.4) shows that the mechanically stable aggregates (MSA) obtained by the dry sieving method were predominantly macroaggregates (>0.25 mm). The proportions of 2-4 mm were highest for all treatments and that of < 0.25 mm were the lowest. SP (24 days) ranked highest followed by SPV (24 days) while S (72 days) recorded the least value for 2-4 mm aggregate size.

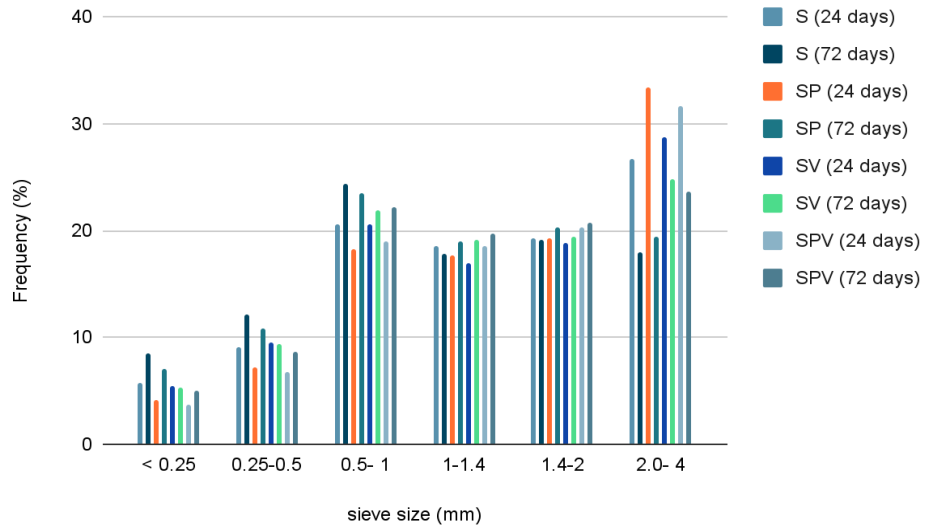


Figure 4.5. Distribution of Mechanical stability aggregate Size fractions (Percentage) under different treatment and time

In general, soil aggregate size distribution is linked to the principal cementing agents in soil aggregates, such as SOM, clay minerals, multivalent cations, and their complexes (Zhao *et al.*, 2017). While microaggregation is dominated by sesquioxides (Yao *et al.*, 1990), macro aggregation is dominated by organic matter (Zhang *et al.*, 1996). According to Tisdall and Oades, micro-and macro-aggregate formation and stability are intertwined processes. According to Six *et al.* (2000), the best soil structures were macro-aggregates and more macro-aggregates improve soil agglomeration and stability. This report is true as the test for aggregate stability (Table 4.1) revealed that aggregates were highly stable (> 30%) for various treatments over some time.

Moreover, the rate of increase in micro aggregate at 72 days over 24 days is about 49%, 66.7%, and 34.32% for treatments S, SP and SPV respectively whereas there was a decrease of 2% in SV treatment. Since micro aggregate (< 0.25 mm) is a minute portion of the soil aggregate, the rate of increase or decrease is very infinitesimal and thus, can be negligible.

Table 4.1: Aggregate Stability across various treatments and time

Fraction s (mm)	S(24 days)	S(72 days)	SP(24 days)	SP(72 days)	SV(24 days)	SV(72 days)	SPV(24 days)	SPV(72 days)
0.25-0.5	83.62	89.07	81.38	86.93	79.92	84.25	87.09	89.02
0.5- 1	88.09	89.51	83.72	88.74	85.97	85.71	83.49	86.86
1-1.4	88.56	88.54	86.33	88.57	88.26	85.86	86.66	87.35
1.4-2	88.42	91.52	86.64	88.45	89.36	86.19	87.43	87.83
2.0- 4	89.82	93.34	85.71	88.94	91.28	87.07	84.76	88.58

Nevertheless, by considering the highest proportions of MSA for each aggregate size, it can be concluded which treatment is the most stable. Result shows that S (72 days) - 8.4%, S (72 days) - 12.14%, S (72 days) - 24.33%, SPV (72 days) - 19.7 %, SPV (72 days) - 20.79% and SPV (72 days)- 31.67 % for $MSA_{<0.25mm}$, $MSA_{0.25-0.5mm}$, $MSA_{0.5-1mm}$, $MSA_{1-1.4mm}$, $MSA_{1.4-2mm}$ and MSA_{2-4m} . From all indications, SPV (72 days) is most stable against wind erosion while S (72 days) is most stable against water erosion (Table 4.1).

