STUDY ON THE EFFECT OF DIFFERENT AGRICULTURAL PRACTICES ON SOIL QUALITY AND ORGANIC CARBON POOLS UNDER MAIZE IN SEMI-ARID REGION OF INDIA

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Soil Science

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2025

DECLARATION

I, hereby declare that the presented work in the thesis entitled "**Study on the effect of different agricultural practices on soil quality and organic carbon pools under maize in semi-arid region of India**" in fulfilment of degree of **Doctor of Philosophy in Soil Science** is the outcome of research work carried out by me under the supervision of **Dr. Nitin Madan Changade** working as an **Associate Professor and Head of Department**, in the **Department of Soil Science and Agricultural Chemistry, School of Agriculture** of Lovely Professional University, Punjab, India and co-supervised by **Dr. Thounaojam Thomas Meetei**, working as a **Teaching cum Research Associate,** in the **Department of Soil Science, College of Agriculture**, Rani Lakshmi Bai Central Agriculture University, Jhansi, UP. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE-I

This is to certify that the work reported in the Ph. D. thesis entitled "**Study on the effect of different agricultural practices on soil quality and organic carbon pools under maize in semi-arid region of India**" submitted in fulfillment of the requirement for the reward of degree of **Doctor of Philosophy in Soil Science** in the **Department of Soil Science and Agricultural Chemistry, Lovely Professional University, Punjab**, is a research work carried out by **Khaidem Jackson**, **(Registration no:12021201)**. To the best of knowledge and belief, the present work is the results of his original investigation and study. No part of the dissertation has ever submitted for any purpose at any university.

The report is appropriate for the fulfilment of the condition for the to the award of **Doctor of Philosophy** in **Soil Science.**

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ABSTRACT

Soil is an important natural resource whose existence determine the fate of different biogeochemical functions. However, the availability of this important resource is at risk due to overuse and mistreatment. The quality, health and other different functionalities have been reduced to such an extent and its recovery has been certainly neglected. To recuperate such loses, increasing the soil organic carbon (SOC) is a vital step to maintain the soil quality and its different functions. An increase in soil quality could determine the fate of soil physical properties, chemical properties, and soil biological functions. Our experiment was performed with a vision in mind for determining the best adoptable agricultural practices for increasing the soil health and quality. Moreover, balancing the SOC at an optimum level could improve the nutrient transformation process, which could enhance the productivity of crops and help in mitigating the climate change scenario as different agricultural practices used for crop production could either act as a great source of CO_2 or a great sink. Upon further consideration into the importance of SOC for maintaining environmental sustainability, cropland fertility and agricultural productivity, the current study was planned with the following objectives: (i) to evaluate the effect of different agricultural practices on the soil health attributes and developing a soil quality index (SQI); (ii) to study the variations in different pools of SOC under different agricultural practices; (iii) to study lability index of SOC; (iv) analyse the microbial populations and (v) determine the effect of different agricultural practices on the yield of Maize. The study was carried out for two seasons during Kharif 2022 and Kharif 2023 in the experimental field of Department of Soil Sciences, Lovely Professional University, Punjab. Ten different agricultural practices were employed viz. T1- Fallow, T2- Straw mulching, T3- Plastic mulching, T4- Minimum tillage, T5- Earthing up, T6- Paired row, T7- Broadcasting, T8- Ridge and Furrow, T9- No weeding and T10- Weeding with weedicide. The recommended dose of fertilizers was incorporated in the field and vermicompost @ 10 tha^{-1} was applied to each treatment in equal proportions at the start of the experiment. The different agricultural practices and tillage system had considerable effect on the SOC and its dynamics. The soil samples were taken from two soil depths (0-15 cm) and (15-30cm) at an

interval of 45 DAS, till the end of the experiment and analysed its soil physical, chemical, and biological parameters. This research investigated the complex relationship between agricultural practices and soil functions, elucidating the effects on physical, chemical, and biological properties. The examination of soil physical functions revealed consistent findings regarding texture, with the experimental field predominantly classified as sandy loam based upon the textural triangle and exhibiting stable textural characteristics throughout the study period. Sand fractions were higher, followed by silt and clay, and minimal fluctuations were observed throughout the study. Despite the least variabilities, soil texture remained relatively stable across treatments. Bulk density also developed no significant changes, influenced by tillage operations and environmental conditions at both soil layers. Chemical properties, especially pH and electrical conductivity (EC), exhibited dynamic responses to the different agricultural practices. Certain treatments induced a decline in pH which was more profound in the straw mulching (T2) with indicated results of from 7.58 – 7.19 and 7.30 – 7.14 from 45 DAS to 450 DAS at the respective soil depths (0-15 cm and 15-30 cm). The organic acids released during the decomposition of biomass could be the reason behind the change. EC fluctuated, which was attributed to vermicompost application and ion leaching, indicating potent effect of vermicompost decomposition as influenced by agricultural practices. Nutrient availability, which were fundamental for sustaining soil fertility and crop productivity, underwent significant changes. Av. Phosphorus (Av. P), and Av. Potassium (Av. K) availability displayed temporal patterns, initially increasing due to fertilizer and vermicompost applications, followed by fluxes attributed to crop uptake and nutrient leaching. The investigation of soil organic carbon (SOC) and its different fractions revealed significant implications for soil health and sustainability. Straw mulching treatment (T2) exhibited higher SOC concentrations, which were elevated by additional inputs such as vermicompost and organic mulches, stressing their role in enhancing soil carbon sequestration and microbial activity. The surface soil of T2 observed an increase in SOC content from 4.93 g kg^{-1} (45 DAS) to 6.87 g kg^{-1} (450 DAS) while the subsurface soil indicated values from 2.77 g kg^{-1} at 45 DAS to 5.53 g kg^{-1} at the end of the experiment (450 DAS). It was closely followed by minimum tillage (T4: 3.80 - 6.67 g kg^{-1} at 0-15 cm and 2.44 - 5.17 g kg^{-1} at 15-30

cm) and paired row (T6: 3.63 – 5.93 g kg^{-1} at 0-15 cm and 2.90 – 5.17 g kg^{-1} at 15-30 cm) treatments. Soil organic carbon stocks (SOCS) were retained most effectively in minimum tillage system (T4: 5.75 – 14.59 $Mgha^{-1}$) in the surface layers; and the straw mulching treatment greatly effectuated SOCS in the subsurface layers (8.92 – 24.35 $Mgha^{-1}$), further emphasizing the influence of agricultural practices on carbon storage. Assessment of soil quality index (SQI) elucidated the overall impact of agricultural practices on soil functioning. Straw mulching (T2) was determined to be the most effective treatment, exhibiting the highest SQI value across both surface (SQI: 0.957 at first harvest and SQI: 0.811 at second harvest) and subsurface soils (SQI: 0.853 at first harvest). The SQI for the subsurface soil at 2^{nd} harvest was determined to be higher in paired row treatment (T6: SQI - 0.848). Other treatments also contributed positively to soil quality, albeit to varying degrees, highlighting the variances of soil management practices and their impact on overall soil health and productivity. Crop yield assessments upheld the efficacy of straw mulching (T2) in enhancing productivity, with significant yield increases (5.03 tha^{-1} at first harvest and 5.76 tha^{-1} at second harvest) observed compared to other treatments. Paired row treatment (T6) also exhibited favourable yield outcomes, however to a lesser extent, indicating the importance of crop management practices in achieving optimal agricultural productivity. In conclusion, this study revealed the pivotal role of agricultural practices in determining soil functions and ultimately, agricultural sustainability. Straw mulching (T2) emerged as a highly recommended practice, demonstrating significant improvements in soil health, fertility, and productivity. However, it also acknowledged the contributions of the other treatments. Adopting practices that prioritize soil health and productivity will be essential for ensuring a sustainable agriculture with the evolving environmental challenges.

Keywords: Soil organic carbon, agriculture practices, soil quality index, soil health, sustainability, etc.

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Place: LPU, Phagwara

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Chapter 1: Introduction

India's food grain output has shifted from being in deficit to surplus since the start of the Green Revolution (GR) in 1960's. Since then, all focus has been on increasing crop yields through intensified agriculture, utilizing high yielding varieties (HYV) and inorganic fertilizers to support the higher nutrient requirements of HYV, all while ignoring the health of the soil. When HYV is used in conjunction with inorganic/synthetic fertilizers, the physical soil qualities eventually deteriorate, which has an impact on the soil's chemical, biological, and fertility state (Kumawat *et al.,* 2021). Overall soil health conditions have been shown to decline, which lowers the soil's innate ability to function and produce. The elevated cost of cultivation conjoined with the declining economic return have a significant impact on farmers' socioeconomic status as well (Steel *et al.,* 2024). The reduced levels of organic matter in the soil are either directly or indirectly linked to all these consequences of GR on soil and human health (Duddigan *et al.,* 2023). The return of organic matter (OM) and the soil's nutrient cycle are significantly impacted by the intensive farming methods used during GR. To achieve suitable soil physical characteristics, which will immediately improve chemical and biological properties with optimal nutrient cycling in the soil, it is vital to have an ideal amount of organic matter in the soil.

Soil organic carbon (SOC) can be viewed as a complex mixture that impacts certain soil properties as well as nutrient cycling. Its presence in the soil delivers a crucial part for extensive soil resource preservation and sustaining productivity in soils. An optimum accumulation of SOC is important to maintain or further enhance the physical, chemical and biological attributes in soil. It also provides a suggestion for sustainable use of soil since a decrease in the soil organic carbon to a certain extent will compromise soil physical properties and limit the mechanisms of soil nutrient cycling and ultimately the productivity. The formation of the SOC is directly associated with the alliance of organic carbon input and its consequent decomposition by the soil microorganisms (Bruni *et al.,* 2022). SOC is associated with the intensity of land use, type of soils, climatic conditions as well as vegetation cover of the area. In another word, the SOC content is directly proportional to the input of organic matter provided in a cropping system and its differential rates of decomposition (Voltr *et al.,* 2021).

Occurrence of organic carbon (OC) in soil is a key indication of quality and productivity index of soil. Soil is considered to be the largest carbon sink in the terrestrial ecosystem (Montagnini and Nair, 2004), and it culminates a capability in managing the global climate change. SOC pool is approximately 2.5×10^{12} tonnes in 2m soil depth which comprises about 57% of the total geological pool and almost thrice the atmospheric C pool (Lal, 2001). A recurrent change to the soil environment could enhance the subsequent chemical and biological activities. There have been instances of severe exhaustion of organic carbon, and this occurs predominant in the semi-arid regions. This is a leading factor in decline of soil health. The everchanging climatic pattern such as increasing temperature and irregular precipitation are primary causes for the loss of SOC. Therefore, focusing on maintaining the soil organic carbon levels at an optimal range could impart a positive effect in the long run (Ma *et al.,* 2023). Apart from this, SOC can induce the biogeochemical C cycle. Focusing on maintaining the soil health is fundamental for agricultural production and maintenance of a healthy ecosystem. Nurturing a good soil health could be a positive response to mitigate the climatic disruptions through reducing the oxidization of CO_2 and other greenhouse gases.

SOC content not only improves cropland fertility and agricultural sustainability but also protects the environment. Climate change could become the next big global disaster. It threatens to further impoverish developing countries with limited resources, by declining the field productivity and increasing CO_2 emissions into the atmosphere. Any minimal alterations in the innate soil activities could produce a profound influence on the concentration of CO_2 in the atmosphere (Liu *et al.,* 2014). Different fractions/pools of soil organic carbon present in soil have significant roles both in soil fertility and carbon reserve. So, SOC not only help to increase the crop production, but it also affects the present global climate change that has paramount influence in the biogeochemical cycles. The carbon storage in SOC is almost three times that of the atmosphere and this relationship is responsible for attenuating the climate change scenario. Any form of changes associated with the SOC stocks could have significant effects on the GHG emission and climate change at a global scale. Another important aspect of the SOC dynamics involves the augmentation rate and decomposition rate of the organic substrates incorporated to the soil. The carbon pools in soil are substantially larger than the combined carbon pools of biomass and atmosphere (Dheri and Nazir, 2021). Changes in the total organic carbon (TOC) is difficult to detect in a short time span since it is in a generally aggregated form with the soil. The OC in soil has a heterogenous constitution. SOC can be classified into active and passive pools which is calculated in accordance with its turnover rate. The active (labile) pools are generally sensitive to any land use changes, and it could serve as a good indicator to define agricultural management effects in soil TOC. The implications and dynamics of SOC has been gaining momentum in recent years for ramifications of the global climate change scenario along with crop production (Deb *et al.,* 2015). The turnover rate of soil organic carbon is minimal in the terrestrial ecosystems (Luk *et al.,* 2021) and for this reason, carbon sequestration in soils has prospects for alleviating the CO_2, a major greenhouse gas in the atmosphere (Rodrigues *et al.,* 2023). But, in India, the organic carbon content of soil is generally low varying from region to region owing to higher decomposition rates. So, it is a prime concern for the tropical and subtropical regions to intensify the organic carbon content in soils where soils are intrinsically low in OC. Different agricultural practices used in crop production have different pools of SOC that affect soil health, soil fertility, soil retention, carbon reserves, microbial population and carbon sequestration. Organic residues or debris when utilized as a mulching material enriches fertility status, attenuates soil degradation and augments soil health. The decreased productivity in a cropping ecosystem could be a result of water scarcity which is prevalent in the arid and semi-arid climatic zone. To bring about stability in the global production scenario, surface mulching with organic debris has phenomenal effectiveness to retain soil moisture (Wang *et al.,* 2016). Soil water retention also had a phenomenal increase by about 30 mm with an effective straw mulch @6000 $kgha^{-1}$ (Liu *et al.,* 2013).

Management practices to inculcate enhancements in the SOC involves changing the agricultural land use practices. The arid and semi-arid climatic zones receive a special characteristic in temperature and precipitation. Therefore, specific agricultural practices must be evolved to manage the SOC dynamics under such conditions. Soil is a dependent variable in achieving the UN sustainability development goals (Keestra *et al.,* 2016). Carbon plays a pivotal role in supporting the hydrological, geological and chemical functioning of a soil system (Monreal *et al.,* 2018). Agricultural soils are more susceptible to any changes pertaining to these functions (Novara *et al.,* 2017). Tillage practices involving use of mechanical farm tools such as cultivators, mould boards, disc ploughs etc., may loosen the surface soil. However, it would eventually lead to aftereffects such as compaction, increase in bulk density and mineralization of carbon. These causes reduction in the SOC stocks, minimized soil water retention and undesirable changes to the soil microbiome. Such risks could be mitigated with changes in the agricultural practices such as minimal tillage, organic matter incorporation and other conservation practices. For example, straw mulching has been observed to provide an increase in the soil quality than plastic or no mulch treatments. Also, the SOC, total NPK and fungal activities were greatly enhanced with implementation of straw mulches (Chen *et al.,* 2021). Other advantages as indicated by certain researchers include improvements in soil structure and aggregation, decreasing the bulk density, reduced erosions, maintaining optimal water retention capacity. All factors could potentially lead to an increased productivity in field crops (He *et al.,* 2011; Choudhary *et al.,* 2018). Additionally, providing a fallow period is also considered as a natural mechanism that could provide recuperation time to an exhausted soil and restore its lost nutrients and microbiome. The physico-chemical and biological soil properties could also be reclaimed during a fallow period (Gikonyo *et al.,* 2022).

The comprehensive study of different agricultural practices on SOC pools will help to understand the choices about the most beneficial agricultural practices to utilize. So, different agricultural practices used for crop production can be a great source of CO_2 or a great sink. In agriculture, maintaining SOC content is very difficult due to its dependence on climatic factors as well as with the agricultural practices used for crop production (Khangura *et al.,* 2023). Organic constituents in soil are intrinsically very low in the arid and semi-arid region of India, which may be due to certain factors; but among all, temperature is of prime importance. The applied organic matter or litter returned to the soil will be decomposed at a much faster pace in comparison with temperate regions (Findlay, 2021). So, it is now time to understand that we cannot restrict the decomposition of organic matter, which is actually a naturally phenomenon, but in a way, we can manage and control the decomposition rate. Any practices that can reserve the organic carbon content in soil can be boon to agriculture and environmental sustainability. Furthermore, reserving applied organic constituents in soil is an important factor for crop production and food security, and also its amount that has been mineralised/transformed to nutrients. So, it is important to discern the agricultural practices which can reserve the applied organic constituents to soil as well as nutrient sustainability. Therefore, finding out the agricultural practice(s) on different pools of SOC and developing soil quality index (SQI) will be necessary for soil and environmental sustainability for achieving global food security.

Research Gap

The importance of SOC content in soil has limitless application. So, different research on SOC has been done by different author(s) so far in relation to sustainable agriculture, conservation agriculture systems, organic farming and integrated nutrient management. But very few worked under different important agricultural practices which are a primary concern for better crop production and achieving global food security. Many also have worked under different agricultural practices but in relation to soil biodiversity, ecosystem services and with few factors. Very limited research has been done so far under SOC pools in relationships with its retention and dynamics under different agricultural practices.

Hence, to identify the agricultural practices that maintain an optimum amount of SOC and improve the nutrient transformation process (quality) will not only help to boost up the productivity of crops for global food security, but it will also reduce the present global climate change scenario as different agricultural practices used for crop production can be a great source of CO_2 or a great sink.

Research Objectives

Keeping in view the importance of SOC in maintaining environmental sustainability, cropland fertility and agricultural sustainability, the study is planned with the following objectives.

1. To evaluate the effect of different agricultural practices on soil health attributes and develop soil quality index (SQI)
2. To study the variations in different pools of soil organic carbon (SOC) under different agricultural practices
3. To study the influence of different agricultural practices on the lability index of SOC
4. To investigate the microbial populations in soil under different agricultural practices
5. To study the effect of different agricultural practices on the yield of Maize

Chapter 2: Review of literature

2.1 Agricultural land use practices:

Land use practice involves the utilization of different tillage operations such as traditional ploughing, no-tillage and conventional tillage practices. Since the soil organic carbon content and soil organic matter has been declining over the years due to various factors like improper tillage practices, poor residue management, intensive farming, burning of biomass, etc., it can be deemed necessary to study the changes in soil organic carbon with respect to various tillage methods. A shift in the soil's carbon balance and an acceleration of SOM mineralization occurs with the intense utilization of agricultural lands. Recycling organic matter supply has been deemed necessary for increasing health and quality of soils. Defects in traditional tillage system can be observed pertaining to the loss of SOC; however no-tillage (NT) and conventional tillage (CT) systems offer a sustainable advantage for storage of SOC. This leads to the belief that transition to no-tillage systems can significantly curb the carbon emissions into the atmosphere (Minnikova *et al.,* 2022). Implementing sustainable soil treatment techniques, such as crop rotation, biofertilizers, and tillage methods (less tilling, no-tilling, etc.), it is probable to improve the carbon in soil to the requisite amounts. It was also reported that soils used for grazing and arable crops may accumulate up to 2.4 x 10^{12} g C due to the organic carbon deposited at a rate of 0.8-1.2 x 10^{12} g C.

The soil organic matter content greatly influences different properties of soil including nutrient cycle (Loveland and Webb, 2003). Alternatively, the soil type, land use practices, climate and vegetation cover are some factors that affect the retention of this complex mixture. A retrospective evaluation on this matter can justify that an intense drop in the SOM content in soil can hamper the productive capability of soil along with the disability of soil nutrient cycling structures. Due to the intensification of agriculture and green revolution in the twentieth century, there has been massive increase in yield of cultivated crops; however less attention was given to the SOM stock (Feller *et al.,* 2012). This led to the degradation in the resilient foundation of an ecosystem. So, enhancing the SOM should be given prime importance as long term sustainability is directly proportional to the maintenance of organic carbon (OC) levels in soil (Manna *et al.,* 2003). Organic farming system incorporates carbon-based substitutes which practically increases biological functions while improving the soil physical properties and plant condition (Reeve *et al.,* 2016).

Productivity of crops and soil carbon sequestration can be related to conservation tillage (CA) practices and nutrient managing outcomes. The global food security is on a decline due to improper soil health and major causes for this are the diminution in the soil carbon pools as well as nitrogen pools. Also, the decrease in these pools has been led by intensive tillage practices alongside improper residue and nutrient management (Topa *et al.,* 2021). Intent on explaining the relationship between tillage practices, productivity and carbon sequestration potential in soils, an experiment was conducted on rice-rice system in the north-east region of India. Combination of tillage practices viz. conventional system, reduced system, and non-tillage, incorporation of residues and retention of residues were considered. Results showed highest productivity in combined treatment of reduced system + integrated plant nutrient management + retention of residues in wet season and conventional system + integrated nutrient system + rice intensification in dry season. Maximum biomass, C and N were reconditioned into the scheme from the above treatments. Also, the treatment has the lowest BD (bulk density), highest SOC and N pools, C retention efficiency and improved soil microbial biomass (Yadav *et al.,* 2017). A change from traditional/conventional tillage to conservation/sustainable tillage system can increase SOC significantly (Abbas *et al.,* 2020). Also, no tillage practice along with application of mulch can implicate higher SOC stocks, lower carbon losses from soil. Similarities can be observed that reducing tillage operations is a means to effectively maintain SOC content.