Increased stability of SPV may be attributed to the presence of glomalin, a protein found symbiotically on the roots of legumes that acts as "glue" for soil aggregates. rather than the OC content. Moreover, Zhou *et al.*, 2020 observed that soybean (legumes) planting had a stronger impact on macroaggregate development than corn (grain) planting in this study.

Clay naturally functions as an aggregant combining organic molecules with cations (like Ca^{2+} , Al^{3+} , and Fe^{3+}) to form macroaggregates and produce a protective coating to protect SOC from microbial degradation and stabilise aggregation (Bronick and Lal 2005). Because of this, S (72 days) stands out among the other treatments.

4.5. Mean Weight Diameter

At 24 days, the percentage increase of MWD over control was 10.32 %, 1.94 % and 9.03 % for SP, SV and SPV respectively (Fig 4.5). Within the shortest time, SP treatment revealed more macro-aggregate stability than soil treated with vermicompost. This coincides with this Blanco-Canqui *et al.* (2011) findings that

legume cover crops resulted in a large (82 percent) increase in MWD when compared to fallow, showing that such legumes may be useful in some cropping systems (Blanco-Canqui and Jasa, 2019).

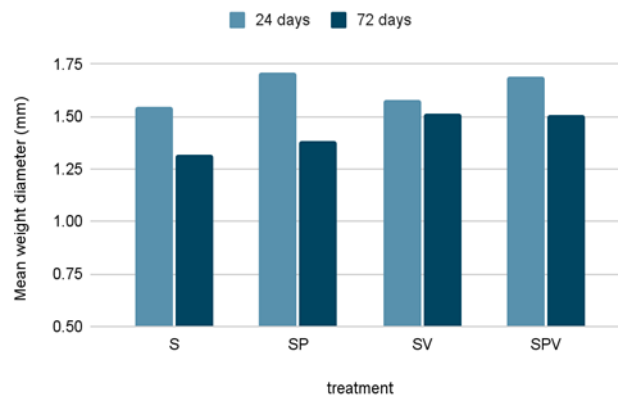


Figure 4.6: Mean Weight Diameter at 24 days and 72 days

Generally, the value of MWD decreased with time for all treatments. It has been suggested that the first step to loose soil structure is the disintegration of macroaggregate to micro aggregate, otherwise called slaking. Herrick *et al.*, (2001) explained slaking as the process that occurs when large, air-dry soil aggregates (>2-4 mm) are rapidly immersed in water, they break down into micro aggregates (less than 0.25 mm in diameter) because aggregates are not strong enough to resist internal pressures induced by rapid water absorption. Mbagwu and Auerswald (1999) reported that soils with high slaking potential are more likely to experience interrill erosion (a movement that occurs as a result of rain splash) Slaking is frequently followed by sealing and crusting. Morin (1993) explained crusting as an undesirable situation where a thin dense layer forms at the soil surface due to the impact of raindrops, resulting in the soil becoming relatively impervious to water.

In this study, daily irrigation led to slaking. The breakdown was approximately 11%, 19%, 4% and 11% for S, SP, SV and SPV respectively. Therefore, it is justifiable to attribute the impact of this internal soil stress to at least one of these factors; swelling of clay particles in different directions, the release of trapped air in soil pores, rapid release of heat following wetting, or the movement of moving water.

4.6. Percentage of Aggregate Destruction

This result (Fig 4.6) indicates that planting could reduce the percentage of aggregate destruction (PAD). It is intriguing to observe an increase in the rate of destruction, especially in vermicompost amended soil (SV and SPV). This is likely due to the properties of vermicompost produced from cattle manure which contributed to the destruction of soil aggregates. It is worthy to note that though vermicompost is termed as "exceptionally superior" to worldwide brands of conventionally produced and marketed compost (Thakur *et al.*, 2021), not all sources will have a positive effect on soil.