Relatively speaking about conservation agriculture (CA), a study on CA towards soil carbon dynamics and sustainability provided explorations on the soil's physical, chemical and biological characteristics and there was notable increase in the SOC content when compared to conventional systems. Additionally, there was observed growth in both the labile (which undergoes rapid changes) and non-labile carbon (which are stable) fraction in CA system over CT. This could indicate a higher microbial biomass in the soil. Also, the physical factors viz. effective root depth, soil texture showed good status in the sustainability index (Bhattacharya *et al.,* 2020). All these factors point toward CA as a sustainable arrangement for soil health.

2.1.1 Interrelation of soil organic carbon and different land use practices

A study done in North Dakota on surface soil (0-15 cm) evaluating the effects of combining two irrigation strategies (irrigated and non-irrigated) with six cropping systems; plant biomass carbon was increased in a field that received no nitrogen fertilization but was not fertilized (Sainju *et al.,* 2010). As mentioned by Frank *et al.,* 2006, grasslands have larger root systems and higher quantities of soil organic carbon than croplands, which causes them to breathe out more CO_2. The SOC level can be lowered by converting grasslands to croplands as a result of CO_2 emissions. Owing to higher cropping intensity in the no-till system, the organic carbon (OC) increased through the adding of C in the system. This developed reductive oxidation owing to lack of tillage/cultivation practice (Mikha *et al.,* 2006; McVay *et al.,* 2006). It could be implied that soil aggregation could be used as a way to reduce the amount of CO_2 in the air.

Dependent on land use systems, planting system, and soil management techniques, soil is systematically regarded as a potent source or a great sink of atmospheric carbon (West & Marland, 2002; Lal, 2003b; Singh & Lal, 2005). Improved aggregation in soil management could be an essential strategy for both reducing atmospheric CO_2 emissions and soil C sequestration (Shrestha *et al.,* 2004; Bronick & Lal, 2005). Changes in land use from forest to other land cover resulted in increased bulk density, decreased water conductance, and increased soil loss, which degraded the soil functions while also decreasing the proportion of soil organic matter (SOM) (Lal, 2003a). SOC concentration and physical characteristics were similarly impacted by farming practices (Hao *et al.,* 2001). Perennial grass cover also enhanced the extent of carbon in soil (Post and Kwon, 2000). Conversely, cropping system modifications had an impact on the soil C stocks (Akala & Lal, 2001; Lal, 2004).

According to Puget and Drinkwater (2001), improved soil C storage and its housing time in soil were partially related to the decomposition of roots and grasses. In the study by Chevallier *et al.,* 2004, SOC was shielded by the production of soil micro and macro aggregates in root substrates. The soil carbon storage may be improved through minimized tillage and fertilizer management (Lal, 2004). Higher residue producing crops exceeded lower residue crops in terms of SOC production. It generally requires an extended period to restore soil C to its original level when it has been lost owing to alterations in land use practices. Modifications in land use could impound a significant change on SOC stock (Guo and Gifford, 2002; Paul *et al.,* 2002). Deforestation caused carbon losses that took 40 years to recoup from their gradual accumulation. It was proposed that following afforestation, initial stock levels needed to recover for at least 80 years.

A beneficial approach for sequestering carbon is zero-tillage agriculture (Post *et al.,* 2004; Bernacchi *et al.,* 2005). A fundamental element for the variability of nitrogen in soils is the SOC stock. The main contributor for raising the emissions of green-house gases (GHG) into the atmospheric system could be the migration of natural vegetation to agricultural land (Ruddiman, 2005). Cropping systems, agricultural techniques, and land use system selection can all greatly reduce greenhouse gas emissions. Implementing a conservation agricultural system could promote preservation of atmospheric CO_2 in the soil (Bernoux *et al.,* 2006). This process was previously referred to as carbon sequestration. Since improper management has caused the soil to lose organic matter, degraded soil has a higher potential for sequestering carbon (Lal, 2004).

2.1.2 Agricultural land use system in relation to soil organic carbon

The agricultural sector could potentially be of assistance in reducing the amount of CO_2 in the atmosphere by photosynthetically fixing carbon inside the crop biomass. Productivity has been improved as a result of increasing crop biomass and crop residue returning to the soil system (Burney *et al.,* 2010). Crop productivity improvement has certain capacity to improve SOM. Adopting conservation measures could promote SOM and cause the soil to function as a sink for carbon (Lal, 2003b; West and Post, 2002).

On the other hand, tillage had little influence on SOM accumulation in soil depths more than 30 cm (Baker *et al.,* 2007). Reduced tillage in agricultural soil can minimize labor costs, lower equipment maintenance, lessening utilization of crude fuels, and induce an improvement in soil-water conservation, all of which contribute to agricultural sustainability (Lal, 2001a). Numerous field studies demonstrated that conservation tillage elevates fractional organic matter, which is considered as a transient, unstable C fraction (Fabrizzi *et al.,* 2003; Liebig *et al.,* 2004).

Increasing crop rotation diversification and switching from conventional tillage to no tillage practices in agricultural management could lead to a boost in soil carbon buildup (West and Post, 2002). A wide range of factors may affect how much agricultural practices alter SOC storage, including the initial SOC levels and the system's SOC saturation level; soil properties including soil texture and soil aggregation (Six *et al.,* 2004); drainage and crop productivity; climatic conditions and time. Conferring to research by West and Post (2002), an alteration in tillage system (conventional to no tillage) can confiscate over 60 $gCm^{-2}yr^{-1}$. In terms of agricultural soils serving as sinks to reduce growing atmospheric CO_2 levels, the coalition of SOC beneath the surface soils was substantial for soil activities like nutrient seeping or microbial proliferation.

Experiments were carried out at modern fallow farming practices in Guatemala's Western Highlands. The soil in cultivated plots had significantly greater levels of nitrates and 25% more SOM than soil in fallow areas that were created when farmed areas received inputs of compost and inorganic fertilizer (Wittman *et al.,* 2008). An analysis of the effects of converting subsequent fallow lands to organic agriculture on total organic carbon (TOC) at 0-10 cm soil depth revealed a substantial reduction in TOC upon conversion of subsequent fallow to cultivable land (Böhm *et al.,* 2010). Chen *et al.,* 2010 studied three land-use types: natural grassland, crop-field, and discarded old-field of 10 years-in the northeast region of the Tibetan highland to determine how land-use affected the microbiological and soil properties. Upon comparing cultivated to wild grassland, it was discovered that depletion of organic soil carbon (SOC) and total nitrogen (TN), among others, were roughly 45 and 43%, respectively. SOC and TN increased by 20-23%, depending on how long the land was left fallow. Additionally, it was found that farming reduced the amount of organic material and bacterial biomass in the soil. For assessing the effect of land abandonment for the rehabilitation of fertility of tropical farmland, soil microbial biomass Carbon was measured along several age series of abandoned cultivated fields over various fallow periods. The findings demonstrated that, dependent on the time frame of fallow, the microbial biomass characteristics (C, N, and P) varied significantly ($p<0.05$) across all sites, depths, and months (Haripal and Sahoo, 2014).

2.2 Changes in Soil Quality and Soil Quality Indexing:

Soil has been considered to the backbone of agriculture and all other land use practices. In general terms, soil quality could convey the potentiality for a soil function in response to a spatial distribution of land use and ecosystems, such that biological activities can be sustained along with environmental health (Karlen *et al.,* 1997). A report in the National Research Council pointed towards the value of soil quality towards sustainable agricultural system. The report stated that soil quality should be protected just like protecting air, water quality and it should be the primary goal of national environmental policy. Assessment for the condition of soil and its sustainability may be derived from the concepts of soil quality (Doran and Jones, 1996). This can serve as a guide for further research in soil, planning and conservation. Despite this, some authors argue that it is narrow-minded to consider soil quality for such purposes (Sojka and Upchurch, 1999). Disrupting such claims, Davidson (2000) found that soil quality and soil management practices go hand in hand. The very concept of sustainable land use, increase in productivity and environmental safety arises from soil quality.

Soil comprises numerous physical, chemical and biological variabilities. All these parameters are actively involved in its functioning. So, to define the soil quality, all of these characteristics need to be evaluated (Maurya *et al.,* 2020). But soil being dynamic in nature, any disturbance in soil can inculcate a change in their innate nature. These physico-chemico-biological entities can serve as indicators in soil health. For example, soil bulk density differs in soils of different texture but within a given soil system, it can provide insight on relative soil compaction and puddling (Prabha *et al.,* 2020). However, assessment of soil quality on basis of its inherent characteristics along with dynamic nature of soil system can provide a much better evaluation for balanced land use and managing practices (Nortcliff, 2002).

For maintaining or improving soil quality and meet our growing requirements for food, feed, fiber, and fuels, it is imperative that soil resources be periodically assessed (Cherubin *et al.,* 2016). A report by Karlen *et al.,* 1997, quality of soil indicates aptitude for a particular soil type to maintain biological efficiency, conserve or improve the quality of the surroundings, and contribute to social well-being while enhancing living conditions within an ecosystem. Soil quality assessment can provide useful information to detect negative or positive variations in physico-chemical and biological attributes due to diverse land-use systems by directing agricultural landowners toward environmentally friendly land use and analysing soil nutrient requirements (McGrath and Zhang, 2003). According to Karlen and Stott (1994), soil quality indices are instruments for evaluating options that efficiently integrate a data range for numerous criteria for making decisions. Scientists, researchers have created a number of equations and evaluation frameworks for determining the soil quality index and determining the shifts in land usage which affect the overall condition of soil.

Agricultural production along with the innate ability of soil to supply nutrients have historically served as the main subjects of soil quality research. However, recent research has indicated that quality of soils is not to be directly quantified; instead, it has to be surmised from various attributes and measurements of soil quality, which are dependent on various external factors like land-use systems and management, ecological and environmental interactions (Doran *et al.,* 1996). These soil attributes are crucial for regulating water flow and storage, providing a suitable medium for plant growth, and buffering the soil and environment from harmful compounds. They also assess the after-effects in soil management, such as increase in biomass accumulation, water utilization effectiveness (Larson and Pierce, 1991). As stated by Shukla *et al.,* 2006, these soil quality indicators can assess land-use sustainability and soil management techniques in an agro-ecosystem.

Brejda and Moorman (2001) reported on the performance of these indicators under various nutrient management techniques, land-use, or conservation activities to ascertain if soil quality is steady, improving, or declining. Although there are several indicators available to evaluate the health of the soil, interpreting them might be challenging (Karlen *et al.,* 1997). According to Nortcliff (2002), among the many soil quality indicators that are available in the soil, research is necessary to determine which one is the most appropriate. Furthermore, it was emphasized that in order to avoid disparities in values between data sets when comparing soil quality indicators, well-defined methodologies must be employed. As a way to broaden on the information on soil quality functions acquired from individual parameters, numerical indices must be used as synthetic tools. These soil quality indicators were divided into four groups by Dalal and Molony (2001): visual indicators, physical indicators, chemical indicators, and biological indicators.

When soil characteristics are combined for creation of integrated quality indices, more information regarding soil quality is obtained than when using separate parameters (Sharma *et al.,* 2014). As useful markers for improved soil quality, improved macropores, cumulative stability and distribution, high SOC, low bulk density, soil resistance and resilience, erosion, and nutrient runoff were noted (Parr *et al.,* 1992). The main indicators for alluvial soils, according to Choudhury *et al.,* 2018, should be mean weight diameter, accessible P, total soil N, and dehydrogenase activity. Karlen *et al.,* 1997 highlighted the significance of biological indices, such as respiration and SMBC, as functional soil quality indicators in relation to longstanding land utilization and approaches to soil management. The selection of indicators differs from site to site since soil quality measurement is purpose- and site-specific (Shukla *et al.,* 2006).

The optimal management approach for production portfolio in vegetables in North-California was determined through an evaluation of the various methods of soil quality indexing (Andrews *et al.,* 2002). The several approaches for comparing the steps in soil quality were: To choose the nominal data set of sensitive soil quality indicators (MDS), expert opinion and principal component analysis (PCA) approaches, were used. Indicator value normalization utilizing both linear scoring functions and non-linear scoring functions. To calculate final SQI, 3 factors are considered. In every combination of indexes, the organic system achieved notably higher scores on the soil quality index (SQI) than the conventional systems. All indexing combinations showed comparable results when compared with the comprehensive multivariate approach. It implies that choosing appropriate soil quality indicators though minimal in numbers, after incorporation into a straightforward index, can sufficiently specify the essential information to identify the optimal management strategy.

The conversion of cropland to forest land after 23 years of cultivation and to orchard land after 7 years of cultivation restored soil structure by raising soil macro-aggregates (9 and 10%, respectively) and their stability, which raised soil quality scores. In a Himalayan watershed, Mandal et al, 2010 gauged the soil quality in relationship to five primary soil functions as impacted by land-use and landscape systems. The findings showed that, in comparison to the reference site, a proportionate change in soil functions under terraced croplands was seen at each landscape position.

Sharma *et al.,* 2017 examined the soil quality indicators in a multivariate soil and nutrient managing techniques in a longstanding dryland agriculture experiment conducted in Akola, Maharashtra. According to the study's findings, applying 25-kilogram potassium ha^{-1} + 50-kilogram Nitrogen ha^{-1} from Leucaena plant biomass kept the soil quality index far higher (2.10) than doing so with FYM (2.01), which applied 25 kg Nitrogen + 25 kg Potassium + 25 kg Phosphorus per hectare. Among the many markers of soil quality, soil organic carbon made up the largest percentage (28%) and was followed by accessible potassium (24%) and microbial biomass carbon (25%) respectively. The impact of several management approaches on soil functions using soil quality indexing were also studied by Fernandes *et al.,* 2011. It was found that the minimum tillage system had the highest soil quality index (0.86) subsequent to conventional tillage (0.79) and no-tillage (0.68). The no-tillage system had the lowest soil quality index. The increased soil quality index in minimum tillage and conventional tillage systems was mostly attributed to the macro porosity and soil capacity for root development.

Rahmanipour *et al.,* 2014 carried out a comparative analysis of the two distinct approaches to soil quality indexing, taking into account the minimal data set (MDS-through PCA) and the whole data set (all the studied soil characteristics included as soil quality indicator-TDS). The findings showed that the integrated quality index (IQI) provided a more accurate estimate. As a result, the integrated quality index produced using MDS may be a suitable technique to create a quantitative approach of evaluating how land use and management practices affect soil quality. By reducing the number of soil parameters in the indicator data set and enabling higher sampling densities to provide a more thorough evaluation of soil quality, the MDS technique also decreased the cost of soil analysis.

Ngo-Mbogba *et al.,* 2015 estimated the different soil properties and quality under certain land use systems in South Cameroon. It was found that the most suitable indicators of soil quality were soil pH, available phosphorus, soil organic matter, and calcium. These indicators explained 88.5% of the changes in soil quality. The soil quality indices were calculated using data sets of thirteen (SQI13), four (SQI4), and two (SQI2) soil quality indicators in different ways. It was discovered that, despite similar trends, there were absolute changes among SQI13, SQI4, and SQI2. Nevertheless, depending on the region and accessible soil variables, the minimum data set size or the number of indicators may vary. Soils which were incorporated with burnt biomass described the maximum soil quality index score, which were subsequently succeeded by soils with unburnt biomass, primary forest, secondary forest and fallow land cover. Gelaw *et al.,* 2015 studied the soil quality indices (SQIs) for a variety of cultivated land uses and found that the agroforestry land-use system had the highest SQI score (0.58) compared to rainfed and irrigated crop production systems (0.47) and 0.51) respectively. Overall soil porosity (SP), total nitrogen (TN), microbial biomass carbon (MBC), water-stable aggregates (WSA), soil organic carbon (SOC), and cation exchange capacity (CEC) were the main factors influencing the integrated SQI values. When combined, these six recognized critical indicators of soil quality accounted for approximately 80% of the SQI total scores.

For the determination on soil quality as an outcome of various tillage practices and different drainage systems, Nakajima *et al.,* 2015 evaluated the soil-quality indices (SQI) using a scoring function analytic procedure. The most significant and selective indication for determining soil quality was found to be saturated hydraulic conductivity, which is a function of soil physical qualities, and soil organic carbon, which is a function of soil chemical properties. There was no statistically significant difference between the two treatments for the soil quality index, which ranged from 0.69 to 0.71 in conventional tillage and no-till systems and from 0.69 to 0.70 in drainage and no-drainage systems.

On the other hand, SQIs and maize production showed a substantial correlation (r = 0.62), indicating that SQI is the best metric for assessing agronomic efficiency. The soil quality indices (SQIs) for various land-use systems in Nepal's Panchase region were established by Kalu *et al.,* 2015. Findings exhibited that the bari land-use had the lowest SQI (0.79), while the protected forest system had the greatest SQI (0.95), succeeded by the public forest (0.91), pastureland (0.88), and agriculture land (0.81). The best soil quality indicators that produced a discernible variation in the SQIs between the various land-use systems were the available phosphorus and soil organic carbon. Greater vegetation and minimal human interference in forest areas result in higher-quality soil; conversely, increased human activity in the agricultural land-use system degrades soil quality. Additionally, the soil quality index (0.87) for native vegetation land-use was higher than that of sugarcane (0.74) and pasture (0.70) land-use systems (Cherubin *et al.,* 2016). The evaluation of the soil quality indices under the current land-use change sequence in southern Brazil. Both visual assessment of structure scores and soil organic carbon stocks were also employed to appraise any changes to the soil quality of the study, and the soil quality index calculated using SMAF showed a substantial correlation.

The soil quality index under Grewia optiva-dominated agroforestry systems was evaluated by Kaushal *et al.,* 2016. They discovered that the fallow land-use system (0.32) had the lowest soil quality index, while Grewia + Finger millet (0.47) and Grewia + Barn yard millet (0.47) had the highest index. Furthermore, Vasu *et al.,* 2016 employed soil profile data from recognized soil series for the areas in Deccan plateau, India, to develop soil-quality indices (SQIs) based on two different approaches. They found that the weighted method, which generated the SQI by principal PCA and EO, was positively correlated with the yield function of crops. Nevertheless, the SQI obtained using the EO weighted index approach was dependable in its association with crop yield, indicating its better performance than PCA, and equivalent for both surface (0-15 cm soil depth) and control sections (0-100 cm soil depth). An improved understanding of the relationship between SQI and specific soil functions as well as management goals is established by taking into account both soil depth and its associated parameters while evaluating SQI.

For a prevailing farming arrangement under rice-rice system, Biswas *et al.,* 2017 conducted a study to establish the soil-quality indices (SQI's) and categorise the important and sensitive soil-quality indicators. The study's conclusions showed that Inceptisols (0.66 - 0.89) defined the maximum soil quality index (SQI) than Entisols (0.23 - 0.76) and Alfisols (0.37 - 0.60). Within the context of the 37 soil quality parameters that were studied, the most sensitive key indicators were found to be Av. Zn, BD and urease activities in Inceptisols; DHA, soil aggregate stability parameter, TOC, and soil pH in Entisols; and SOC, soil aggregate stability parameter, and labile carbon in Alfisols.

Ghimire *et al.,* 2018 observed the different soil quality indices (SQI's) in various land use systems of the Nepalese Chure area. It was observed that the forestry land use system managed the highest SQI (0.82), while the degraded lands had the lowest (0.40). Bari and khet had decreasing trends in SQI (0.66) and 0.64, respectively. The main factors influencing SQIs under various land use systems were organic matter and total nitrogen present in soil; whilst, the usage of more chemical fertilizers and intensive plowing techniques was linked to lower SQIs in agricultural land-uses. Fertilization with phosphorus increased the no-till system's effectiveness in raising soil quality indices (Souza *et al.,* 2017). The most efficient way to maintain and restore soil quality and ecosystem sustainability is accomplished by enhancing soil microbial biomass, aggregate stability, soil respiration, and microbial and faunal diversity in soil (Ebabu *et al.,* 2020). This can be accomplished through the coordinated utilization of lands with proper and suitable land management practices.