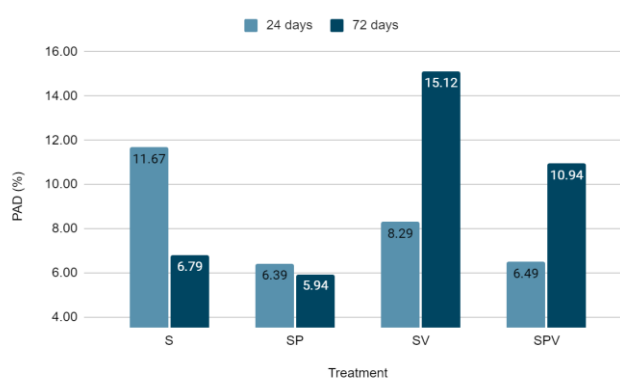


Figure 4.7. Rate of Aggregate Destruction %

The roots of soybean plants were likely responsible for the formation of humic substances (Hua *et al.*, 2012). Humic substances interact synergistically with amorphous iron, aluminium, and aluminosilicates to form persistent binding agents (Shi *et al.*, 2002), which increases aggregation.

Within the first 24 days, aggregates of bare soil (control treatment) were damaged most, however not as much as SV at 72 days. Percentage aggregate destruction is lower for treatment without vermicompost application.

Most likely, macroaggregates are destroyed to produce microaggregate. This is because macroaggregates are transients and are far more susceptible to destruction by cultivation and wet-dry cycles caused by wetting and evaporation. This concept will be explained with respect to organic carbon in the subsequent sections.

4.7. Effect of Vermicompost on Plant Root Growth

The effect of sole application of vermicompost had negative effect on soil. However, vermicompost application significantly improved plant root growth (Fig 4.8). Arancon and Edwards (2005) applied small amounts of vermicompost in their flower gardens, they reported healthy and productive plants. The increasing effect of plant growth can be attributed to an increase in humic acid content and consequently beneficial symbiotic microorganisms and plant growth hormones (Atiyeh *et al.*, 2000a; Atiyeh *et al.*, 2000b).

In their study, Xu and Mou (2016) applied vermicompost of unstated sources and found out that vermicompost treatments significantly increased the growth of spinach, as evidenced by increased leaf count, leaf area, and fresh/dry weight of root and shoot. Soil amendment helped shoot growth more than root growth. Also, Peyvast *et al.* (2008) discovered that spinach plants grown in soil amended with 10% vermicompost had the highest leaf number, area, and FW.

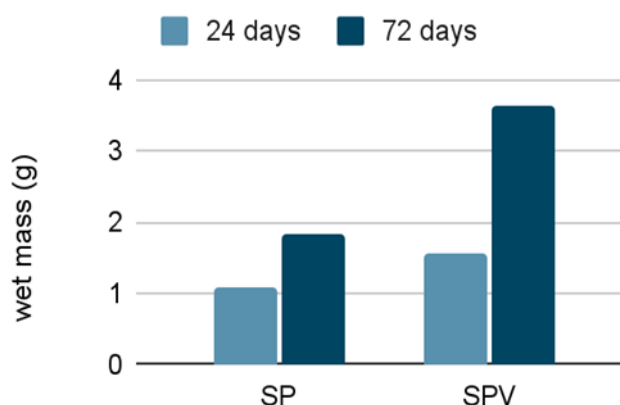


Figure 4.8. Root Fresh weight of treatments SP and SPV

4.8. Effect of Treatment on EC and pH

Fig 4.9 shows that Electrical conductivity (EC) values range from non-saline in SP (0.241 dS/m) to very slightly saline in SV (1.06 dS/m). SV recorded about 17% higher than the control because of the presence of additional organic matter. It is very likely that SV treatment contains some levels of salt such as Na., though pH is neutral (Fig 4.10). This suggests that a high application rate of vermicompost made from cow dung is not recommended because it might cause salinity stress. Moreover,

reports show that the addition of organic soil amendment increases soil EC (Candemir and Gulser 2010; Uz *et al.* 2016).