2.3 Soil health condition and climate change scenario:

As far as history is concerned, human activities along with climate change have been two sides of the same coin and has vastly influenced the physical characteristics of soil and its pertaining biogeochemical processes (Grieve, 2001). These changes impact the terrestrial and aquatic ecosystems directly or indirectly. The soil organic carbon (SOC) is considered as a crucial indicator for soil health, and it is vital in managing physico-chemical along with biological functioning of soil. The soil organic carbon (SOC) encompasses about fifty percent of soil organic matter (Pribyl, 2010) with the labile and recalcitrant fractions being the major components (Dalal and Chan, 2001). The carbon stock in soil is relative measure of the sequestered carbons and emitted carbon from soils in the form of CO_2 and CH_4. These affect the global environment and rationally change the global climatic conditions (Allen *et al.,* 2011).

The global CO_2 concentration in the atmosphere has increased by 39% and has exceeded 390 ppm over the last 65,000 years (IPCC, 2007). The mean global temperature has increased by 0.76 ± 0.19°C due to increment of global CO_2 concentration and other greenhouse gases. This has severe impacts on the ecosystems. The OC concentration is also severely depleted, and this is more significant in the arid-semiarid tropical regions due to their high temperature. The change in climate on a global scale especially high temperature and unpredictable rainfall hugely impacts the OC concentration in soils. Soils have a high level of Carbon storing capacity which is about 3 times the volume stored in other land-dwelling ecosystems. The SOC delineates a central part in the global Carbon cycle. An increase in SOC content within the soil system may be able to mitigate global climate change.

Climate, microbes, plants, terrain, and time imposes substantial influence on the concentration of C in soils. The soil-carbon equilibrium can be altered by fluctuations in the climatic conditions and its different management strategies. Climate impounds a substantial effect on the soil organic carbon repository. A noteworthy cause for the 3.5% carbon reserve globally was originally believed to be from the soil. Due to changes in the climatic conditions, the global average temperature has increased during the past century, resulting in heat waves, droughts, and high precipitation. Global climate change is primarily caused by green-house gases (GHGs) namely, carbon dioxide (CO_2) and methane gas (CH_4) (Purakayastha *et al.,* 2007, Murty *et al.,* 2002). Given their high carbon storage capacity, soils have the ability to function as atmospheric CO_2 sinks. Prior research (Raymond and Bauer, 2001) has demonstrated that soil organic matter contains three times the amount of carbon as that found in terrestrial vegetation. The residence mean times of soil C are also greater than those of vegetation C. According to Wang and Hseih (2002), this process of sequestering carbon in soil could also be referred to as the organic carbon's longer-term storage in soil. Assessments were performed to compute soil carbon content and its minimum residence durations for particular regions in order to learn more about rising atmospheric CO_2 and its potential impact on future global climate change (Fung *et al.,* 2005; Matthews *et al.,* 2005).

The impact of greenhouse gases has raised a lot of concerns over the past ten years, which has prompted numerous investigations on the composition, distribution, quality, and behaviours of SOC. Numerous quantitative estimates of the global carbon content of soil have been produced as a result of increasing global temperature and its impact on soils with regard to SOC. As specified by Eswaran *et al.,* 1993, the estimated worldwide supply of SOC at this time is 1,500-1,550 Pg. Based on 48 soil samples, the initial evaluation of the organic carbon content in soils of Indian sub-continent was 24.3 Pg (1 Pg equals 10^{15} g) (Gupta and Rao, 1994). Due to its greater organic matter concentration, forest soils are considered as the planet's principal sinks of carbon. Forest ecosystems have about 40% of the world's entire store of SOC. Based on changes in soil organic matter, soils can either operate as sources or sinks of carbon in the atmosphere. When land usage is altered, the intricate equilibrium between the pace of organic matter supply and the pace of decomposition is upset (Lal and Bruce, 1999). Several factors, namely climate, type of vegetation cover, availability of nutrients, disturbance in soil condition, and altering land-use management system, can also affect the amount of organic matter in the soil (Leifeld and Kogel-Knabner, 2005). Soil carbon is significantly impacted by physical soil qualities, including composition, size, and structure. The pace at which breakdown of soil organic carbon breaks occurs is also inclined towards the size of soil particles. A key mechanism in an ecosystem's internal biogeochemical cycle is the release of nutrients from trash decomposition and recycling a significant proportion of carbon which was limited in a plant to the atmosphere.

2.4 Soil and its carbon pools

An important aspect of the global cycling of Carbon is associated with soils. After the oceans (38×10^3 Pg) and lithosphere (5×10^3 Pg), soils occupy the 3rd principal active C pool (1.55×10^3 Pg of organic carbon and 0.75×10^3 Pg of inorganic carbon at a 1-meter soil depth) (Lal, 2001). Soils inculcates a minimal rate of carbon turnover in land ecosystems. The economic viability of soil C sequestration surpasses that of other methods in sequestering carbon (Lal, 2008). Furthermore, SOM delivers a better prospect to increase fertility while offering an additional energy source for the soil ecosystems (Janzen, 2006). The findings of Sleutel *et al.,* 2006 indicated that soils managed through reduced tillage and residue integration possessed supplementary soil organic matter, which could assist as a major sink and nutrient pool for the soil biological functions. Other investigations by Bhattacharyya *et al.,* 2015 indicated that certain fractions of SOM are considered to be highly sensitive indicators for any changes in land-use practices because they play a larger role in preserving soil quality. When compared to forestry and horticultural land-uses, a decline was observed in the SOC pool in agricultural land use system (Martin-Lammerding *et al.,* 2013; Singh *et al.,* 2011). It is probable that the amount and caliber of SOC deposited in various land use systems tend to fluctuate, and that these fluctuations derives distinct yet significant impacts on soil properties like chemical fertility and structural stability. The capacity to select appropriate land-use systems, either alone or in combination, is crucial for reducing the influence of shifting land-use patterns on climate change worldwide. A cumulative buildup of SOC stock is anticipated to result from cropping strategies and management techniques that guarantee a higher percentage of organic residues being returned to the soil (Kaur *et al.,* 2008).

SOC sequestration in a widespread assortment of soil carbon inputs is sometimes unaffected by high level carbon inputs. According to this finding, soil C dynamics regulate soil C sequestration (Gulde *et al.,* 2008). The relative sufficiency of microbial biomass, proportion of organic matter and the soil aggregates all affect the extent to which the SOC may be expressed (Six *et al.,* 2004; Jastrow *et al.,* 2007). Considering the immediate effects on the characteristics of the soil, soil organic matter could be the most widely recognized and discussed indicator of soil quality. essentially, soil quality is defined as the soil's ability to perform all ecological operations, withstand erosion, and lessen adverse effects on nearby air and water resources. Agrochemical sorption, pH buffering, cation exchange capacity, structure, aggregate stability, water infiltration, water availability, biological activity, and sorption of agrochemicals are the main markers of soil quality that are impacted by SOM.

The physicochemical properties of a soil regulate the quantity of C it can sequester. Numerous physical and chemical characteristics of soil have been found to be important in both preventing and slowing the decomposition of organic residue (Six *et al.,* 2004). A soil comprising maximum humic substance aggregates with textures of silt and clay fraction has a higher potential to store carbon (Six *et al.,* 2004). A soil is deemed to be carbon saturated when it reaches its full potential for sequestering of carbon (Goh, 2004). The volume and quality of soil organic matter are associated with the sustainability and maintenance of soil functions. According to Allmaras *et al.,* 2000, an experimental investigation verified that the shift to crop production practices caused a decrease in SOM when linked with the initial grassland conditions. Due to varying tillage effects, soil carbon losses range from 28 to 77% depending on the geographic area. Accumulation of SOM, a catalyst in C sequestration, can enhance soil fertility and quality (Wright and Hons, 2005). Climate, residue management strategies, and soil type all affect the way tillage practices influence the area. The dynamics of SOM are connected to the development and stabilization of soil aggregates. Microbiota, soil organic C, clay, and carbonate concentration all influence the extent of soil agglomerates (Bronick and Lal, 2005).

Light carbon fractions were established as very responsive towards several soil management techniques (Souza *et al.,* 2017). The best measure for the lability of SOC was thought to be oxidizable carbon as measured by $KMnO_4$. Every labile carbon fraction of the soil organic matter that the traditional tillage method lowered in the topsoil layer. Extended phosphorus fertilization enhanced the microbial biomass carbon (MBC) content, particulate organic carbon (POC), and soil carbon content (OC oxidizable) but did not alter the overall amount of organic carbon.

2.5 SOC stocks (SOCS):

SOC institutes the primary element of soil fertility, productivity, and quality since its decrease is anticipated to have a number of detrimental consequences on crop productivity. Given that the SOC affects the biogeochemical processes of soil, it is considered to be a crucial component in managing soil sustainability and quality. For the soil biological system, it provides nutrients and energy, and through mineralization, it influences the soil's ability to supply nutrients. Additionally, it has an impact on hydraulic characteristics, water retention, and aggregate stability (Haynes, 2005). SOC regulates soil nutrient availability indirectly while also acting as a direct source for plant nutrition. Furthermore, it functions in preserving the general quality of the ecosystem because soil holds a sizable portion of the carbon storage (Verma *et al.,* 2010).

Manjaiah *et al.,* 2000 evaluated the nitrogen (N) and SOCS under different cropping arrangements at the Indian Agricultural Research Institute, New Delhi. It was found that the maize-mustard system had the lowest SOC stock while the rice-wheat system observed the highest SOCS. Conversely, cropping systems including maize and chickpea had the highest N-stock and the system involving maize and mustard the lowest. The distribution of the total soil carbon mass among the different cropping systems was found to be 58.4, 25.7, and 15.9% in the 0-15, 15-30, and 30-60 cm soil depths, respectively. Furthermore, the research of Kumar *et al.,* 2012 provided insight on the SOCS as maximum in the silvi-pasture system (74.82), followed by natural grassland (44.33) > agri-horticultural system (43.97) > horti-pastoral (42.97) > agri-hort (27.81). The lowest was under the agri-silviculture (27.33 $Mgha^{-1}$).

The long-standing outcome of incorporating both manure and synthetic fertilizer implementation on SOC storage capacity in the soybean-wheat cropping system at Almora (Uttarakhand) were assessed (Kundu *et al.,* 2007). It was recorded that in the control treatment of 0 to 45 cm soil depth, the NPK + farmyard manure application plots observed a hike of 40 and 70% higher SOC stocks (60.3 $Mgha^{-1}$) compared to the NPK treated (43.1 $Mgha^{-1}$) and control plots (35.5 $Mgha^{-1}$). The soybean-wheat cropping system in the unfertilized control plots added 890 kg ha^{-1} of carbon each year on average, and 19% of its total C-inputs directly contributed to the surge in soil organic carbon content. Therefore, the long-term soybean-wheat system's rise in soil organic carbon content was facilitated by annual carbon addition, which was more than what was necessary to maintain pH balance in the soil. In an estimation of the SOCS under various soils in Rajasthan by Singh *et al.,* 2007, the primary sink for sequestering carbon was the surface soil (0-25 cm), which held 31 percent of the total SOCS (2.13 Pg). Entisols had the largest carbon stocks, averaging 0.72 Pg on 43.60 percent of the total area; Aridisols averaged at 0.70 Pg on 28.90 percent of the total area; Inceptisols averaged at 0.61 Pg on 24.01 percent of the total area; Alfisols had the lowest, measured 0.105 Pg on 3.20 percent of the total area. SOCS were impacted by land-use patterns. It was found that in arid regions, single and double-cropping patterns denoted higher average SOCS than scrublands, while for semiarid regions, the opposite was true, with higher average SOC stocks in scrublands than cropping locations. Assessment of the SOCS in the predominant soil forms and land use patterns in the Andhra Pradesh (India) district of Warangal reported that the total carbon stock in the forest soil was the highest, with the lowest in the castor system and a decreasing trend in the fodder system> paddy> maize> cotton> red gram> chili> permanent fallow land (Venkanna *et al.,* 2014). The trend of soil nitrogen stock was likewise comparable, with the highest stores found in forest soils and least in castor land-use systems. The largest SOCS was found in Alfisols (52.8 $Mgha^{-1}$) compared to Inceptisols (51.2 $Mgha^{-1}$) and Vertisols (49.3 $Mgha^{-1}$). Nonetheless, the Vertisols group included larger soil inorganic carbon (SIC) stock (22.90 $Mgha^{-1}$) than Inceptisols (17.50 $Mgha^{-1}$) and Alfisols (12.40 $Mgha^{-1}$). As a result, Vertisols and associated soils had the highest total carbon stock.

A long-term study in the alluvial plains of India which a predominant rice based cropping pattern detected that the rice-wheat-jute system at Barrackpore had the highest carbon sequestration, at 535 kg $ha^{-1}yr^{-1}$, compared to the rice-mustard and sesame (414 $kgha^{-1}yr^{-1}$) and rice-fallow and rice (402 $kgha^{-1}yr^{-1}$) systems at the Central Rice Research Institute (CRRI), Cuttack (Mandal *et al.,* 2008).Also, the impact of pasture and herbal canopy cover on soil organic carbon (SOC) sequestration was investigated in Vadodara, India. The researchers found that the herbal land cover had a greater SOC content (15.6-23.2 g kg^{-1}) than the pasture cover (7.8-9.8 g kg^{-1}). SOC, MBC, and dissolved organic carbon were deemed to be higher in both types of land cover during the monsoon season and comparatively lower in the summer (Dinakaran and Krishnayya, 2011).

The effects of mineral elements and climatic variations on soil organic carbon reserves were studied by Zeraatpishe and Khormali, 2012. According to the findings, the majority of the soils' aggregates with a size less than 0.053 mm had the lowest OC content. There was direct association in aggregate size with the carbon stock in soils; as aggregate size increased, so did the carbon stock. Illite and chlorite showed a substantial link with soil organic carbon, however there was no significant correlation between the organic carbon and clay mineral composition. Therefore, in contrast to clay minerals, this study indicated that climate influences most likely control the organic carbon supply. Changing the land use in northern Iran from natural forests to croplands observed that alteration in land use exacerbated the losses of total nitrogen and OC content in soil (Beheshti et al. 2012). When forest land was converted to rice farming, the amount of total nitrogen and soil organic carbon in the 0-40 cm soil layer decreased by 36% and 29%, respectively. Land-use changes (LUC) affected the sensitivity of soil organic carbon stocks and pools (Poeplau and Don, 2013). It was found that cropland adjacent to forests and cropland adjacent to grasslands had the largest fluctuations in mean SOCS following LUC. In the upper surface soil (0-30 cm), conversions of pastureland to cropland and pastureland to forestland result in mean SOCS reductions. Particulate organic matter had considerably the highest sensitivity to LUC, as evidenced by the observation that it accounted for 50% and 34% of the sequestered SOCS in the 0-30 cm surface soil, respectively, followed by afforestation of farmland and grassland.

The maximum SOCS in the 0-50 cm soil depth were found in the soils of forest land (47.59 $Mgha^{-1}$) compared to a decreasing trend for horticulture (42.40 $Mgha^{-1}$), fallow (36.30 $Mgha^{-1}$), and cultivated lands (35.10 $Mgha^{-1}$). Sharma *et al.,* 2014 assessed the SOCS present under different land-usage systems in the foothills of the Himalayas. There have been reports of up to 25% lower soil organic carbon stocks in degraded and farmed areas than in forest soils. This indicates that losses of soil organic carbon are increasing up to 12.4 Mg ha^{-1} in deforested areas and the conversion of forest land to cultivated areas. According to Bhardwaj, 2013, the silvi-pasture system (17.01 t ha^{-1}) had the lowest soil organic carbon store while the forest land-use system had the greatest (52.01 tha^{-1}) in the upper 40 cm soil layer. Total carbon stocks had been significantly influenced by soil depth; in temperate Himalayan conditions, SOC content dropped from 1.25% in the top 20 cm soil layer to 0.83% in the second soil layer at a depth of 20-40 cm.

Investigation on the effect of tillage systems and land-cover on SOCS found that after six years of cropping, no-till system stored more soil organic carbon (17.6 Mg ha^{-1}) than the conventional tillage system (12.3 Mg ha^{-1}). This suggests that the conventional tillage system supported higher carbon loss than the no-till system (Pinheiro *et al.,* 2015). When compared to a grass land-use system, the cultivation of vegetable crops under different tillage regimes (no-till, animal traction, and conventional tillage) developed a negative influence in SOCS. After assessment of the nitrogen and SOCS in the soil from various farming and land-utilization scenarios, it was recorded that natural forest land-use regimes possessed the largest soil organic carbon (175.3 Mg C ha^{-1}) and total nitrogen (13.6 Mg N ha^{-1}) stocks, while the lowest were found in untreated gully lands (14.5 Mg C ha^{-1}) and (1.20 Mg N ha^{-1}) (Tesfahunegn and Gebru, 2020). In comparison to the natural forest land-use system, the stocks of soil organic carbon under untreated gully (UTG) and teff mono-cropping (TM) were reduced by 91.7 and 87.1%, respectively.

2.6 Total Organic Carbon (TOC) and its different carbon fractions:

For the purpose of accessibility, soil organic matter is separated into two main pools: labile fractions and non-labile fractions. These fractions range in complexity from exceedingly decomposable to very resistant (Haynes, 2005). Soil organic carbon has a high turnover rate and is susceptible to changes in land use, which makes it a part of the labile carbon component. According to Majumder *et al.,* 2008, the different pools of SOC provide energy to the soil system, which in turn has a significant impact on the nutrient cycling necessary to preserve the yield output and the quality output of the soil. Blair and Crocker, 2000 found that the physico-chemical, and biological features of soils, including their ability to self-organize, are in direct relationship with the SOC pool and lability. Labile carbons are oxidizable in a 333 mM $KMnO_4$ solution (Blair *et al.,* 1995). Thus, adding SOC pools and lability index to the carbon management index (CMI), which was first put forth by Blair *et al.,* 1995, can offer a helpful metric for evaluating how well management techniques are able to support soil quality. Even though a lot of studies have been done that can offer a lot of useful information about soil management, not many of them incorporate the total SOC pools and the lability index into the CMI to evaluate how well land-use management systems can support soil quality. When tropical forests are converted to agricultural land, the SOC pool can be reduced by as much as 50-75% (Lal, 2004) or by 15 to 40 percent in approximately, 2-years for soil depth up to 1 meter (Ingram and Fernandes, 2001). A restorative land use and less destructive farming techniques have the ability to sequester carbon in soils as a result of this reduction of the SOC pool. The natural forest ecosystem procured the peak values of SOC, Total N, and C:N ratio, according to Selassie and Ayanna, 2013, whereas the agricultural system inculcated the lowest within the same parameters. Across all land-use systems, the SOC and total N decreased as soil depth increased. According to the study's findings, the physic-chemical characteristics of soil were negatively impacted when forest area was converted to cultivated land. Similarly, the concentration and TOC stocks in soils were considerably minimized when the forested areas were converted for agriculture (Wei *et al.,* 2013). The observations demonstrated that the conversion of forest land to agricultural land altered the distribution of total organic carbon (TOC) between various soil aggregate classes and soil depths in addition to reducing the total amount of soil organic carbon stored. The macro-aggregate associated organic carbon fraction showed the biggest decrease, whereas farmland soils showed an increase in micro-aggregate associated carbon and silt plus clay related organic carbon storage remained unaffected by changes in land use.

Evaluation of SOC fractions for various land-utilization systems in black cotton soil of central India resulted in the highest levels of SMBC, water-soluble carbon (WSC), and labile carbon (LC) being found in horticultural and plantation forests, which are dominated by eucalyptus, mahua, and tendu plant species (Lakaria *et al.,* 2012). A soybean-wheat cropping system that consistently receives 6 t ha^{-1} FYM annually among diverse agricultural land uses greatly increased various carbon pools. On the other hand, aonla, guava, and gram plantations as rabi season crops enhanced different soil carbon pools in agri-horti systems. Differences in the land-use regimes developed a considerable influence on the dehydrogenase activity as well as diverse carbon fractions such as WSC, SMBC, and SOC (Jha *et al.,* 2012). With the exception of subsurface soils, the ratio of resistant carbon to total carbon remained constant (66-68%) throughout all land-use systems. The resistant portion of carbon rose with soil depth under various land-use systems, as evidenced by the larger amount of resistant carbon pool (78% of total carbon) in the sub-surface soils.

A report by Zhang *et al.,* 2013 suggested that whenever manure application increased, total organic carbon in the sand-sized fraction (> 53 μm) and the silt-sized fraction (2-53 μm), non-protected coarse particulate organic matter (cPOM>250 μm), increased as well. The majority of the carbon collected as mineral linked carbon fraction in the no-till system as opposed to the conventional tillage system. It was an outcome in investigating the physical fractions of SOM across various land cover and tillage regimes (Pinheiro *et al.,* 2015). In the upper soil layer (0-5 cm), grassland cover exhibited highest levels in carbon sequestration and the mineral-associated fractions of carbon (14.9 g C kg^{-1}) and nitrogen (5.1 g N kg^{-1}). Throughout all treatments that had a substantial correlation with the mineral fractions, the heavy fraction contained more than 55% of the stored soil carbon.

The relationship between the availability of nutrients and OC components in the soil were considerably increased when sandy barren lands were converted to cultivated systems (Moharana *et al.,* 2017). The maximal levels of water-soluble carbon (WSC) (0.19 g kg^{-1}), and TOC (6.12 g kg^{-1}) were maintained by the pearl millet-wheat cropping combination. In contrast, among all agricultural systems taken into consideration, the fallow land had the lowest amounts of TOC (2.41 g kg^{-1}), and WSC (0.08 g kg^{-1}). There were significant correlations ($P < 0.05$) between the available soil nutrients and both labile and highly labile carbon. Another study by Moharana *et al.,* 2019 on the comparison of 100% inorganic NPK fertilizers found that the combined use of rock phosphate augmented composts with fertilizers (enriched composts, such as rice straw, mustard, and tree leaves) + 50% NPK elevated TOC and Av. N, MBC, and the respective fractions in soil. It also assessed the SOC and nitrogen fractions and management indices under the wheat-green gram sequence. The amount of total nitrogen, labile-N, and mineral nitrogen in the soil has greatly increased with the application of enriched composts, either by themselves or in conjunction with 50% NPK. The plots treated with mustard stover compost and 50% NPK had the highest carbon management index, while the plots treated with rice straw compost and 50% NPK had the highest nitrogen management index. The outcomes indicated that the very labile carbon (VLC) fraction is considerably highly sensitive to any form of management approaches than the less labile carbon (LC) fraction and TOC.

The influence of several fertilizer sources and agroforestry methods on SOC fractions in Himalayan foothill soils was investigated by Kumar *et al.,* 2021. The investigation showed that compared to an open system, an agroforestry system had greater levels of microbial biomass carbon (298.31 µg g^{-1}) and active (extremely labile-13.8% + labile-4.8%) and passive carbon pools (less labile-8.3% + non-labile-11.1%). Upon comparing

100% integrated nutrient sources to the control treatment, all carbon fractions-including microbial biomass carbon-were found to be higher. Mishra and Sarkar, 2020 investigated the SOC pools in Meghalaya, India, under various land-use and management schemes. With the exception of the non-labile carbon pool, the results indicated a strong link between TOC and the various carbon pools in the majority of the different land-use systems. Less labile carbon had a positive correlation with the passive carbon pool but a positive correlation with the total organic carbon.

2.7 Soil Microbial Biomass Carbon (SMBC):

The terrestrial environments are composed of the biomass of soil microorganisms, which are essential for the transformation of nutrients. According to one definition, the phrase "microbiological activity" refers to all of the metabolic processes and interactions that the microflora and microfauna in soil undertake. The preservation of soil fertility is significantly influenced by soil enzyme activity. The SOM turnover is largely dependent on the microbial biomass and any alteration in it could disrupt its turnover rate. Consequently, the fertility and stability of an ecosystem are directly impacted by the microbial activity in the soil. Jin *et al.,* 2010 suggested that altering the quantity and chemical makeup of organic/crop residues returned to the soil can impact SOC dynamics due to shifts in plant community composition. The latter, in turn, can have an impact on the size of the pool and the functioning of the SMBC (Kasel and Bennett, 2007).

According to Singh *et al.,* 2015, the principal investigation on how changes in land use affected soil CO_2 carbon flux and carbon storage showed that agriculture-ecosystem developed the maximal soil carbon flux, succeeded by degraded forest and Jatropha plantations, while the natural forest system developed the lowest. SMBC and SOC also envisaged significant changes along different land use systems, ranging from 257 - 723 $\mu g\ g^{-1}$ and 3.78 - 9.47 $Mgha^{-1}$, respectively. Natural forest area had the highest SOC and MBC, followed by jatropha plantations, degraded forests, and agriculture-ecosystems with the lowest values. The seasonal fluctuations in temperature, precipitation, plant growth and development, along with the buildup of OM from litter fall, together with to the types of forest, have a profound influence on the volume of SMBC. Throughout the growing season, alterations in the volume of soil microbial biomass are assumed to introduce a significant role in regulating the soil C and N turnover. The microbial mass in the soil serves as an active reservoir for nutrients that are available to plants and forms an environment for transformation for the OM in soil. Estimating microbial biomass is a useful technique for acknowledging and forecasting the long-term changes since it reacts to changes in ecosystem circumstances far more quickly compared to the total amount of organic matter. Utilizing chemical and biological metrics, Yang *et al.,* 2010 examined the MBC, SOC, and other parameters in areas of natural forest and Larix olgensis cropping in North-eastern China, for the 2008 growing period. In the two distinct types, MBC and MBN both drastically decreased as soil depth increased. According to their findings, in temperate Northeast China, NSF outperforms larch plantations in terms of maintaining MBC and nutrients.

The breakdown of OM and its residual is carried out by microbial biomass, the most labile component of SOM (Haynes, 2005). Seasonal variations in microbial biomass are caused by local and regional elements such soil characteristics, plant community composition, and climate (Esperschütz *et al.,* 2007). In the forest ecosystem of the Mussoorie hills in the western Himalaya, Prasad et al. 2016 investigated the SMBC and SMBN. A comparison of the native Quercus leucotrichophora forest and the Cupressus torulosa plantation in a rehabilitated land revealed that the concentration of SOC, MBC, and MBN was higher in the winter than in the summer and during rainy seasons in both the natural forest and plantation stands. Given the strong correlation found between soil water content and MBC concentrations, soil moisture changes due to seasonal fluctuations may account for fluctuations in MBC. There are significant variations in the bacterial and fungal colony in the soil between forest and barren environments, as well as between different types of forests. On contrast to forest land, low levels of soil organic carbon and microbial biomass carbon is relative on barren places. Materechera and Murovhi, 2011 found that barren terrain frequently has low soil microbial biomass, probably as a result of the low carbon substrate level, which restricts soil microbial growth.

2.8 Soil Biology:

Studies on soil ecology frequently require quantifying soil biological activity because these indicators have been suggested as a measure of soil stress and disturbance (Hernández *et al.,* 1997). In order for energy and nutrients to be accessible for recycling within the ecosystem, microbial activity is essential. Greater attention is given to the fluctuations of the microbial biomasses and its important functioning in plant nutrient absorption under various ecological circumstances (Onwonga *et al.,* 2010). The amount and quality of the litter, the incorporation of additional plant litters, and alterations in the soil physical properties alongside chemical properties may all have a consequential impact on the higher and more varied soil microbial biomass carbon observed under forest land (Arunachalam and Pandey, 2003). According to Tripathi and Sharma, 2005, various land-use systems had a major impact on biological activity. Under tree plantation as opposed to tree plus cropping systems, soil respiration and dehydrogenase activity were highest along with other soil parameters as moisture level, temperature, Av. N and Av. P.

Upon evaluating the soil microbial biomass carbon alongside Nitrogen across varied land use practices, it was found that the land use practices developed a major impact on the SMBC and SMBN (Kara and Bolat, 2008). SMBC was maximal in forest soils (1028.29 µg g^{-1}), lowest in agricultural soils (485.10 µg g^{-1}). A similar pattern was seen for soil microbial biomass nitrogen, which was lowest in agricultural soils (42.60 µg g^{-1}) and highest under forest soils (129.99 µg g^{-1}). Investigation on the depth and season dependent variations in the soil microbial population under arecanut-based agroforestry systems suggested that the bacterial population peaked in the spring and the fungal population in the fall (Tangjang *et al.,* 2012). The topsoil (0-10 cm) layer had the highest microbial counts, with the exception of the rainy season, when the population was concentrated in the subsurface (10-20 cm) layer. The microbial colony forming units showed a strong correlation with both the total nitrogen concentration and soil organic carbon. In agroforestry systems, plant species, additional organic wastes, soil mineral nutrients, and vegetation density all had an impact on the microbial population. The activity of enzymes involved in the cycling of N in soil under various land use systems was evaluated by Fagotti *et al.,* 2012. The maximal enzyme activity was prevalent in native forest soils > agricultural soils > reforestation with Pinus taeda > reforestation with Araucaria angustifolia. Compared to Pinus taeda and agricultural soils, the activity of urease and glutaminase was threefold more prevalent in native forest and Araucaria angustifolia soils. Asparaginase activity was three times higher in the Araucaria angustifolia soils than in the agri-soils, while the native forest soils in Pinus taeda developed roughly half the asparaginase activity. According to Yang *et al.,* 2018, increased frost throughout the winter months reduces the availability of soil nitrogen, which results in a decrease in soil respiration, microbial biomasses, and enzymatic activities involved in soil C-cycling in subalpine spruce forest lands. Nevertheless, these impacts did not persist until the following growing season. Aredehey et al. 2019 also suggested that rainfed farmed land has lower levels of these soil characteristics than grassland, which has higher levels of rhizobia, organic carbon, and nitrogen.

The significance of soil microbes in sequestering C under various tillage techniques was assessed by Zhang *et al.,* 2013 using varying sizes of soil aggregate. According to the findings, the soil organism was more abundant and active in conservation tillage systems (no-tillage system and ridge system) than in conventional tillage (CT). Macro-aggregates (1-2 mm) between various fractions of the aggregate had more nematode abundance and diversity, while micro-aggregates (< 0.25 mm) had higher soil microbial biomass and diversity. More gram-positive bacteria and nematodes were found in aggregates smaller than 1 mm, which resulted in increased carbon accumulation; conversely, more fungus was found in aggregates larger than 1 mm, which helped to improve carbon retention. The fluctuation in soil microbial biomass carbon and nitrogen under Taiwan's sub-alpine forest soils caused by various vegetation species was investigated by Ravindran and Yang, 2015. The study's findings indicated that, in comparison to hemlock and grassland soils, spruce plants had the highest SMBC and SMBN. Additionally, under all types of vegetative land cover soils, they were lowest at deeper depths and highest in surface soils. Microbial populations in all types of land cover soils exhibited a similar tendency, with the highest populations under spruce soils and the lowest in grassland soils decreasing with depth.

In contrast to a traditional system where intercrop mulch was not employed, Zhang *et al.,* 2018 observed that the usage of cover crops as intercrop mulch under an orchard enhanced activity of soil enzymes called β-glucosidase, β-xylosidase, and cellobiohydrolase by 12.3, 22.0, and 14.7%. By applying intercrop mulch, the relative abundance of Actinobacteria and Verrucomicrobia was lower than in the usual system (7.2%), and the abundance of Firmicutes was enhanced (18.7%). Birt and Bonnett (2018) investigated the short-term impacts of inorganic nitrogen and soil organic carbon on the activities and functions of microorganisms in grassland urban and woodland soils. The findings showed that, in comparison to grassland soils, woods soil had higher levels of soil organic matter and phenolic compounds

A constant rigorous management technique drastically impacted the makeup of the bacterial population and the availability of nutrients beneath the bamboo forest. Nitrate-nitrogen (NO_3-N), soil pH, potassium availability, and available phosphorus were the primary determinants of the composition of the bacterial population (Chen *et al.,* 2019). The soil enzymes β-glucosidase, urease, and phosphatase showed a decline in activity after 15 years of rigorous management techniques, but they recovered after 25 years of management. The impact of switching from jhum farming to various plantings and secondary forests was examined and the study observed that SOC and soil water-holding capacity under alternative land uses rose as a result of land-use changes (Lungmuana *et al.,* 2023). SMBC and SMBN, the ratio of SMBC to SOC, basal soil respiration, and soil enzymes such as β-glucosidase, dehydrogenase, arylsulphatase, and urease were all enhanced by the SOC storage. In comparison to secondary forests, arecanut, rubber, and teak plantations, respectively, the metabolic quotient (qCO_2-substrate use efficiency) in the jhum cultivation system was 21.5, 25.8, 27.8, and 39.9 percent higher into 0-15 cm soil depth. This suggested microbial stress because there were more disturbances in the soil's surface layer. Lopes and Fernandes, 2020 investigated how different conservation agriculture techniques affected the organization of the microbial community. The findings showed that while gram-negative and arbuscular mycorrhizal fungi, microbial biomass carbon, basal respiration, and the ability to degrade amino acids, microbial stress status, and actinomycetes biomarkers increased under fallow soils. When compared to conservation tillage, arbuscular mycorrhizal fungi proliferated while stress biomarkers reduced in conventional tillage.

Chapter 3: Materials and methodology

The experiment on "**Study on the effect of different agricultural practices on soil quality and organic carbon pools of Maize in semi-arid region of India**" was carried out in the experimental field of Department of Soil Sciences, Lovely Professional University, Punjab for two seasons viz. Kharif-2022 and Kharif-2023. Different major agricultural practices (10 numbers) for growing Maize were selected. The recommended dosage of fertilizers was applied to the treatments and an equal amount of compost (10 tonnes/ha) were added in the study area to find its effect on the soil quality and different pools of SOC. The soil samples were collected at random from four sites at each experimental plot at depths of 0-15 cm and 15-30 cm. Each soil sampling and recordings were performed at an interval of 45 days from the start of the experiment until its completion. Analysis of collected soil samples were performed in the laboratory of Dept. of Soil Sciences, LPU. The details of materials and methods employed along with the procedures adopted for physical, chemical, and biological analysis are provided below.

3.1 Experimental site

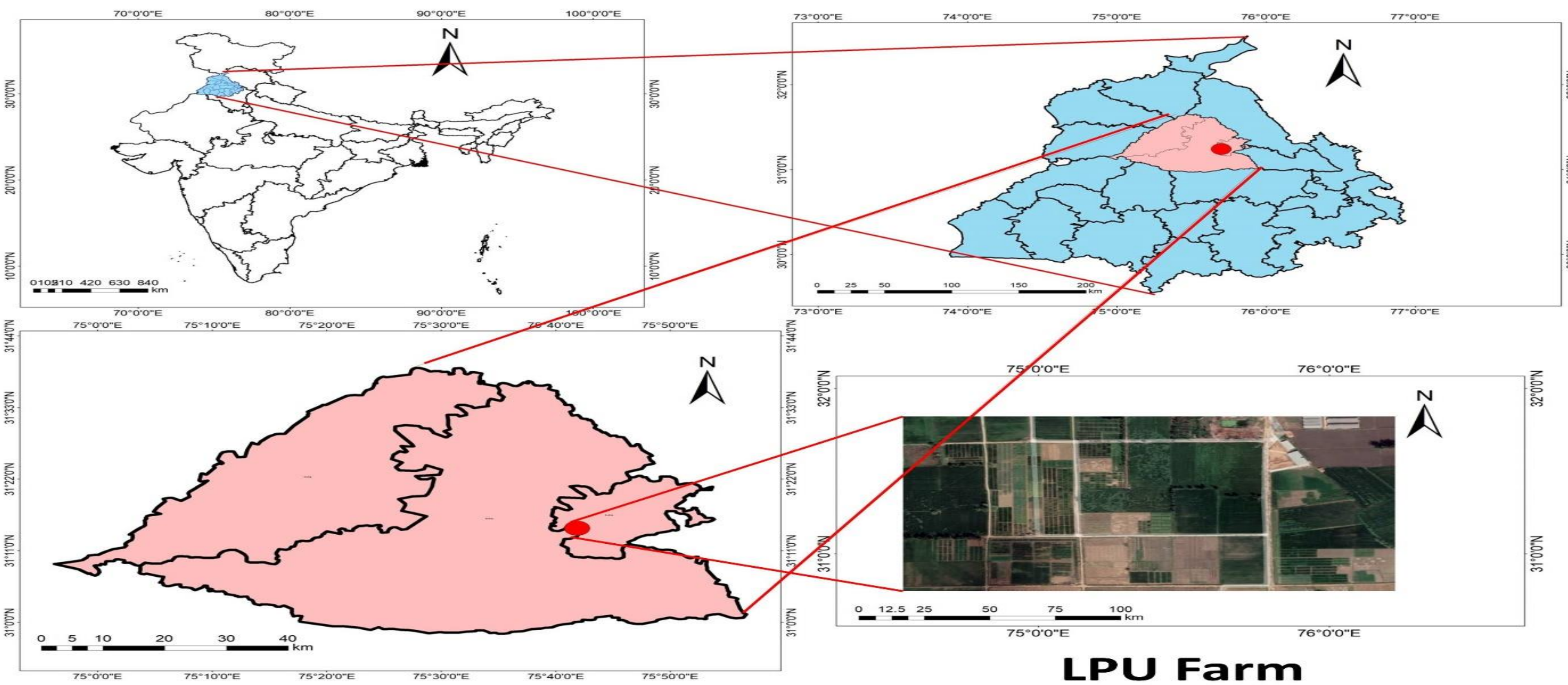


Fig 1: Study Area, LPU Farm.

3.2 Climatic record during the experimental period

Table 1: Climatic record during the experimental period

Year	**2022**							**2023**								
Month	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**
Max. Temp. (°C) (avg)	39.80	37.23	34.45	35.57	32.23	25.87	24.84	15.58	25.43	27.45	33.07	37.85	36.43	33.94	34.52	33.73
Min. Temp. (°C) (avg)	31.33	29.58	25.90	24.20	20.48	14.17	10.26	7.07	11.94	14.99	16.41	22.64	24.60	26.48	27.00	24.11
Max. RH (%) (avg)	45.63	65.32	75.32	72.13	54.77	55.20	90.16	91.55	81.18	73.09	74.43	68.03	82.47	88.13	90.97	92.00
Min. RH (%) (avg)	41.23	63.26	64.29	63.37	44.19	45.33	71.68	76.81	54.86	47.29	31.60	40.37	46.90	67.97	70.39	65.27
Rainfall (mm) (avg)	2.35	8.25	0.91	0.38	0.00	0.00	0.06	1.58	0.00	1.79	0.39	1.80	3.15	9.00	2.61	0.79

3.3 Experimental Details

The experiment was conducted from June 2022- September 2023. Before sowing of the crop, pre sowing irrigation was performed and afterwards a proper tillage operation was provided to the experimental area. The study area was thoroughly ploughed twice; once with a cultivator and the other a rotavator. The primary objective of the tillage operation was to ensure removal of crop residues and weeds, reduce the soil to a finer tilth and attain a proper depth of fine soil. However, the plot for minimum tillage practice was left undisturbed. The recommended dosage of fertilizers @ 150:75:75 $kgha^{-1}$ for each of N: P_2O_5: K_2O were provided to the entire treatment plots in the form of urea, Single Super Phosphate (SSP), and muriate of potash (MOP) respectively. The entirety of phosphorus and potassium were incorporated during land preparation phase while the nitrogen was given in three separate instances: once at land preparation, another at knee-high stage and the last one at pre-tasselling stages of plant growth. In addition to the inorganic fertilizers, vermicompost @ 10 tha^{-1} was thoroughly provided in equal proportions to all the experimental plots. This was done only once at the start of the 1st trial season. The suggested package of practices for Kharif season for cultivation of maize such as irrigation practices, weeding, etc. were followed as per the book and adopted whenever necessary by the farmers/helpers. After cultivation of the first season from June to September 2022, the study area was kept fallow with intermittent weeding during the fallow period. The second trial phase started in June of 2023 and similar above practices were adopted for the second season of growing also.