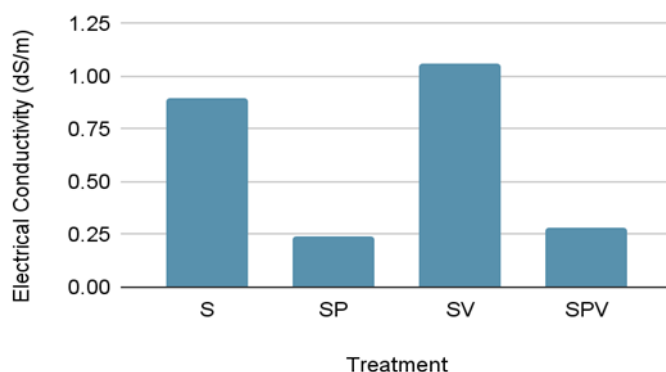


Figure 4.9. Electrical Conductivity of treatment at 72 days

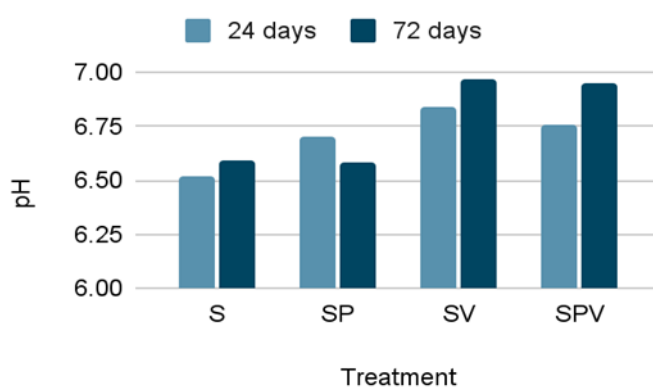


Figure 4.10. pH at 24 and 72 days

The soil's EC is a measure of the number of soluble salts, the higher the values, the higher the levels of salts or nutrient concentration in the soil. No doubt, the presence of roots in SP and SPV is the reason for the low EC value because of nutrient uptake by plant roots.

Soil pH (Fig 4.10) ranges from slightly acidic to neutral. While there is a marked increase at 72 days in all treatments S, SV and SPV; the pH of SP reduced after 24 days. The pH of soil nutrients, microbiology, and soil physical condition are all affected by this factor.

4.9. Impact of Treatment on Soil Organic Carbon Content of Soil Aggregates

The ability of soil to retain carbon, vital nutrients, and moisture may be enhanced by the agglomeration of soil particles into different aggregate-size classes (Tisdall and Oades, 1982; Schaefer *et al.*, 2020). The result shows different soil aggregate sizes have varied concentrations of OC (Fig 4.11).

While micro aggregates tend to hold more OC in all treatments, with SPV (72 days) having the highest value ($\approx 4\%$), meso aggregate and macroaggregate are varied. This is in line with Christensen (1986); De Jonge *et al.* (1999); and Li *et al.* (2006) findings. Fig 4.12 revealed that micro aggregates tend to hold more OC in all treatments which is significantly higher than other aggregate sizes.