A maize variety (Suvarna NMH-589) was used as the primary crop for experimentation, and it was grown for two seasons. Before sowing, it was pre-soaked in water and treated with Carbendazim + Mancozeb (known fungicides) @2.5g/litre water for 24 hours. A total of 10 treatments were employed which were replicated 3 times and laid out in Randomized Block Design (RBD). The seed rate was 10 kg per acre. The net plot size of an experimental plot was kept at 5m × 3m which totals to 15 m^2. The gross size of the experimental area was 720 m^2 with a net cultivated area of 450 m^2. The details of the experiment and layout of the plots has been described within the tables as under:

Table 2: Treatment Details

Treatments	Agricultural Practices Employed
T1	Fallow
T2	Straw Mulching
T3	Plastic Mulching
T4	Minimum Tillage
T5	Earthing up
T6	Paired Row
T7	Broadcasting
T8	Ridge and Furrow
T9	No Weeding
T10	Weeding with Weedicide

Table 3: Details of Layout

DETAILS OF LAYOUT	
Experimental design	: Randomized Block Design (RBD)
Number of treatments	: 10
Number of replications	: 3
Total number of plots	: 30
Net plot size	: 5 m x 3 m (15 m^2)
Length of the field	: 35.5 m
Width of the field	: 20 m
Gross cultivated area	: 710 m^2
Net cultivated area	: 450 m^2

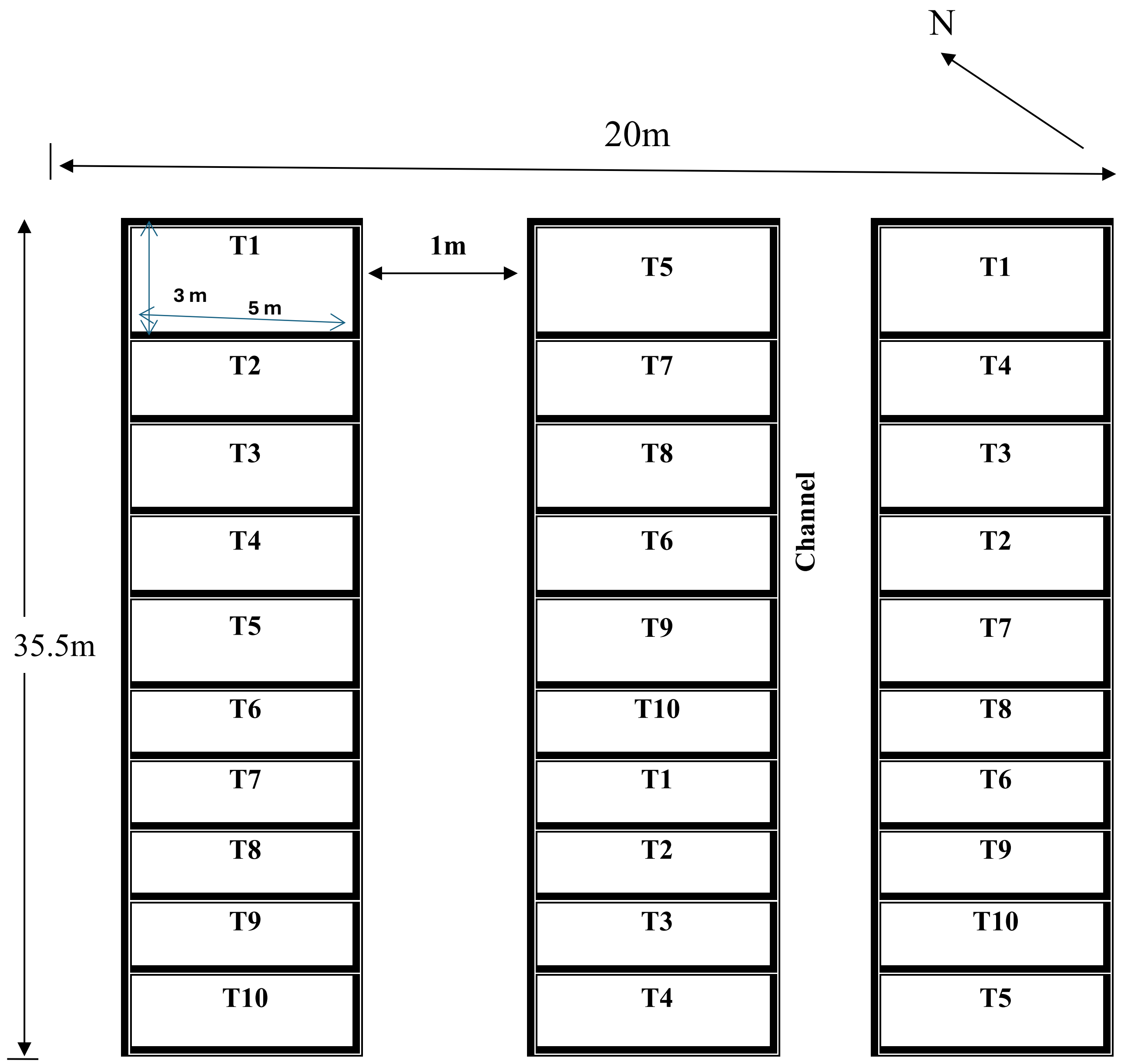


Fig 2: Experimental field layout

Table 4: Agricultural Operations Timeline

Sl. No	Operations	Time of execution	Equipment/ Technique used
1.	Pre-sowing irrigation	20th June, 2022	Tubewell
2.	Tillage Practices (Season I)	23rd June, 2022	Cultivator + Rotavator
3.	Preparation of layout	24th June, 2022	Spade, Leveller

4.	Incorporation of fertilizers (NPK)	24th June, 2022	Broadcasting
5.	Incorporation of Vermicompost @ 10 tha^{-1} (incorporated only once in both the seasons)	24th June, 2022	Broadcasting on soil surface
6.	Seed treatment (Carbendazim + Mancozeb @2.5g/litre water for 24 hours)	25th June, 2022	Plastic bucket for complete seed soaking
7.	Sowing of seeds	27th June, 2022	Line sowing
8.	Incorporation of straws to T2	11th July, 2022	Laying out on the soil surface
9.	Incorporation of plastic mulch to T3	11th July, 2022	Scissors, Hand knife
10.	2nd Irrigation	12th July, 2022	Tubewell
11.	Earthing up of T5	15th July, 2022	Spade
12.	First Hand Weeding	18th July, 2022	Khurpi, Sickles
13.	Spraying of post emergence herbicide (Halosulfuron-methyl 75% W.G) to T10 only	19th July, 2022	Knapsack sprayer
14.	3rd irrigation	29th July, 2022	Tubewell
15.	Second Hand weeding	10th Aug, 2022	Khurpi, Sickles
16.	4th irrigation	18th Aug, 2022	Tubewell
17.	5th irrigation	3rd Sept, 2022	Tubewell
18.	Third Hand weeding	8th Sept, 2022	Khurpi, Sickle
19.	Harvesting	23rd September, 2022	Hand plucking
Fallow Period (25th September 2022 to 20th June 2023)			
20.	Similar practices were also adopted in the 2nd season, 2023 as per the 1st season.		

3.4 Collection of Soil Samples:

Utilizing a soil auger, the soil units were collected from each of the selected agricultural practices at two different soil depths (0-15 cm and 15-30 cm). Site for sample collection was settled at random from four sites in each treatment plot. Roughly 1 kg of soil samples was collected from each of the sampling areas and placed into plastic bags. The residues and stubbles were removed and discarded from the collected samples and finally mixed together to obtain composite samples. Part of the collected samples were separated and put aside in a refrigerator at 4°C for analysis related to biological properties. The remaining samples were air dried and passed through a 2 mm sieve for removal of pebbles and other impurities. They were kept in plastic bags for studying the soil physical and chemical properties at later stages of the research. A single composite sample was taken for study of the entire physicochemical and biological soil properties for the initial reading. Collection of soil samples were performed at an interval of 45 days until completion of the research. A total of 60 (30 + 30 for different soil depths) composite samples were made from all the treatment plots. At least 11 soil collection phases were carried out from the initiation of the experiment to the end of the research. A timeline for collection of the samples is provided in the table below.

Table 5: Soil Sample Collection Date sheet

Sl. No.	Season	Soil Sample Collection Timeline (45 Days Interval)
1.	Season- I (2022)	25th June, 2022 (Initial)
2.		8th August, 2022
3.		21st September, 2022
4.	Fallow Period	4th November, 2022
5.		18th December, 2022
6.		1st February, 2023
7.		17th March, 2023

8.		30th April, 2023
9.	Season- II (2023)	23rd June, 2023
10.		7th August, 2023
11.		20th September, 2023

3.5 Soil Indicators:

Soil indicators are functions which indicate the variations in soil quality. These indicators need to be sensitive to any relative changes in different management practices over time. Without this sensitivity, it has negligible use in monitoring soil quality change (Doran and Parkin, 1994). These indicators include the physical, chemical and biological parameters of soil. According to a report by the Soil Quality Institute (USDA, 2006), the main focus of analysing soil quality is not to attain good aggregate stability, biological functions or any other soil properties, rather its major purpose is to protect and increase long-term agricultural productivity and habitats of all organisms including humans.

Table 6: Methods followed for estimation of different soil health attributes

Soil Acidity parameters		
Parameter	**Method/Instrument**	**Reference**
Soil pH (1:2)	pH Meter (Soil Water Suspension method)	Jackson (1973)
Electrical Conductivity	EC Meter (Soil Water Suspension method)	Jackson (1973)
Ex. Calcium and Magnesium	Complexometric Titration Method	Jackson (1973)
Soil fertility		

Soil organic carbon	Wet digestion method	Walkley and Black (1934)
Available Nitrogen	Alkaline Potassium Permanganate Method	Subbiah and Asija (1956)
Available Phosphorus	Olsen method	Olsen (1954)
Available Potassium	Ammonium acetate Method	Jackson (1973)
Available Sulphur	Turbidemetric Method	Bardsley and Lancaster (1960)
Soil physical properties		
Soil Texture	Hydrometer	Bouyoucos (1962)
Bulk Density	Core method	Jalota *et al.* 1998
Soil microbiological properties		
Bacterial Count	Serial dilution and pour plate method	Lim (1992)
Fungal Count	Serial dilution and pour plate method	Lim (1992)
De-hydrogenase activity	TPF reduction method	Casida (1977)
Soil microbial biomass carbon	Chloroform fumigation extraction method	Vance *et al.* 1987

3.6 Pools of oxidisable organic carbon

The different C pools were analysed with the utilization of a revised Walkley and Black method as defined by Chan *et al*. (2001) using different concentrations H_2SO_4. The 5, 10 and 20 mL of concentrated H_2SO_4 resulted to three different acid-water solution ratios of 0.5:1, 1:1 and 2:1 (which is parallel to 12.0 N, 18.0 N and 24.0 N of H_2SO_4 respectively). The amount of SOC were quantified using 5, 10 and 20 mL of conc. H_2SO_4 in relation with TOC, allowing the partitioning of TOC into the ensuing four different pools of decreasing oxidizability.

Table 7: Pools of oxidizable organic carbon

C_{frac1} (Very labile pools)	The OC which is oxidisable at 12.0 N H_2SO_4;
C_{frac2} (Labile pools)	SOC oxidisable under 18.0 N H_2SO_4 minus SOC oxidisable under under 12.0 N H_2SO_4
C_{frac3} (Less labile pools)	SOC oxidisable under 24.0 N H_2SO_4 minus SOC oxidisable under under 18.0 N H_2SO_4 (the 24.0 N H_2SO_4 corresponds to the standard Walkley and Black method);
C_{frac4} (Recalcitrant pools)	TOC minus the residual OC after subsequent reaction with 24.0 N H_2SO_4 (revised method developed by Nelson and Sommers, 1983) (Majumder, 2006).

3.7 Soil organic carbon stock (SOCS)

The SOC stocks were estimated as per the formula provided by Sharma *et al.,* 2014:

$$\text{SOC stocks}\left(\frac{\text{Mg}}{\text{ha}}\right) = SOC \times \rho \times d \times 10{,}000$$

where, SOC = soil organic carbon (estimated in g g^{-1}), ρ = bulk density of soil (estimated in g cm^{-3}) and d = depth of soil layer (m). The value of 10,000 signifies the stock present in 1 ha of land.

3.8 Total organic carbon (TOC)

The total organic carbon (TOC) was estimated by using a revised method of Nelson and Sommers (1996) as specified by Majumder (2007). The method integrates digesting 0.5 g of soil samples with 5 mL of 2.0 N potassium dichromate solution ($K_2Cr_2O_7$) along with 10 mL of conc. Sulphuric acid (conc. H_2SO_4) while keeping the temperature at

150^{0}C for 30 minutes in an oven and accompanied by subsequently cooling of the contents. The titration of the digests was performed with standardized ferrous ammonium sulphate solution [$Fe(NH_4)_2(SO_4)_2$].

3.9 Oxidizable organic carbon (C_{24N})

The oxidizable organic carbon was estimated by the standard Walkley and Black wet oxidation method (Walkley and Black, 1934). In this method, 1g of pounded soil sample which was passed through a 2.0 mm sieve was set in a 500 mL Erlenmeyer flask. Afterwards, 10 mL of 1.0N potassium dichromate solution ($K_2Cr_2O_7$) was poured into the flask, subsequently accompanied by addition of 20 mL concentrated (36.0 N) sulphuric acid (conc. H_2SO_4). The reaction is allowed to progress for 30 minutes, and the surplus dichromate was estimated by titrating against 0.5 N ferrous ammonium sulphate [Fe $(NH_4)_2(SO_4)_2$].

3.10 Lability index (LI)

The lability index (LI) for the SOC was calculated using the different fractions of carbon (viz. C_{frac1}, C_{frac2} and C_{frac3}). The C_{frac1}, C_{frac2} and C_{frac3}, which was considered to be very labile, labile and less labile pools, were assumed with a weightage of 3, 2 and 1 respectively. Subsequently, their actual values were converted to a proportional amount of TOC and weighed with the weighing factor to get a lability index for the SOC content of the studied cropping systems. The index was calculated as (Hazra et al. 2018):

$$\text{Lability index} = \frac{Cfrac1}{TOC} \times 3 + \frac{Cfrac2}{TOC} \times 2 + \frac{Cfrac3}{TOC} \times 1$$

Table 8: Initial soil readings:

Parameters	Readings	
	0-15cm	15-30cm
Soil Texture	Sandy loam	Sandy loam
pH	7.25	7.19
EC (mmhos cm^{-1})	0.582	0.496
BD (g cm^{-3})	1.39	1.44
Av. N (kg ha^{-1})	105.18	82.16
Av. P (kg ha^{-1})	10.77	6.20
Av. K (kg ha^{-1})	208.24	135.43
Av. S (kg ha^{-1})	22.11	19.85
Ex. Ca + Mg (meq per 100 g soil)	7.65	6.06
SOC (g kg^{-1})	3.22	2.36
C_{frac1} (g kg^{-1})	0.95	0.62
C_{frac2} (g kg^{-1})	0.43	0.38
C_{frac3} (g kg^{-1})	0.72	0.49
C_{frac4} (g kg^{-1})	2.17	1.93
TOC (g kg^{-1})	4.27	3.42
SOCS (Mg ha^{-1})	4.27	3.42
Lability Index (LI)	1.34	1.12
SMBC (µg g^{-1})	109. 42	85.33
DHA (µg g^{-1} day^{-1})	18.63	11.91
Bacterial count ($\times 10^6$)	20.33	17.67
Fungal count ($\times 10^6$)	21.67	19.33

3.11 STATISTICAL ANALYSIS OF INDIVIDUAL PARAMETERS

The data on different soil analysis and yield attributes was analysed by applying the technique of 'analysis of variance (ANOVA)' for Randomized block design (RBD) (Gomez and Gomez, 1984) using Microsoft Excel software. The values of standard error of mean (SE) and critical difference (CD) were estimated at 5% level of significance for comparing the treatment means.

3.11.1 Development of Soil Quality Index (SQI)

For the development of Soil Quality Index, the following steps was followed:

1. Indicator selection and generation of minimum data set (MDS).
2. Setting up of scoring values of the indicators and transforming them into 0 to 1 scale.
3. Assigning weight to different indicators.
4. Assembling the indicators into SQI and testing the significance of their differences across land uses.

3.11.2 Indicator Selection and Generation of Minimum Data Set (MDS)

3.11.2.1 Indicator Selection:

For the Selection of the Indicators, four major soil functioning units was chosen for effectively establishing the effects of the different agricultural practices systems on soil health and soil quality parameters. Following indicators were used to characterize the soil functions in the study:

Table 9: Soil function and indicator selection

Soil function	Indicator
1.Filtering and buffering (environmental goal)	Bulk density, soil organic carbon, Carbon pools, Total organic carbon
2.Nutrient cycling (productivity and environment goal)	SMBC, DHA, Soil pH, available nutrients – Av. NPK, Av. S, Ex. Ca and Mg.
3.Physical stability and support (productivity and environmental goals)	Soil texture, bulk density, soil pH

3.11.2.2 Generation of minimum data set (MDS)

During this experiment, a total of 25 soil attributes viz. soil texture (sand, silt, clay), pH, EC, Av. N, Av. P, Av. K, Av. S, Ex. Ca + Mg, BD, SOC, carbon fractions (C_{frac1}, C_{frac2}, C_{frac3} , C_{frac4}), TOC, LI, SOCS, Active pools, Passive pools, SMBC, DHA, Bacterial count and Fungal count were selected as indicators based on their functionalities in filtering and buffering capacity, productivity, soil degradation and other derivative indices. For identification and selection of the most sensitive indicators through MDS approach, redundant variables were eliminated through Principal component analysis (Andrew *et al.,* 2002 and Shukla *et al.,* 2006) and the minimum data set (MDS) was formed. Standardized Principal component analysis (PCA) with varimax rotation of all the data was accomplished using SPSS package. Through the principal component analysis (PCA), each principal component (PC) with eigen value ≥ 1 and retaining at least 5% of the variation in the datasets were accounted for and selected. The indicators that were highly loaded and had weighted loading levels which were within 10% of the largest weighted factor were selected for the MDS. In order to identify redundant features, Pearson's correlation analysis was carried out for each PC where several attributes were exhibited and if an attribute did not correspond with the heavily loaded attributes, it was retained in the MDS. The characteristic with the highest factor loading among those that were well-correlated ($r > 0.7$) was chosen for the MDS. The principal components (PCs') receiving high eigen values and the different variables with high factor loading was presumed to be variables that best represent system attributes.

3.11.3 Setting up of scoring values of the indicators and transforming them into 0 to 1 scale:

Knowledge of the variations/differences of various soil quality indicators in similar soil types from the different agricultural practices incorporated is needed to convert the raw data on soil parameters/soil quality indicators into numerical scores. Prior to development and testing composite soil quality index, it is a requisite to score each indicator and establish boundaries and shape of the scoring function. This step balances and normalizes biological, chemical, and physical indicator measurements with different units so that they can be combined into composite indices. The soil parameters will transform into a unit-less (0 to 1 scale) by developing it into three types of standardized scoring functions (i) More is better (ii) Less is better (iii) and Optimum is better.

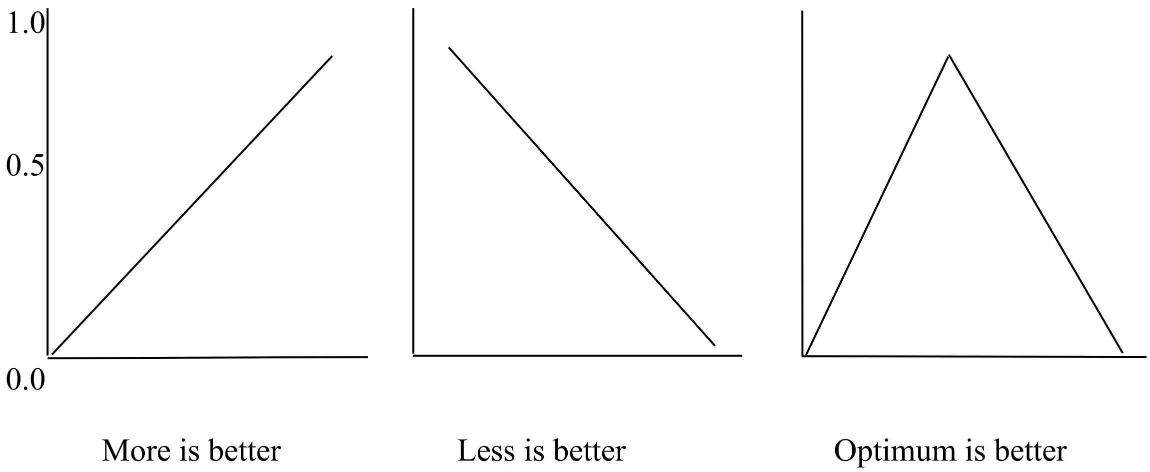


Fig 3: Standard scoring function (SSF) used for normalization of soil quality indicators.

3.11.4 Assigning weight to different indicators:

Each individual variable of the MDS was allotted a weight, that was intended as the ratio between the indicator factor loading and the cumulative component load or factor load.

3.11.5 Assembling the indicators into SQI and testing the significance of their differences across land uses.

Finally soil quality index was determined for the different agricultural practices from the formula given by Andrews *et al.,* 2002,

$$\text{Soil Quality Index (SQI)} = \sum_{i=1}^{n} \text{Wi Vi}$$

Where, Wi = Weight of variables

Vi = Score of variables

Here the hypothesis was that a higher index score means better soil quality or higher performance of soil function.

2. Straw Mulching

1. Seed sowing

3. Hand Weeding

4. Field visit by supervisor and other respected faculties

5. **Labwork-photo 1**

6. **Labwork- photo 2**

7. **Labwork- photo 3**

8. Labwork- photo 4

9. Labwork- photo 5

10. Labwork- photo 6

Chapter 4: Results and discussions

4.1 Soil physico-chemical properties:

4.1.1 Soil Texture:

Table 10: Soil Textural Classification [Sand (0-15cm)]

Treatments	Sand (0-15cm) (%)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	61.87a	61.82a	61.89a	61.87a	61.87a	61.85a	61.53a	61.88a	61.81a	62.15abc
T2 (Straw Mulching)	61.80a	61.85a	61.80a	61.82a	61.80a	61.83a	61.47a	61.46a	61.92a	61.61c
T3 (Plastic Mulching)	62.03a	62.08a	62.06a	62.03a	62.08a	61.97a	61.67a	62.29a	62.41a	62.28ab
T4 (Minimum Tillage)	61.77a	61.82a	61.84a	61.77a	61.77a	61.81a	61.63a	60.99a	61.65a	61.78abc
T5 (Earthing up)	61.93a	61.98a	61.96a	61.97a	61.98a	61.94a	61.60a	61.42a	61.94a	61.87abc
T6 (Paired row)	61.90a	61.95a	61.95a	61.91a	61.95a	61.98a	61.60a	61.69a	61.94a	62.05abc
T7 (Broadcasting)	61.87a	61.92a	62.00a	61.92a	61.97a	61.87a	61.67a	61.85a	62.09a	62.39ab
T8 (Ridge and Furrow)	61.93a	61.98a	62.02a	61.94a	62.03a	62.05a	61.67a	61.93a	62.07a	62.32ab
T9 (No weeding)	61.97a	61.98a	61.99a	61.97a	61.93a	61.98a	61.80a	61.81a	61.56a	61.73bc
T10 (Weeding with weedicide)	61.90a	61.95a	61.89a	61.91a	61.85a	61.93a	61.53a	61.75a	62.20a	62.42a
CD	0.53	0.53	0.51	0.51	0.48	0.44	0.50	1.16	1.18	0.61
SEm±	0.18	0.18	0.17	0.17	0.16	0.15	0.17	0.39	0.40	0.20

Table 11: Soil Textural Classification [Silt (0-15 cm)]

Treatments	Silt (0-15 cm) (%)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	23.20a	23.21a	23.21a	22.98a	23.10a	23.18a	23.21a	23.18a	23.65a	23.22a
T2 (Straw Mulching)	23.17a	23.20a	23.19a	23.29a	23.21a	23.14a	23.18a	23.17a	23.29a	23.20a
T3 (Plastic Mulching)	23.00a	23.00a	23.00a	23.09a	22.93a	23.01a	23.00a	22.98a	22.77a	22.99a
T4 (Minimum Tillage)	23.20a	23.20a	23.20a	23.23a	23.20a	23.16a	23.20a	23.17a	23.73a	23.20a
T5 (Earthing up)	23.03a	23.03a	23.03a	22.86a	22.84a	23.07a	23.02a	23.06a	22.86a	23.02a
T6 (Paired row)	23.13a	23.16a	23.16a	23.04a	23.08a	23.07a	23.15a	23.17a	23.32a	23.16a
T7 (Broadcasting)	22.93a	22.95a	22.95a	23.61a	22.92a	22.96a	22.94a	22.91a	22.69a	22.95a
T8 (Ridge and Furrow)	23.07a	23.10a	23.09a	22.94a	22.84a	23.01a	23.08a	23.10a	22.94a	23.09a
T9 (No weeding)	23.03a	23.06a	23.06a	23.39a	22.83a	23.15a	23.05a	23.05a	22.88a	23.05a
T10 (Weeding with weedicide)	23.03a	23.05a	23.05a	23.06a	22.98a	23.02a	23.04a	23.04a	22.88a	23.04a
CD	0.47	0.47	0.47	0.77	0.58	0.39	0.48	0.48	1.59	0.48
SEm±	0.16	0.15	0.16	0.26	0.19	0.13	0.16	0.16	0.53	0.16

Table 12: Soil Textural Classification [Clay (0-15 cm)]

Treatments	Clay (0-15 cm) (%)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	14.93a	14.97a	14.90a	15.15a	15.03a	14.98a	15.26a	14.94a	14.54a	14.64a
T2 (Straw Mulching)	15.03a	14.95a	15.01a	14.89a	14.99a	15.04a	15.35a	15.37a	14.79a	15.20a
T3 (Plastic Mulching)	14.97a	14.92a	14.95a	14.88a	14.99a	15.02a	15.33a	14.73a	14.82a	14.72a
T4 (Minimum Tillage)	15.03a	14.98a	14.95a	15.01a	15.04a	15.04a	15.16a	15.83a	14.62a	15.02a
T5 (Earthing up)	15.03a	14.98a	15.01a	15.17a	15.18a	14.99a	15.38a	15.52a	15.20a	15.11a
T6 (Paired row)	14.97a	14.89a	14.89a	15.05a	14.97a	14.95a	15.25a	15.14a	14.73a	14.79a
T7 (Broadcasting)	15.20a	15.14a	15.05a	14.47a	15.12a	15.17a	15.39a	15.24a	15.22a	14.66a
T8 (Ridge and Furrow)	15.00a	14.92a	14.88a	15.12a	15.13a	14.94a	15.25a	14.97a	15.00a	14.59a
T9 (No weeding)	15.00a	14.96a	14.96a	14.64a	15.24a	14.87a	15.15a	15.14a	15.55a	15.21a
T10 (Weeding with weedicide)	15.07a	15.00a	15.06a	15.03a	15.17a	15.06a	15.42a	15.21a	14.92a	14.54a
CD	0.59	0.60	0.60	0.78	0.64	0.51	0.63	1.15	1.80	0.72
SEm±	0.20	0.21	0.21	0.26	0.22	0.17	0.21	0.39	0.61	0.24

Table 13: Soil Textural Classification [Sand (15-30 cm)]

Treatments	Sand (15-30 cm) (%)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	62.92b	62.69a	62.71a	62.73b	62.92b	62.86b	62.29ab	62.39bc	62.42a	62.41a
T2 (Straw Mulching)	62.97ab	62.96a	62.98a	63.37ab	62.97ab	62.91ab	62.28ab	62.56bc	62.30a	62.22a
T3 (Plastic Mulching)	62.97ab	62.80a	62.38a	63.10ab	62.97ab	62.98ab	62.26b	62.29c	62.36a	62.41a
T4 (Minimum Tillage)	63.09a	62.82a	63.02a	63.29ab	63.09a	63.11a	62.37ab	63.03ab	63.09a	63.48a
T5 (Earthing up)	63.02ab	63.38a	62.81a	63.02ab	63.02ab	63.02ab	62.31ab	63.40a	63.36a	63.17a
T6 (Paired row)	63.05a	63.21a	63.35a	63.17ab	63.05a	63.00ab	62.34ab	62.80abc	63.05a	62.95a
T7 (Broadcasting)	63.03ab	62.71a	62.64a	62.96ab	63.03ab	63.01ab	62.27ab	62.76abc	62.37a	62.00a
T8 (Ridge and Furrow)	62.98ab	62.58a	63.16a	62.76b	62.98ab	62.92ab	62.45a	62.65bc	62.31a	62.15a
T9 (No weeding)	63.01ab	62.97a	62.99a	63.02ab	63.01ab	63.03ab	62.31ab	62.81abc	62.68a	62.88a
T10 (Weeding with weedicide)	63.09a	62.64a	62.78a	63.61a	63.09a	63.07ab	62.32ab	63.37a	63.32a	63.42a
CD	0.20	0.73	1.02	0.71	0.12	0.18	0.15	0.63	0.92	1.48
SEm±	0.04	0.25	0.34	0.24	0.04	0.06	0.05	0.21	0.31	0.50

Table 14: Soil Textural Classification [Silt (15-30 cm)]

Treatments	Silt (15-30 cm) (%)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	23.63a	23.63a	23.60a	23.67a	23.60a	23.62a	23.56a	23.55ab	23.63a	23.66ab
T2 (Straw Mulching)	23.63a	23.63a	23.51a	23.46a	23.40a	23.63a	23.55a	23.55ab	23.30a	23.40c
T3 (Plastic Mulching)	23.66a	23.67a	23.56a	23.50a	24.03a	23.68a	23.41a	22.91b	23.66a	23.51bc
T4 (Minimum Tillage)	23.61a	23.61a	23.73a	23.59a	23.91a	23.61a	23.36a	23.68ab	23.61a	23.68ab
T5 (Earthing up)	23.65a	23.65a	23.23a	23.46a	24.05a	23.64a	23.47a	23.79a	23.65a	23.62ab
T6 (Paired row)	23.73a	23.73a	23.46a	23.54a	23.97a	23.70a	23.63a	22.85b	23.73a	23.76a
T7 (Broadcasting)	23.64a	23.65a	23.54a	23.39a	23.97a	23.63a	23.60a	23.83a	23.64a	23.66ab
T8 (Ridge and Furrow)	23.62a	23.63a	23.52a	23.15a	23.88a	23.61a	23.42a	24.03a	23.62a	23.65ab
T9 (No weeding)	23.66a	23.66a	23.66a	23.41a	24.10a	23.66a	23.48a	23.44ab	23.66a	23.68ab
T10 (Weeding with weedicide)	23.65a	23.65a	23.71a	23.42a	24.10a	23.63a	23.65a	23.79a	23.65a	23.72a
CD	0.19	0.18	0.81	0.45	1.07	0.18	0.31	0.79	0.42	0.18
SEm±	0.06	0.06	0.27	0.15	0.36	0.06	0.10	0.27	0.14	0.06

Table 15: Soil Textural Classification [Clay (15-30 cm)]

Treatments	Clay (15-30 cm) (%)									
	1ST TRIAL		**Non-Growing Period**					**2ND TRIAL**		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	13.45a	13.67a	13.69a	13.60a	13.49a	13.52a	14.15a	14.05ab	13.95a	13.93a
T2 (Straw Mulching)	13.40a	13.41a	13.52a	13.17a	13.63a	13.46a	14.18a	13.89abc	14.40a	14.39a
T3 (Plastic Mulching)	13.37a	13.53a	14.06a	13.40a	13.00a	13.33a	14.33a	14.80a	13.97a	14.08a
T4 (Minimum Tillage)	13.30a	13.57a	13.25a	13.12a	13.00a	13.28a	14.27a	13.29bc	13.30a	12.85a
T5 (Earthing up)	13.33a	12.97a	13.96a	13.51a	12.92a	13.34a	14.22a	12.81c	13.00a	13.21a
T6 (Paired row)	13.22a	13.06a	13.18a	13.28a	12.98a	13.30a	14.03a	14.36ab	13.22a	13.29a
T7 (Broadcasting)	13.32a	13.64a	13.82a	13.65a	13.00a	13.36a	14.13a	13.41bc	13.99a	14.34a
T8 (Ridge and Furrow)	13.40a	13.79a	13.32a	14.10a	13.15a	13.47a	14.14a	13.32bc	14.07a	14.19a
T9 (No weeding)	13.32a	13.37a	13.36a	13.57a	12.88a	13.31a	14.22a	13.75abc	13.66a	13.43a
T10 (Weeding with weedicide)	13.26a	13.71a	13.51a	12.97a	12.81a	13.30a	14.03a	12.84c	13.03a	12.87a
CD	0.22	0.77	1.42	0.68	1.08	0.26	0.34	1.04	1.07	1.50
SEm±	0.07	0.26	0.48	0.23	0.36	0.09	0.11	0.35	0.36	0.51

From the **Tables (10, 11, 12, 13, 14 and 15)**, the texture of soil at both soil depths (0 – 15 cm and 15 – 30 cm) was determined. The sand, silt and clay fractions did not show any significant changes at all soil depths across the treatments and along the increasing number of days (DAS). The highest and lowest values of sand fraction were 62.41% and 61.47%; 63.61% and 62.45% at the surface soil layer and subsurface soil layer respectively. Similarly, the highest silt fractions (23.65% at 0 – 15 cm, 24.10% at 15 – 30 cm) and lowest silt fractions (22.83% at 0-15 cm, 22.85% at 15-30 cm); for clay, maximum (15.83% at 0 – 15 cm, 14.80% at 15 – 30 cm) and minimum (14.47% at 0 – 15 cm, 12.81% at 15 – 30 cm) were observed. From the textural triangle, both the surface and subsurface soils was classified to be sandy loam texture.

4.1.2 Soil pH:

Table 16: Effect of different agricultural practices on pH (0-15cm)

Treatments	pH (0-15cm)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	7.54	7.51	7.50	7.55	7.50	7.47	7.51	7.49	7.43	7.40
T2 (Straw Mulching)	7.58	7.37	7.27	7.26	7.27	7.23	7.23	7.29	7.28	7.19
T3 (Plastic Mulching)	7.68	7.76	7.73	7.72	7.70	7.71	7.70	7.65	7.59	7.55
T4 (Minimum Tillage)	7.36	7.16	7.18	7.23	7.36	7.38	7.37	7.41	7.45	7.47
T5 (Earthing up)	7.41	7.36	7.39	7.38	7.40	7.35	7.35	7.38	7.36	7.37
T6 (Paired row)	7.51	7.42	7.42	7.42	7.40	7.37	7.38	7.41	7.44	7.48
T7 (Broadcasting)	7.49	7.38	7.37	7.34	7.36	7.39	7.35	7.42	7.44	7.50
T8 (Ridge and Furrow)	7.35	7.29	7.23	7.24	7.25	7.25	7.22	7.29	7.35	7.38
T9 (No weeding)	7.40	7.82	7.82	7.80	7.84	7.77	7.82	7.85	7.87	7.88
T10 (Weeding with weedicide)	7.46	7.28	7.31	7.30	7.25	7.27	7.26	7.34	7.36	7.36

Table 17: Effect of different agricultural practices on pH (15-30cm)

Treatments	pH (15-30cm)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	7.40	7.28	7.29	7.28	7.29	7.29	7.27	7.31	7.24	7.21
T2 (Straw Mulching)	7.30	7.16	7.15	7.16	7.15	7.17	7.17	7.20	7.16	7.14
T3 (Plastic Mulching)	7.40	7.52	7.51	7.51	7.50	7.50	7.49	7.44	7.43	7.42
T4 (Minimum Tillage)	7.25	7.17	7.24	7.25	7.28	7.32	7.33	7.32	7.37	7.38
T5 (Earthing up)	7.40	7.31	7.37	7.38	7.38	7.39	7.41	7.38	7.42	7.45
T6 (Paired row)	7.38	7.26	7.31	7.33	7.32	7.35	7.39	7.42	7.47	7.51
T7 (Broadcasting)	7.48	7.25	7.31	7.34	7.35	7.37	7.36	7.31	7.36	7.41
T8 (Ridge and Furrow)	7.36	7.17	7.24	7.31	7.34	7.34	7.40	7.36	7.41	7.44
T9 (No weeding)	7.51	7.78	7.73	7.72	7.69	7.70	7.72	7.67	7.70	7.73
T10 (Weeding with weedicide)	7.18	7.18	7.20	7.23	7.23	7.24	7.26	7.21	7.24	7.26

The soil buffering function (pH) is one of the most important reactions in the ecosystem. During the experimental period, the horizontal distribution of data from 45 DAS to 450 DAS observed pH range from 7.19 – 7.88 at surface soil and 7.14 – 7.78 at subsurface soil **(Table 16 and 17)**. The first treatment T1 (Fallow) observed a slight decrease in going from 45 to 450 DAS in both soil depths. At 0-15 cm, the observed value was 7.54 (45 DAS) which slightly reduced to 7.40 by 450 DAS. Similarly, a reduction in pH from 7.40 (45 DAS) – 7.21 (450 DAS) was noted in the study. The 2nd treatment T2 (Organic mulching) also followed similar findings. The values ranged from 7.58 – 7.19 and 7.30 – 7.14 from 45 DAS to 450 DAS at the respective soil depths (0-15 cm and 15-30 cm). The plastic mulch treatment (T3), however, had a slight increase from 7.68 (45 DAS) to 7.76 (90 DAS), observed no significant change until the value 7.70 (315 DAS). Afterwards, it slightly decreased to 7.55 at 450 DAS in the surface soil. In the subsurface soil, it follows a similar trend. It increased from 7.40 at 45 DAS to 7.51 at 180 DAS and further declines to 7.44 at 360 DAS. In the minimum tillage treatment (T4), pH ranges from 7.36 – 7.47 (surface soil) and 7.25 – 7.38 (subsurface soil) at 45 to 450 DAS respectively. In the earthing up (T5) and paired row (T6) treatments, a slight decrease in pH was observed in the surface soil. However, in its subsurface counterpart, a slight increase was signified in the horizontal data distribution. There was no noteworthy variation in the surface soil pH of broadcasting treatment (T7), but a slight decline from 7.48 – 7.41 was noted in the subsurface soil. The ridge and furrow treatment (T8) noted a decrease from 7.35 at 45 DAS to 7.22 at 315 DAS which raised to 7.38 by 450 DAS at 0-15 cm soil depth. At 15-30 cm, the range of pH was 7.36 – 7.44 from 45 – 450 DAS. In T9 (no weeding) treatment, noted pH readings were 7.40 – 7.88 (surface soil) and 7.51 – 7.73 (subsurface soil) at 45 to 450 DAS. In T10 (weeding with weedicide) treatment, the values ranged from 7.46 – 7.36 (surface soil) and 7.18 – 7.26 (subsurface soil) at 45 to 450 DAS.

The relative changes on the soil physicochemical properties largely depends on the disparities in temperature, plant cover and root exudations. A change in the land cover could also thoroughly change the biogeochemical properties in a soil system. The pH of the soil decreases with the application of organic mulches which is much more profound than the non-mulched treatments. An interrelation between soil pH and organic mulches could be developed as organic acids are released during decomposition of organic residues. This causes a decline in pH in the agricultural soils (Mrabet *et al.,* 2001; Sinha *et al.,* 2019). Also, findings of Gulzar *et al.,* 2020 provided insight on the lesser pH in minimum tillage system in comparison to other conventional practices, which is relevant with our current findings. The pH in the subsurface soil is also lower in minimum tillage practices. In other conventional tillage practices, pH at different soil depths remained maintained uniformity due to proper soil mixing during cultivation (López-Fando and Pardo, 2009). In another study by Ghimire *et al.,* 2017, higher nitrogen retention in agricultural practices could also increase soil pH since localized mineralization of nitrogen takes place, which could be true for our agricultural practices such as fallow, earthing up and weeding with weedicide treatments.

4.1.3 Electrical conductivity (EC) (mmhos cm^{-1}):

Table 18: Effect of different agricultural practices on EC (0-15cm)

Treatments	EC (0-15cm) (mmhos cm^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	0.672	0.623	0.659	0.658	0.643	0.633	0.625	0.614	0.605	0.592
T2 (Straw Mulching)	0.634	0.614	0.605	0.577	0.553	0.549	0.544	0.540	0.529	0.512
T3 (Plastic Mulching)	0.729	0.723	0.732	0.721	0.744	0.738	0.731	0.706	0.706	0.716
T4 (Minimum Tillage)	0.654	0.749	0.692	0.681	0.686	0.674	0.665	0.667	0.659	0.652
T5 (Earthing up)	0.577	0.515	0.551	0.587	0.556	0.545	0.538	0.525	0.506	0.494
T6 (Paired row)	0.686	0.659	0.618	0.622	0.624	0.603	0.597	0.593	0.548	0.523
T7 (Broadcasting)	0.736	0.757	0.763	0.799	0.777	0.775	0.787	0.752	0.733	0.713
T8 (Ridge and Furrow)	0.543	0.500	0.521	0.532	0.561	0.491	0.478	0.469	0.468	0.455
T9 (No weeding)	0.593	0.572	0.578	0.613	0.584	0.583	0.564	0.583	0.562	0.537
T10 (Weeding with weedicide)	0.611	0.645	0.669	0.648	0.641	0.641	0.637	0.624	0.609	0.606

Table 19: Effect of different agricultural practices on EC (15-30cm)

Treatments	EC (15-30cm) (mmhos cm^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	0.570	0.553	0.555	0.543	0.563	0.583	0.564	0.549	0.532	0.524
T2 (Straw Mulching)	0.537	0.525	0.530	0.538	0.536	0.537	0.527	0.514	0.484	0.476
T3 (Plastic Mulching)	0.631	0.622	0.614	0.598	0.617	0.605	0.580	0.578	0.571	0.554
T4 (Minimum Tillage)	0.612	0.657	0.658	0.666	0.652	0.663	0.625	0.646	0.629	0.607
T5 (Earthing up)	0.497	0.446	0.436	0.461	0.471	0.449	0.446	0.431	0.437	0.415
T6 (Paired row)	0.575	0.543	0.522	0.534	0.540	0.544	0.517	0.513	0.480	0.458
T7 (Broadcasting)	0.657	0.666	0.661	0.656	0.663	0.641	0.654	0.646	0.635	0.634
T8 (Ridge and Furrow)	0.486	0.431	0.416	0.426	0.463	0.424	0.422	0.410	0.410	0.393
T9 (No weeding)	0.516	0.473	0.483	0.486	0.459	0.458	0.470	0.458	0.467	0.455
T10 (Weeding with weedicide)	0.558	0.550	0.514	0.481	0.487	0.469	0.500	0.510	0.485	0.468

The values of EC showed significant variability during the entire experimental period as described in **Tables 18 and 19**. Treatment T1 indicated a gradual decrease from 0.672 – 0.592 mmhos cm^{-1} (0-15 cm) and 0.570 – 0.524 mmhos cm^{-1} (15-30 cm). T2 followed similar readings which inscribed as 0.634 – 0.512 mmhos cm^{-1} (0-15 cm) and 0.537 – 0.476 mmhos cm^{-1} (15-30 cm). A slight increase in EC was observed in the surface soil of T3 and T4 during the non-growing period. In the surface soil, it ranged from 0.729 mmhos cm^{-1} at 45 DAS to a maximum of 0.744 mmhos cm^{-1} at 225 DAS and a final reading of 0.716 mmhos cm^{-1} at 450 DAS for plastic mulching treatment T3. The subsurface soil noted a range from 0.631 to 0.554 mmhos cm^{-1}. In T4, values in surface soil were 0.654 mmhos cm^{-1} at 45 DAS which increased to 0.686 mmhos cm^{-1} at 225 DAS and 0.652 mmhos cm^{-1} at 450 DAS. In the subsurface soil, it ranged from 0.612 – 0.607 mmhos cm^{-1} at 45 DAS – 450 DAS. A slight decrease could be noted in treatment T5 in both surface (0.577 – 0.494 mmhos cm^{-1}) and subsurface (0.497 – 0.415 mmhos cm^{-1}) soils. Similar findings were noticed in T6 treatment whose readings were 0.686 – 0.523 mmhos cm^{-1} (surface soil) and 0.575 – 0.458 mmhos cm^{-1} (subsurface soil) at 45 – 450 DAS. Variability in the readings were recorded in surface soil of T7. It increased from 0.736 mmhos cm^{-1} at 45 DAS to 0.799 mmhos cm^{-1} at 180 DAS and decreased to 0.713 mmhos cm^{-1} towards the end of the experimental period. In the subsurface soil, values were ranged from 0.657 – 0.634 mmhos cm^{-1}. Both surface and subsurface soils of T8 and T9 showed a gradual decrease in their readings. T8 noted readings of 0.543 – 0.455 mmhos cm^{-1} (surface) and 0.486 – 0.393 mmhos cm^{-1} (subsurface). For T9, values ranged from 0.593 – 0.537 mmhos cm^{-1} at surface layers and 0.516 – 0.455 mmhos cm^{-1} at subsurface soil layers. In case of T10, the surface soil increased in its EC readings from 0.611 mmhos cm^{-1} at 45 DAS to 0.669 mmhos cm^{-1} at 135 DAS and further declined to 0.606 mmhos cm^{-1} at 450 DAS. The subsurface counterpart noted a gradual decrease from 0.558 – 0.468 mmhos cm^{-1}.