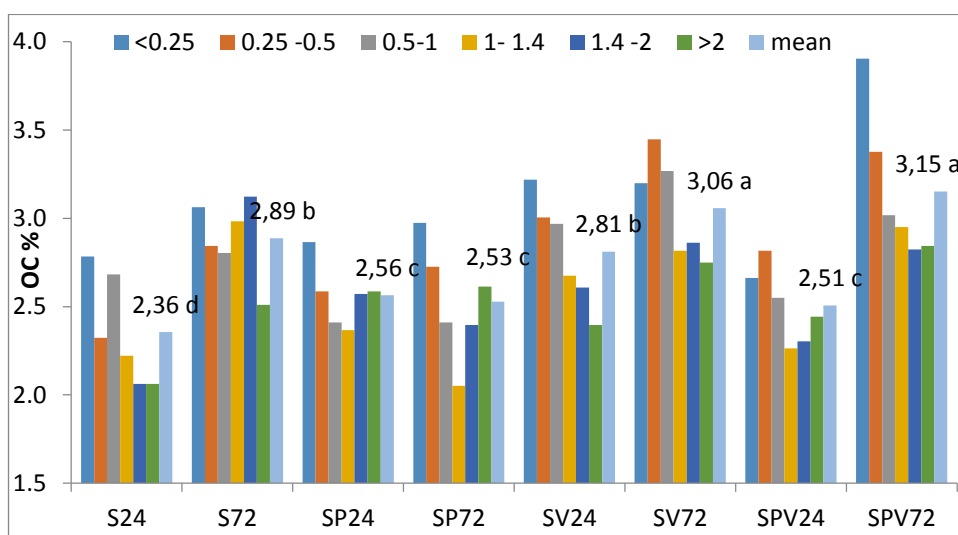


Fig 4.11 Percentage of organic carbon in different aggregate sizes and time

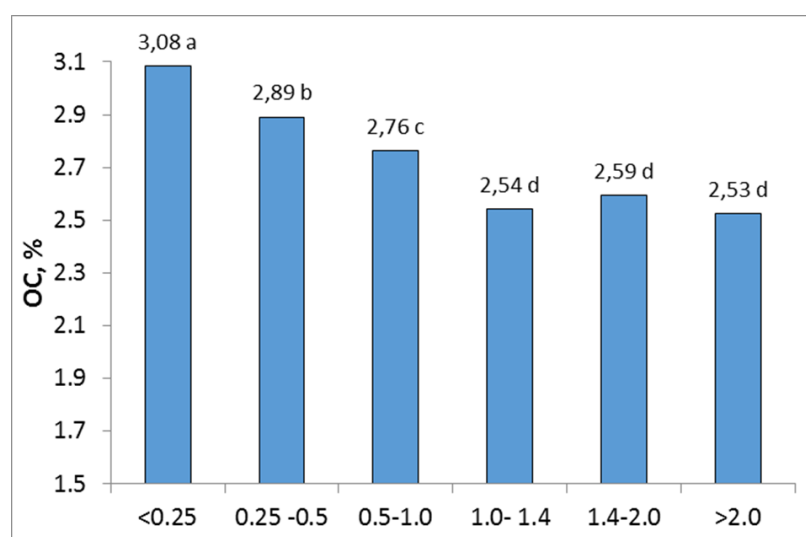


Fig 4.12. Percentage of organic C in different aggregate sizes. Means were separated at P (<0.01)

Blanco-Canqui and Lal (2004) explained that by increasing the binding pressures between soil microaggregates, the OC intake may promote macro aggregation. The combined impact of vermicompost and soybean plants, no doubt increased the OC content in the micro aggregate. In a review of microaggregates in soils, Totsche *et al.* (2018) attributed organic substances (such as polysaccharides, proteins, and extracellular polymeric substances) to agglutinate and form a soil micro aggregate or composite building unit are referred to as glueing agents. These glueing agents are building units that keep microparticles together, yet, they have the advantage of being more flexible.

Generally, SOC content for all treatments at 72 days is higher than at 24 days. This is attributed to the breakdown of large aggregates to small aggregates after prolonged wetting. Soil macroaggregates are complicated entities that primarily contain labile organic carbon (Veloso *et al.*, 2019). It has also been reported that the rates of the breakdown of carbon decrease with the size of different aggregate size classes, and the favourable influence of cover crops on the OC contents of soil aggregates reflected their participation in soil carbon storage.

According to Six *et al.* (2000), macroaggregates ($> 250 \mu\text{m}$) are formed on the recent addition of organic matter whereas stable micro aggregates and organomineral complexes are formed as SOM decomposes inside these macroaggregates (Gale *et al.*, 2000b). Microaggregates ($< 250 \mu\text{m}$) change over, more slowly than macroaggregates due to their smaller size and increased stability. As a result of the production of smaller, more stable soil fractions with increasingly intimate interactions between organic matter and mineral surfaces, macroaggregate formation results in longer Mean Residence Time (MRT) of SOM in soil with time.

Reduced SOC below the threshold level exacerbates soil structure deterioration, increases bulk density (BD), lowers aggregation, reduces soil moisture storage, reduces aeration, and affects grain production (Fageria, 2012, Fuentes *et al.*, 2009). The increased bulk density values at 72 days (Fig 4.1) is caused by the consolidation of particles after the daily wetting.

4.10. Water Retention Curve

At the low end of the matric potential, variations in the soil water retention curve can be used to infer structure and aggregate stability. Although the organic carbon content of SP at 24 days is slightly higher than that of SPV, SPV holds more water than SP at the saturation point (Fig 4.13). The perceived negative effect of this vermicompost on soil aggregation is not noticeable within a short time. However, after a long while, the rate of deterioration increased (Fig 4.7). Mamedov and Levy (2013) reported that these changes affect soil structure and thus, water retention.

When organic matter is added to clay soil, soil tend to act like sandy soil with increased macropore. Though compost materials have the potential to improve the hydro-physical properties of agricultural soils by increasing the size and number of soil pores (Reynolds *et al.*, 2009), increasing water retention, improving erosion resistance and reducing runoff (Aranyos *et al.*, 2017) yet, this study showed that soybean planting is more effective.