The EC of a soil solution indicates the ionic activity (cations and anions) in the system. It is an important parameter for gauging the organic matter mineralization in soils (Candemir and Gülser, 2010). Inorganic fertilization is a primary cause for the increase in EC on wheat- maize cropping in Indo-Gangetic plains (Choudhary *et al.,* 2018, Chandel *et al.,* 2021). Nevertheless, the application of vermicompost integrates potent effect on soil EC. As stated by Demir *et al.,* 2020, organic matter application enhances the chemical properties of soil. The EC of soil can be managed by amending it with vermicompost and it could create potential changes to the EC. The application of 10 t ha^{-1} vermicompost resulted in the decrease of EC (Uz and Tavali, 2014), which is in accordance with our current research. Irrigation is also a primary factor which generates significant changes to EC in the soil system (Gunasekaran *et al.,* 2021). The leaching of basic cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) in soils or drainage through streams as runoff could offset the soil EC.

4.1.4 Bulk density (BD) (g cm^{-3}):

Table 20: Effect of different agricultural practices on BD (0-15cm)

Treatments	BD (0-15cm) (g cm^{-3})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	1.39	1.42	1.40	1.43	1.42	1.43	1.41	1.40	1.42	1.41
T2 (Straw Mulching)	1.37	1.38	1.36	1.38	1.36	1.37	1.38	1.35	1.36	1.35
T3 (Plastic Mulching)	1.38	1.40	1.41	1.42	1.40	1.44	1.41	1.40	1.38	1.37
T4 (Minimum Tillage)	1.37	1.38	1.42	1.41	1.43	1.42	1.45	1.43	1.42	1.43
T5 (Earthing up)	1.40	1.37	1.37	1.39	1.40	1.41	1.41	1.37	1.38	1.36
T6 (Paired row)	1.36	1.38	1.36	1.37	1.37	1.38	1.37	1.35	1.34	1.35
T7 (Broadcasting)	1.38	1.41	1.39	1.42	1.38	1.39	1.39	1.37	1.40	1.41
T8 (Ridge and Furrow)	1.37	1.35	1.36	1.37	1.38	1.40	1.40	1.41	1.37	1.39
T9 (No weeding)	1.39	1.42	1.44	1.43	1.45	1.42	1.41	1.38	1.39	1.38
T10 (Weeding with weedicide)	1.40	1.41	1.43	1.44	1.42	1.43	1.42	1.41	1.39	1.41

Table 21: Effect of different agricultural practices on BD (15-30 cm)

Treatments	BD (15-30 cm) ($g\ cm^{-3}$)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	1.45	1.43	1.44	1.43	1.45	1.44	1.46	1.48	1.47	1.48
T2 (Straw Mulching)	1.46	1.45	1.46	1.48	1.48	1.46	1.47	1.43	1.44	1.47
T3 (Plastic Mulching)	1.45	1.44	1.43	1.44	1.46	1.47	1.46	1.47	1.45	1.46
T4 (Minimum Tillage)	1.44	1.46	1.47	1.47	1.49	1.48	1.47	1.48	1.49	1.48
T5 (Earthing up)	1.45	1.44	1.45	1.42	1.46	1.45	1.47	1.45	1.47	1.46
T6 (Paired row)	1.46	1.45	1.46	1.45	1.46	1.49	1.48	1.46	1.48	1.47
T7 (Broadcasting)	1.48	1.46	1.47	1.49	1.5	1.52	1.51	1.47	1.51	1.49
T8 (Ridge and Furrow)	1.47	1.49	1.51	1.48	1.49	1.47	1.48	1.45	1.46	1.45
T9 (No weeding)	1.46	1.48	1.46	1.49	1.47	1.48	1.47	1.48	1.51	1.49
T10 (Weeding with weedicide)	1.48	1.47	1.46	1.47	1.46	1.48	1.51	1.48	1.49	1.50

The bulk density (BD) provides a physical characteristic in the soil system. During the experimental period, it was observed that BD developed no substantial changes due to tillage practices and other environmental conditions. A slight variability in the BD was discerned in the treatments during the non-growing period in both soil layers **(Table 20 and 21)**. T1 showed BD values of 1.39 g cm^{-3} at 45 DAS to 1.41 g cm^{-3} at 450 DAS at the surface soil. At the subsurface soil layer, the values were 1.45 g cm^{-3} at 45 DAS to 1.48 g cm^{-3} at 450 DAS. Treatment T2 showed very slight variations. The BD of T2 ranged from 1.37 – 1.35 g cm^{-3} (0-15 cm) and 1.46 – 1.47 g cm^{-3} (15-30 cm) at 45 DAS and 450 DAS respectively. Treatment T3 noted a range from 1.38 g cm^{-3} (45 DAS) to 1.37 g cm^{-3} (450 DAS) on the surface soil. The subsurface soil indicated values range from 1.45 – 1.46 g cm^{-3}. Minimum tillage treatment (T4) also developed no significant changes in BD in both soil layers. In the surface layers, it ranged from 1.37 – 1.43 g cm^{-3} and 1.44 – 1.48 g cm^{-3} in the subsurface layers. T5 ranged from 1.40 – 1.36 g cm^{-3} (surface soil) and 1.45 – 1.46 g cm^{-3} during 45 DAS to 450 DAS respectively. The paired row treatment (T6) indicated BD from 1.36 g cm^{-3} (45 DAS) to 1.35 g cm^{-3} (450 DAS) at 0-15 cm soil depth. The BD in subsurface soil layer developed from 1.46 g cm^{-3} (45 DAS) to 1.47 g cm^{-3} (450 DAS). Contrastingly, T7 showed increase in BD from 1.38 g cm^{-3} (45 DAS) to 1.41 g cm^{-3} (450 DAS) at surface layers. The subsurface layers also noted a range from 1.48 – 1.49 g cm^{-3}. Treatment T8 ranged from 1.37 – 1.39 g cm^{-3} (0-15 cm) and 1.47 – 1.45 g cm^{-3} (15- 30 cm) at 45 DAS and 450 DAS respectively. The BD of T9 was determined as 1.39 g cm^{-3} at 45 DAS to 1.38 g cm^{-3} at 450 DAS in the surface soil. The subsurface soil noted increase from 1.46 – 1.49 g cm^{-3} at 45 DAS to 450 DAS. Treatment T10 noted changes in BD from 1.40 – 1.41 g cm^{-3} (0-15 cm) and 1.48 – 1.50 g cm^{-3} (15- 30 cm).

The bulk density in a reduced tillage system increases significantly in comparison to other conventional agricultural tillage practices in the soil layers (Hati *et al.,* 2015; Martin Lammerding *et al.,* 2015). However, over a longer period of time from the time of cultivation, less significant differences were observed in the reduced tillage system and conventional tillage (Dal Ferro *et al.,* 2023). This, in fact, corresponded to our findings on minimum tillage treatment (T4) over other agricultural practices at both soil depths. Mulching treatments also lead a decline in BD in case of straw mulch and an increase in case of plastic mulching (Wang *et al.,* 2017). This could be attributed towards the proper soil aggregation, increased porosity and organic matter (OM) in the soil system of mulched plots (Acharya *et al.,* 2023).

4.1.5 Av. Nitrogen (Av. N) (kg ha^{-1}):

Table 22: Effect of different agricultural practices on Av. N (0-15cm)

Treatments	Av. N (0-15cm) (kg ha^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	100.35abcd	104.53abc	112.90abc	117.08ab	112.67ab	108.17abc	108.72ab	117.08a	121.26abc	129.62abcd
T2 (Straw Mulching)	108.71abc	117.08ab	121.26ab	125.44a	125.74a	133.03a	133.80a	142.16a	150.53a	154.71a
T3 (Plastic Mulching)	96.17abcd	87.81bc	100.35abc	108.71ab	104.26ab	103.99bc	108.44ab	117.08a	100.35bc	117.08bcde
T4 (Minimum Tillage)	83.63de	100.35abc	104.53abc	108.47ab	108.71ab	117.08abc	121.26ab	129.62a	133.80a	142.17ab
T5 (Earthing up)	87.81cde	83.62c	96.17bc	104.54ab	100.35ab	100.08c	108.71ab	117.08a	125.44ab	121.26bcde
T6 (Paired row)	112.90ab	121.26a	125.44a	125.13a	129.21a	129.62ab	133.27a	137.80a	142.17a	133.80abc
T7 (Broadcasting)	96.17abcd	108.71abc	108.44abc	104.53ab	100.35ab	104.26bc	104.64b	125.44a	100.67bc	104.54de
T8 (Ridge and Furrow)	91.99bcde	100.20abc	104.53abc	104.54ab	105.71ab	108.14abc	108.71ab	112.89a	121.26abc	116.96bcde
T9 (No weeding)	117.08a	83.63c	96.17bc	96.17b	99.81ab	108.71abc	117.08ab	125.44a	120.43abc	108.48cde
T10 (Weeding with weedicide)	71.08e	79.45c	91.99c	96.17b	91.45b	95.90c	104.53b	112.89a	91.99c	100.24e
CD	19.15	25.05	23.89	26.22	25.64	25.99	24.22	28.35	26.41	21.71
SEm±	6.45	8.43	8.04	8.83	8.63	8.75	8.15	9.54	8.89	7.31

Table 23: Effect of different agricultural practices on Av. N (15-30 cm)

Treatments	Av. N (15-30 cm) (kg ha^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	83.64a	83.62a	79.36ab	87.81ab	87.54ab	95.90ab	95.09abc	100.20ab	100.08abc	108.71ab
T2 (Straw Mulching)	79.36a	96.17a	91.90a	100.35a	104.53a	108.45a	112.53a	112.90a	117.08a	120.99a
T3 (Plastic Mulching)	80.36a	71.08a	62.63ab	75.26ab	87.54ab	83.09abc	87.54abc	91.45abc	95.90abc	100.08ab
T4 (Minimum Tillage)	83.54a	83.62a	79.45ab	83.63abc	91.45ab	91.99abc	100.35ab	95.90abc	104.26ab	108.71ab
T5 (Earthing up)	79.83a	69.90a	66.81ab	79.45abc	83.63ab	83.36abc	87.81abc	91.99abc	96.17abc	100.08ab
T6 (Paired row)	81.57a	96.16a	83.54ab	91.99ab	95.90ab	96.17ab	100.13ab	100.35ab	108.71ab	110.81ab
T7 (Broadcasting)	80.73a	87.80a	75.18ab	75.26abc	83.36ab	83.26abc	83.63abc	87.33abc	87.81bc	91.99ab
T8 (Ridge and Furrow)	75.18a	75.26a	66.90ab	75.26abc	74.99ab	83.36abc	87.08abc	87.80abc	96.17abc	104.26ab
T9 (No weeding)	78.76a	66.90a	54.36b	58.39c	58.54b	62.72c	62.72c	66.90c	79.18c	87.54ab
T10 (Weeding with weedicide)	76.60a	75.26a	66.90ab	66.13bc	66.63b	71.08bc	71.27bc	75.26bc	79.45c	83.63c
CD	15.10	25.99	27.76	23.39	33.45	25.85	22.80	23.74	20.50	28.42
SEm±	5.08	8.75	9.34	7.87	11.26	8.70	7.67	7.99	6.90	9.57

A gradual increase in the amount of available Nitrogen (Av. N) was noticed when the experiment progressed from 1st trial to non-growing period in both soil layers **(Table 22 and 23)**. T1 (fallow) maintained an optimum amount of Av. N during the entire experimental period. At 0-15 cm soil layer, T1 observed values of 100.35 kg ha^{-1} (45 DAS), increasing to 117.08 kg ha^{-1} (360 DAS) and 129.62 kg ha^{-1} (450 DAS). At 15-30 cm soil depth, it ranged from 83.64 kg ha^{-1} (45 DAS) – 108.71 kg ha^{-1} (450 DAS). The values of 108.71 kg ha^{-1} (45 DAS) to 142.80 kg ha^{-1} (360 DAS) and finally 154.71 kg ha^{-1} (450 DAS) were observed in T2 at surface layers. In the subsurface layers, it ranged from 79.36 kg ha^{-1} (45 DAS) – 120.99 kg ha^{-1} (450 DAS). T3 noted readings 96.17 kg ha^{-1} (45 DAS) – 117.08 kg ha^{-1} (450 DAS) in surface soil while the subsurface soil recorded 80.36 kg ha^{-1} (45 DAS) to 100.08 kg ha^{-1} (450 DAS). Treatment T4 varied from 83.63 kg ha^{-1} (45 DAS) to 142.17 kg ha^{-1} (450 DAS) in the surface soil. The subsurface soil established a range of 83.54 kg ha^{-1} (45 DAS) to 108.71 kg ha^{-1} (450 DAS). The remaining studies also followed similarity, whereby an increase in Av. N was observed at the end of the second trial (450 DAS). The surface soil of T5, T6, T7, T8, T9 and T10 expressed results of 87.81, 112.90, 96.17, 91.99, 117.08, 71.08 kg ha^{-1} at 45 DAS which increased to 121.26, 133.80, 104.54, 116.96, 108.48 and 100.24 kg ha^{-1} at 450 DAS respectively. The subsurface soil in treatments T5, T6, T7, T8, T9 and T10 had value ranges from 79.83, 81.57, 80.73, 75.18, 78.76, 76.60 kg ha^{-1} at 45 DAS and 100.08, 110.81,91.99, 104.26, 87.54, 83.63 kg ha^{-1} at 450 DAS respectively.

The application of inorganic fertilizers and vermicompost could have provided an increase in the Av. N during the initial phases of the experiment. During the non-growing period, we could infer an optimum Av. N present in the soil at both soil depths of fallow treatment. This was probably an outcome of not planting any crops in the fallow treatment (T1). In the straw mulching (T2) and plastic mulching (T3), the slight increase in Av. N during the non-growing period could probably be an outcome established due to the decomposition of organic matter (OM) from their respective treatments. The rest of treatments also developed a gradual increase in Av. N in the upper soil depths. This was clearly shown in the **Tables 19** and **20.** A study by Monsefi *et al.,* 2014 implied that tillage and mulching developed no discernible effect on the soil Av. N. However, our research indicated that mulching and other agricultural practices underwent notable variations on Av. N. The results are analogous with Akhtar *et al.,* 2018, which revealed that generation of higher Av. N in straw mulching treatments at surface soils and become less in the subsurface layers. Mulching provided favourable soil water and temperature, which were conducive environments for net mineralization of OM in the mulches, causing a hike in Av. N (Coppens *et al.,* 2006). In another study by Borie *et al.,* 2006, higher Av. N was recorded in reduced tillage (minimum tillage) rather than the other conventional tillage employed after the harvest of crops. Sufficient evidence was also revealed in a study by López- Fando and Pardo, 2009, which reported a higher nitrogen composition in the surface soil after 5 years of experimentation and the order of tillage practices in which higher Av. N was recorded in: zero tillage > minimum tillage > conventional tillage. Av. N was reportedly more in the surface soils and lower in the subsurface layers (Das *et al.,* 2021).

4.1.6 Av. Phosphorus (Av. P) (kg ha^{-1}):

Table 24: Effect of different agricultural practices on Av. P (0-15cm)

Treatments	Av. P (0-15cm) (kg ha^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	11.17bc	12.60cde	12.37ef	12.27c	12.18b	11.98e	12.00b	11.88c	11.92c	12.12c
T2 (Straw Mulching)	13.57a	14.30a	14.28a	14.30a	14.13a	13.82b	13.68a	13.47a	14.04a	14.35a
T3 (Plastic Mulching)	13.01a	13.84ab	13.96a	13.86a	13.69a	14.18a	13.91a	13.22a	13.59ab	13.92a
T4 (Minimum Tillage)	11.63bc	12.28def	12.44de	12.53bc	12.39b	12.69c	12.67b	12.36bc	12.52bc	13.12b
T5 (Earthing up)	11.51bc	12.37def	12.42de	12.41c	12.52b	12.63cd	12.46b	12.51b	12.96abc	12.94b
T6 (Paired row)	10.83c	11.72f	12.05fg	12.34c	12.34b	12.39cd	12.29b	12.04bc	12.50bc	12.81bc
T7 (Broadcasting)	11.77b	13.31bc	13.29ab	13.04b	12.39b	12.30de	12.04b	12.07bc	12.57bc	12.69bc
T8 (Ridge and Furrow)	11.59bc	12.76cd	12.80c	12.62bc	12.34b	12.37cd	12.24b	12.18bc	12.46bc	12.64bc
T9 (No weeding)	11.40bc	11.96ef	11.88g	12.32c	12.35b	12.27de	12.06b	12.07bc	12.19c	12.78bc
T10 (Weeding with weedicide)	11.15bc	12.78cd	12.76cd	12.64bc	12.41b	12.49cd	12.32b	12.15bc	12.54bc	12.51bc
CD	0.60	0.69	0.36	0.53	0.67	0.34	0.53	0.49	0.88	0.44
SEm±	0.20	0.24	0.12	0.18	0.22	0.11	0.18	0.17	0.30	0.15

Table 25: Effect of different agricultural practices on Av. P (15-30 cm)

Treatments	Av. P (15-30 cm) (kg ha^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	6.36c	6.34c	6.50d	6.50c	6.56d	6.60c	6.60d	6.64c	7.24cd	7.32c
T2 (Straw Mulching)	6.98b	7.00b	7.15ab	7.24ab	7.34ab	7.36a	7.38ab	7.43a	7.93a	8.09ab
T3 (Plastic Mulching)	7.42a	7.38a	7.35a	7.44a	7.51a	7.53a	7.54a	7.59a	8.06a	8.34a
T4 (Minimum Tillage)	6.45c	6.50c	6.71c	7.05b	7.09bc	7.11ab	7.12bc	7.18ab	7.23cd	7.31c
T5 (Earthing up)	5.92de	6.02d	6.31de	6.33c	6.53d	6.55c	6.57d	6.56c	7.50bc	7.70bc
T6 (Paired row)	6.92b	6.85b	7.07b	7.22ab	7.47a	7.45a	7.45ab	7.46a	7.60b	7.62bc
T7 (Broadcasting)	5.85e	5.95d	6.15e	6.52c	6.58d	6.54c	6.55d	6.53c	7.17cd	7.70bc
T8 (Ridge and Furrow)	7.05ab	6.82b	6.94b	7.00b	7.11bc	7.17ab	7.20ab	7.27ab	7.42bcd	7.86abc
T9 (No weeding)	5.77e	5.99d	6.29de	6.39c	6.80cd	6.85bc	6.84cd	6.88bc	7.40bcd	7.78abc
T10 (Weeding with weedicide)	6.31cd	6.36c	6.46d	6.46c	6.49d	6.54c	6.57d	6.54c	7.17d	7.63bc
CD	0.28	0.15	0.12	0.27	0.28	0.42	0.31	0.44	0.30	0.32
SEm±	0.10	0.05	0.04	0.09	0.10	0.14	0.11	0.15	0.10	0.11

The available Phosphorus (Av. P) were observed to be possess significant variations in the treatments and along the horizontal data distribution. Upon observation of the data for both surface and subsurface soils from 45 DAS to 450 DAS, the Av. P seems to be gradually increasing along the number of days after sowing (DAS) in all treatments **(Tables 24 and 25)**. The values of T1 ranged from 11.17 – 12.12 kg ha^{-1} (0-15 cm) and 6.36 – 7.32 kg ha^{-1} (15-30 cm). The range for treatment T2 was 13.57 – 14.35 kg ha^{-1} (0-15 cm) and 6.98 – 8.09 kg ha^{-1} (15-30 cm). In case of T3 and T4, the observed values were 13.01 – 13.92 kg ha^{-1} (0-15 cm), 7.42 – 8.34 kg ha^{-1} (15-30 cm) and 11.63 – 13.12 kg ha^{-1} (0-15 cm), 6.45 – 7.31 kg ha^{-1} (15-30 cm) respectively. The remaining treatments also followed similar inclinations. The surface layers of T5, T6, T7, T8, T9 and T10 indicated value ranging from 11.51 – 12.94 kg ha^{-1}, 10.83 – 12.81 kg ha^{-1}, 11.77 – 12.69 kg ha^{-1}, 11.59 – 12.64 kg ha^{-1}, 11.40 – 12.78 kg ha^{-1} and 11.15 – 12.51 kg ha^{-1} respectively. Similarly, the subsurface layers observed values of 5.92 – 7.70 kg ha^{-1}, 6.92 – 7.62 kg ha^{-1}, 5.85 – 7.70 kg ha^{-1}, 7.05 – 7.89 kg ha^{-1}, 5.77 – 7.78 kg ha^{-1} and 6.31 – 7.78 kg ha^{-1} respectively.