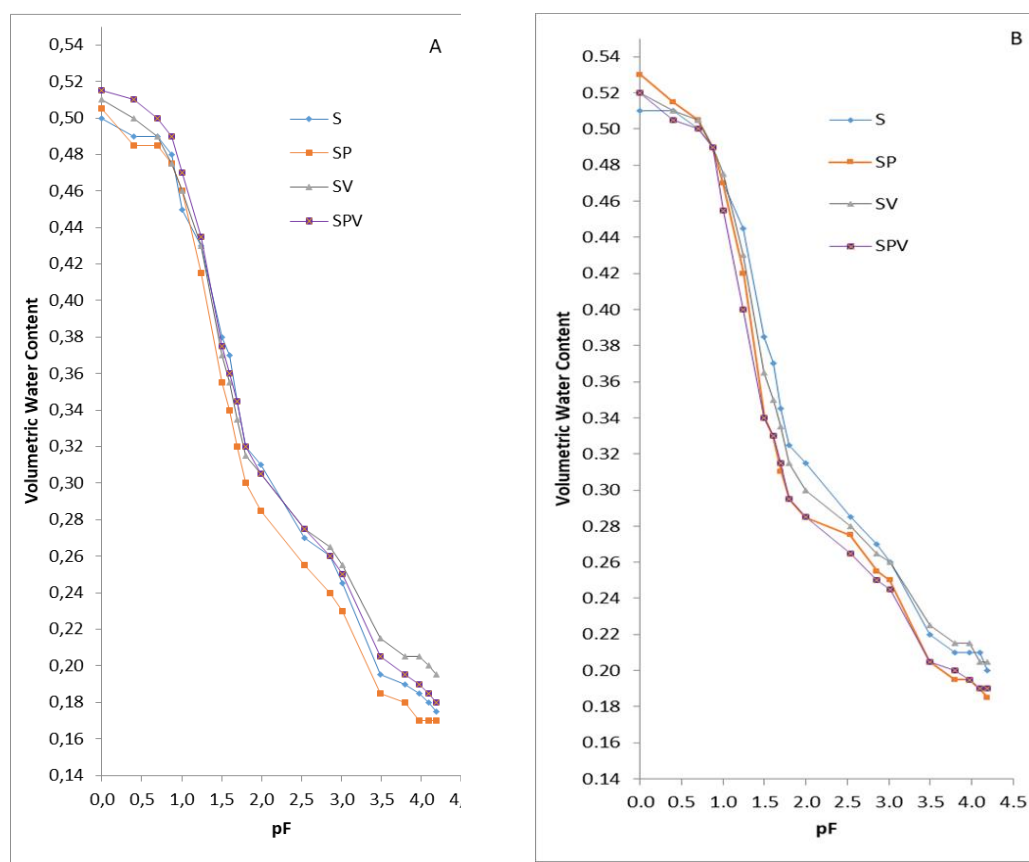


Figure 4.13. Soil Water Retention at (A) 24 days (B) 72 days

4.11. Plant Available Water Content

The moisture stored in or flowing through the soil affects structure, stability and erosion and is of primary concern to plant growth. SP in comparison to SPV at 72 days contains more PAWC water (Fig 4.14). The higher the water content, the larger micropores (capillary pores). Fig 4.15 give a vivid picture.

At saturation point, FC and PWP; SP (72 days) holds more water than SP (24 days) whereas, SPV (72 days) contains less water at FC and slightly no difference at Saturation point and PWP. Also, more macropores have been formed with vermicompost addition.

Soil water retention of the 72 days samples was higher under SP treatment for pF 0.0 and 2.5 Log (H₂O) pressures. Moreover, FC at 24 days was higher for SPV than at 72 days.

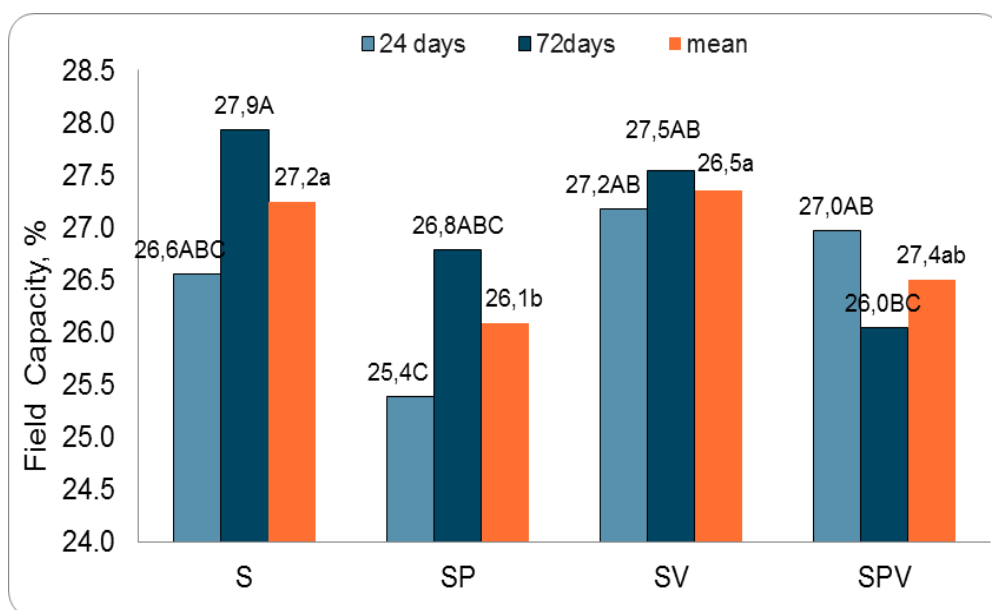


Figure 4.14: Interaction and Mean Values of Field Capacity during different sampling days under the management systems (control Soil, S; Soil with Soybean planting, SP; Soil with vermicompost addition, SV; Soil with Soybean plants and vermicompost, SPV). Upper case indicates interaction among factors ($p < 0.05$)

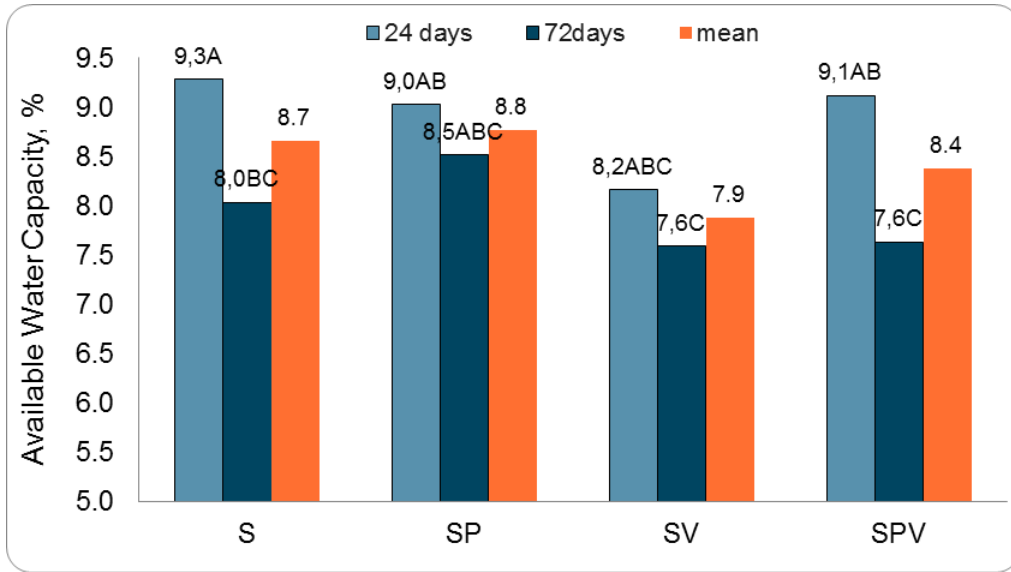


Figure 4.15: Interaction and Mean Values of Available Water Capacity during different sampling days under the management systems (control Soil, S; Soil with Soybean planting, SP; Soil with vermicompost addition, SV; Soil with Soybean plants and vermicompost, SPV). Upper case indicates interaction among factors ($p < 0.05$)

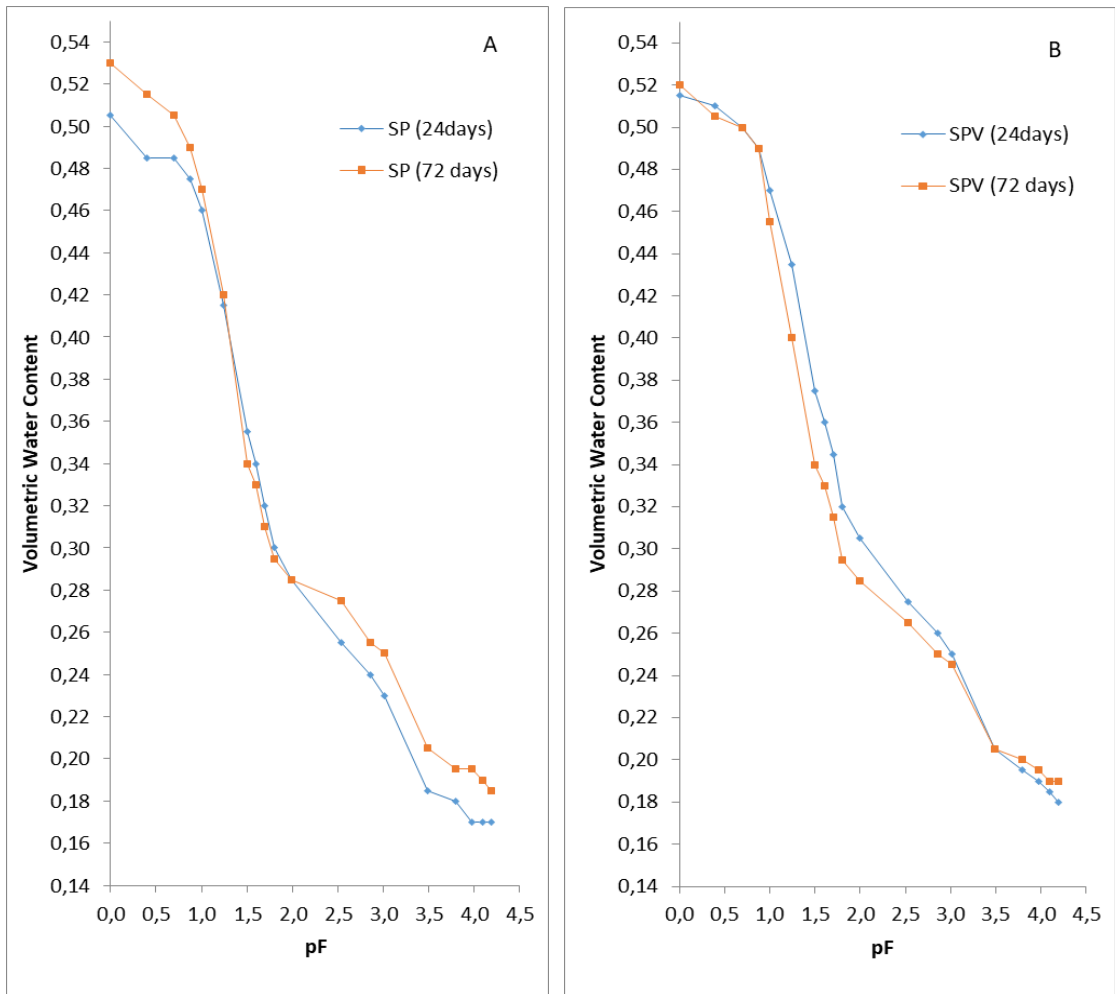


Figure 4.16. Effects of planting (A) and vermicomposting (B) treatments on water retention curves

5. CONCLUSION AND RECCOMENDATION

This study was conducted to investigate the influence of vermicompost application and soybean planting on the structural properties of clay soil over some time, 24 days and 72 days. The higher positive effects of bulk density, pore size distribution, and K_s were observed in treatment with soybean plant SP and SPV (24 days). It confirms the interrelationship between bulk density, porosity, and hydraulic conductivity. Also, the ability of soybeans plants improve water infiltration into the soil, lower runoff water velocity, and reduce soil erosion processes.

Soybean planting impacted structural parameters of soil better than sole addition of vermicompost. However, the combined effect of vermicompost and soybean plants is more effective than soybean planting without vermicompost.

Time is a factor in the stability of aggregates. Most macroaggregates are stable against destruction after 24 days. Moreover, continual wetting caused slaking and a release of its labile OC so that micro aggregates have higher SOC content, becoming colloidal particle of humus material. Additionally, the prolonged wetting process resulted in the consolidation of soil particles, creating a somewhat stable soil.

Most structural parameters are improved over a long period. Generally, a lower water content value of SPV at 72 days shows that SPV treatment is more well-structured. The combined effect of vermicompost and soybean plants is more effective than soybean planting without vermicompost.

It is intriguing to observe an increase in the rate of destruction, especially in vermicompost amended soil (SV and SPV). This is probably attributable to some properties of vermicompost produced from cattle manure which contributed to the destruction of soil aggregates. It is worthy to note that though vermicompost is termed as "exceptionally superior" to worldwide brands of conventionally produced and marketed compost, not all sources will have a good effect on soils. Further studies should be conducted on various sources of vermicompost such as cattle manure, peat, bark, and sewage sludge.

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