The addition of synthetic fertilizers accompanied by vermicompost could have increased the Av. P in the soil layers. This was consistent with the findings of Chandel *et al.,* 2021. The straw mulching treatment maintained significant status quo with Av. P. The organic mulches acquired a tendency for accumulation of Av. P (Sinkevičienė et al, 2009). The Av. P were also notably more for the surface layers than the subsurface soils. This could be result of the organic matter (OM) deposition in the upper zone of soil leading to an increase in Av. P at upper soil depths (Akhtar *et al.,* 2018). The mulching treatments had significant higher presence of Av. P at both soil layers than the other non-mulched treatments. Adak *et al.,* 2023 observed a spike of 13.56% and 30.70% Av. P at 0-15 cm and 15-30 cm soil depths respectively in the mulched and non-mulched treatments. The higher Av. P in mulched plots could be an indication of organic acids being liberated at the time of decomposition of the accumulated residues and native P-solubilization of organic residues in mulching treated plots (Piegholdt *et al.,* 2013; Dorneles *et al.,* 2015; Adak *et al.,* 2023). The minimum tillage system also offered higher Av. P in surface soil and decreased in lower layers than the other agricultural practices. This might be result of decreased mixing of P from fertilizers during tillage practices and possible increase of organic P which developed higher mobility than inorganic P (Lopez-Fando and Pardo, 2009).

4.1.7 Av. Potassium (Av. K) (kg ha^{-1}):

Table 26: Effect of different agricultural practices on Av. K (0-15 cm)

Treatments	Av. K (0-15 cm) (kg ha^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	240.00d	229.25ab	226.52ab	223.62abc	222.43a	221.38b	217.77bc	217.04ab	251.74d	229.15bc
T2 (Straw Mulching)	232.88e	228.16ab	226.03ab	224.42abc	223.28a	222.69ab	217.99bc	219.16ab	278.30b	252.39a
T3 (Plastic Mulching)	259.46a	216.20cd	214.99bc	210.14cd	210.11b	210.05c	206.32de	210.94bc	286.42a	236.64ab
T4 (Minimum Tillage)	218.93f	235.21a	227.17ab	226.25ab	227.37a	227.03ab	225.46ab	216.90ab	249.29d	235.20ab
T5 (Earthing up)	252.13ab	237.14a	235.24a	234.73a	232.79a	230.34a	229.05a	227.82a	262.24c	228.89bc
T6 (Paired row)	240.93d	209.68de	207.88c	207.17de	207.01b	206.66c	209.89cd	209.52bc	251.50d	235.37ab
T7 (Broadcasting)	207.17g	198.05f	198.30c	192.10e	192.01c	191.97e	195.67f	194.33d	238.68e	214.77cd
T8 (Ridge and Furrow)	243.66cd	210.07de	206.32c	199.31de	198.67bc	198.25de	198.44ef	199.12de	251.87d	232.22bc
T9 (No weeding)	243.77cd	221.41bc	214.76bc	211.37bcd	208.99b	207.06c	202.17def	202.99de	257.32cd	240.37ab
T10 (Weeding with weedicide)	249.60bc	204.57ef	203.12c	203.71de	202.23bc	202.04cd	198.01ef	198.72de	234.03e	207.13d
CD	5.00	7.87	15.80	13.18	11.20	7.79	9.37	12.20	7.72	14.13
SEm±	1.68	2.65	5.32	4.44	3.77	2.62	3.17	4.11	2.60	4.76

Table 27: Effect of different agricultural practices on Av. K (15-30 cm)

Treatments	Av. K (15-30 cm) (kg ha^{-1})									
	1ST TRIAL		**Non-Growing Period**					**2ND TRIAL**		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	141.96b	142.94b	145.74d	145.83b	147.54a	150.47b	150.79c	150.88c	151.39bcd	151.56c
T2 (Straw Mulching)	148.63ab	151.48a	149.50bcd	149.21ab	153.28a	153.37ab	153.75bc	153.99bc	148.73cd	156.89bc
T3 (Plastic Mulching)	147.03ab	149.23ab	150.54abcd	151.45ab	156.65a	156.72ab	156.13abc	158.06abc	153.04abcd	161.88ab
T4 (Minimum Tillage)	148.73ab	153.34a	154.11ab	155.89a	156.27a	157.85ab	155.23abc	155.99abc	153.74abc	155.57bc
T5 (Earthing up)	146.63ab	147.41ab	148.80cd	155.12a	159.53a	160.78ab	160.81ab	160.39ab	153.76abc	165.93a
T6 (Paired row)	149.16ab	150.57a	151.71abc	151.32ab	151.77a	151.12b	153.39bc	153.76bc	148.14d	155.64bc
T7 (Broadcasting)	146.55ab	149.23ab	149.29bcd	153.18ab	156.66a	162.64a	162.49a	162.95a	156.23ab	166.06a
T8 (Ridge and Furrow)	146.73ab	151.17a	148.12cd	151.41ab	158.83a	159.23ab	159.25ab	159.36ab	155.41ab	162.91ab
T9 (No weeding)	147.24ab	151.06a	150.37abcd	151.60ab	156.05a	156.63ab	157.31abc	157.26abc	148.01d	157.84bc
T10 (Weeding with weedicide)	151.92a	151.89a	154.68a	154.96a	158.70a	158.97ab	159.84ab	159.37ab	157.30a	158.46abc
CD	6.59	6.25	3.71	7.10	11.22	10.13	6.20	6.78	5.09	7.40
SEm±	2.22	2.10	1.25	2.39	3.78	3.41	2.09	2.28	1.71	2.49

The analysis of available Potassium (Av. P) exhibited significant variation in both the soil layers **(Tables 26 and 27)**. Upon further detailing, it was observed that Av. P was higher during the two trial periods and lower in the non-growing period for surface soils. However, a slight increase could be ascertained in the subsurface soil along its horizontal distribution. In treatment T1, Av. P delineated a value of 240.00 kg ha^{-1} (45 DAS), declining to 217.77 kg ha^{-1} (315 DAS) and 229.15 kg ha^{-1} (450 DAS) in the surface layer. In its subsurface counterpart, a gradual increase from 141.96 kg ha^{-1} (45 DAS) to 151.56 kg ha^{-1} (450 DAS) could be observed. In T2, the values ranged from 232.88 kg ha^{-1} (45 DAS), declining to 217.99 kg ha^{-1} (315 DAS) and finally at 252.39 kg ha^{-1} (450 DAS) in 0-15 cm soil depth. In 15-30 cm, it increased from 148.63 kg ha^{-1} (45 DAS) to 156. 89 kg ha^{-1} (450 DAS). The T3 treatment charted a range from 259.45 kg ha^{-1} (45 DAS), 206.32 kg ha^{-1} (315 DAS) and 236.64 kg ha^{-1} (450 DAS); 147.03 kg ha^{-1} (45 DAS) – 161.88 kg ha^{-1} (450 DAS) in surface and subsurface layers respectively. In case of T4, both the surface (218.93 – 235.20 kg ha^{-1}) and subsurface layers (148.73 – 155.57 kg ha^{-1}) recorded a minor increase in Av. K. The remaining treatments T5, T6, T7, T8, T9 and T10 registered value ranges from 252.13 – 228.89 kg ha^{-1}, 240.93 – 235.37 kg ha^{-1}, 207.17 – 214.77 kg ha^{-1}, 243.66 – 232.22 kg ha^{-1}, 243.77 – 240.37 kg ha^{-1} and 249.60 – 207.13 kg ha^{-1} between 45 DAS and 450 DAS in the surface soil respectively. The subsurface layers denoted values ranging from 146.63 – 165.93 kg ha^{-1}, 149.16 – 155.64 kg ha^{-1}, 146.55 – 166.06 kg ha^{-1}, 146.73 – 162.91 kg ha^{-1}, 147.24 – 157.84 kg ha^{-1} and 151.92 – 158.46 kg ha^{-1} respectively. Mulching treatment did not offer significance on the Av. K content in soil (Sinkevičienė *et al.,* 2009). However, residue application and retention offered better Av. P in soil through the decomposition of highly K loaded biomass (Meena *et al.,* 2018). Av. K within a tillage system developed increased accumulation in the surface layers than the subsurface (Thomas *et al.,* 2007) and it was consistent with our results. The lowering of Av. K during the trial periods and non-growing periods could potentially be a result of uptake by plants and leaching down of nutrients towards the subsurface layers, which induced an increase in Av. K in going from 45 to 450 DAS.

4.1.8 Av. Sulphur (Av. S) (kg ha^{-1}):

Table 28: Effect of different agricultural practices on Av. S (0-15 cm)

Treatments	Av. S (0-15 cm) (kg ha^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	22.62ab	23.81abc	23.58abc	22.77ab	22.62ab	22.62ab	22.54ab	22.54ab	23.12a	23.65c
T2 (Straw Mulching)	24.46a	25.61a	25.38a	24.53a	24.46a	24.46a	24.38a	24.38a	25.38a	25.99a
T3 (Plastic Mulching)	23.73ab	24.99ab	24.84ab	23.92ab	23.77ab	23.77ab	23.77ab	23.77ab	24.72a	25.38abc
T4 (Minimum Tillage)	23.35ab	24.57abc	24.38abc	23.54ab	23.42ab	23.42ab	23.35ab	23.35ab	24.65a	24.92abc
T5 (Earthing up)	22.34ab	23.50abc	23.31abc	22.50ab	22.35ab	22.35ab	22.27ab	22.27ab	23.50a	24.11abc
T6 (Paired row)	21.39b	22.39bc	22.27bc	21.43b	21.35b	21.35b	21.32b	21.32b	23.35a	23.61c
T7 (Broadcasting)	22.77ab	23.96abc	23.73abc	22.96ab	22.81ab	22.81ab	22.73ab	22.73ab	24.34a	24.61abc
T8 (Ridge and Furrow)	23.31ab	24.53abc	24.38abc	23.54ab	23.35ab	23.35ab	23.35ab	23.35ab	24.95a	25.87ab
T9 (No weeding)	21.66b	22.81abc	22.58abc	21.81b	21.66b	21.66b	21.62b	21.62ab	23.77a	23.96bc
T10 (Weeding with weedicide)	21.35b	21.81c	21.66c	21.55b	21.39b	21.39b	21.39b	21.39b	23.42a	23.65c
CD	2.25	2.66	2.62	2.29	2.25	2.25	2.24	2.24	2.10	1.79
SEm±	0.76	0.89	0.88	0.77	0.76	0.76	0.76	0.76	0.71	0.60

Table 29: Effect of different agricultural practices on Av. S (15-30 cm)

Treatments	Av. S (15-30 cm) (kg ha^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	19.71abcd	20.82a	20.74a	20.74a	20.82a	20.82a	20.93a	20.55a	20.55a	20.97a
T2 (Straw Mulching)	21.51a	22.66a	22.70a	22.70a	22.62a	22.62a	22.58a	22.66a	22.81a	23.08a
T3 (Plastic Mulching)	20.70ab	21.70a	21.78a	21.78a	21.66a	21.66a	21.81a	21.78a	21.74a	22.12a
T4 (Minimum Tillage)	20.40abc	21.62a	21.66a	21.66a	21.58a	21.58a	21.66a	22.16a	21.74a	21.81a
T5 (Earthing up)	19.56abcd	20.47a	20.44a	20.44a	20.47a	20.47a	20.28a	20.40a	20.55a	21.32a
T6 (Paired row)	18.64cd	20.01a	19.98a	19.98a	19.98a	19.98a	20.13a	19.86a	19.94a	20.51a
T7 (Broadcasting)	19.48bcd	20.17a	20.32a	20.32a	20.13a	20.13a	20.40a	20.17a	20.28a	20.97a
T8 (Ridge and Furrow)	20.05abcd	21.13a	21.32a	21.32a	21.09a	21.09a	21.35a	21.39a	21.35a	21.28a
T9 (No weeding)	18.44cd	19.71a	19.78a	19.78a	19.71a	19.71a	19.78a	19.36a	19.67a	19.90a
T10 (Weeding with weedicide)	18.25d	19.63a	19.82a	19.82a	19.59a	19.59a	19.71a	19.75a	19.25a	20.21a
CD	1.85	1.63	1.72	1.72	1.61	1.61	1.54	1.52	2.03	0.89
SEm±	0.62	0.55	0.58	0.58	0.54	0.54	0.52	0.51	0.68	0.30

The available Sulphur (Av. S) specified variability in relation to the increasing number of days **(Tables 28 and 29)**. The surface soil layer indicated variability from 45 DAS and 450 DAS exhibited slight increase in Av. S in the surface soil. The fallow treatment (T1) noted an increase from 22.62 – 23.65 kg ha^{-1} while the straw mulching treatment (T2) denoted increase from 24.46 – 25.99 kg ha^{-1} from 45 DAS to 450 DAS respectively. Similarly, the plastic mulching treatment (T3), minimum tillage treatment (T4) and earthing up treatment (T5) exhibited readings in a range of 23.73 – 25.38 kg ha^{-1}, 23.35 – 24.92 kg ha^{-1} and 22.34 – 24.11 kg ha^{-1} respectively in going from 45 DAS to 450 DAS. The remaining treatments T6, T7, T8, T9 and T10 exemplified ranges of 21.39 – 23.61 kg ha^{-1}, 22.77 – 24.61 kg ha^{-1}, 23.31 – 25.87 kg ha^{-1}, 21.66 – 23.96 kg ha^{-1} and 21.35 – 23.65 kg ha^{-1} respectively from 45 DAS to 450 DAS. The subsurface layer measured no notable changes. The value ranges of fallow treatment (T1), straw mulching treatment (T2), plastic mulching treatment (T3), minimum tillage (T4), earthing up treatment (T5), paired row treatment (T6), broadcasting (T7), ridge and furrow treatment (T8), no weeding treatment (T9) and weeding with weedicide treatment (T10) signified least changes in a range from 19.71 – 20.97 kg ha^{-1}, 21.51 – 23.08 kg ha^{-1}, 20.70 – 22.12 kg ha^{-1}, 20.40 – 21.81 kg ha^{-1}, 19.56 – 21.32 kg ha^{-1}, 18.64 – 20.51 kg ha^{-1}, 19.48 – 20.97 kg ha^{-1}, 20.05 – 21.28 kg ha^{-1}, 18.44 – 19.90 kg ha^{-1} and 18.25 – 20.21 kg ha^{-1} respectively. According to Sharma *et al.,* 2020, different tillage practices could significantly influence the accessibility of Av. S and the application of organic matter (OM) developed highest Av. S, which was in agreement with our results.

4.1.9 Ex. Ca + Mg (meq/100 g soil):

Table 30: Effect of different agricultural practices on Ex. Ca+Mg (0-15cm)

Treatments	Ex. Ca+Mg (0-15cm) (meq/100 g soil)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	D1B (90)	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	D1H (360)	D1I (405)	D1J (450)
T1 (Fallow)	9.60a	6.23c	5.53c	5.77c	5.63c	5.60c	5.57cd	5.53cd	5.60bcd	5.40cd
T2 (Straw Mulching)	6.13cd	5.17d	5.20c	5.47c	5.37c	5.37c	5.37cd	5.37cd	7.00bc	6.73c
T3 (Plastic Mulching)	6.74cd	7.24b	8.47b	8.40b	8.30b	8.33b	8.37b	8.33b	7.37b	8.60b
T4 (Minimum Tillage)	10.03a	10.23a	10.67a	10.60a	10.40a	10.33a	10.23a	10.27a	12.80a	10.67a
T5 (Earthing up)	8.70b	4.13e	4.07de	4.13d	3.93d	3.90d	3.83e	3.80f	4.80de	4.47d
T6 (Paired row)	7.93c	6.43c	5.43c	5.50c	5.43c	5.47c	5.70c	5.67c	7.47b	6.70c
T7 (Broadcasting)	4.68e	4.83de	3.57e	3.63d	3.57d	3.53d	3.47e	3.47f	4.50e	3.83d
T8 (Ridge and Furrow)	6.67cd	4.23e	3.9de	3.93d	3.80d	3.73d	3.63e	3.60f	4.50e	4.17d
T9 (No weeding)	6.07d	5.17d	5.00c	5.13c	4.97c	5.00c	4.90d	4.80de	6.33bcd	5.67cd
T10 (Weeding with weedicide)	8.13b	5.03d	4.37d	4.27d	4.10d	4.10d	4.07e	4.13ef	5.80bcd	5.13cd
CD	0.48	0.71	0.64	0.74	0.69	0.72	0.76	0.81	2.15	1.69
SEm±	0.16	0.24	0.22	0.25	0.23	0.24	0.26	0.27	0.72	0.57

Table 31: Effect of different agricultural practices on Ex. Ca+Mg (15-30 cm)

Treatments	Ex. Ca+Mg (15-30 cm) (meq/100 g soil)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	5.53cd	7.03c	6.43cd	6.60cd	6.67cd	6.63cd	6.73cd	6.73cd	6.93de	7.03cd
T2 (Straw Mulching)	6.43bc	6.90c	7.30bc	7.37bc	7.47bc	7.37bc	7.47bc	7.40bc	9.03bcd	7.70bc
T3 (Plastic Mulching)	8.6a	10.20a	10.37a	10.57a	10.60a	10.53a	10.57a	10.53a	13.13a	10.80a
T4 (Minimum Tillage)	6.77b	8.00b	8.13b	8.27b	8.33b	8.33b	8.47b	8.37b	10.17b	8.50b
T5 (Earthing up)	5.13d	5.53d	5.83d	5.80d	5.90d	5.97d	6.07d	6.07d	8.80bcd	5.97d
T6 (Paired row)	5.67cd	6.80c	6.40cd	6.50cd	6.63cd	6.60cd	6.73cd	6.67cd	9.07bcd	6.73cd
T7 (Broadcasting)	6.1c	4.03e	3.97e	4.17d	4.20e	4.17e	4.23e	4.27e	6.77de	4.43e
T8 (Ridge and Furrow)	5.4cd	4.03e	4.37e	4.40d	4.47e	4.50e	4.53e	4.47e	6.33e	4.67e
T9 (No weeding)	6.3bc	7.20bc	7.07c	7.07bc	6.70cd	6.73cd	6.80cd	6.70cd	7.57cde	6.90cd
T10 (Weeding with weedicide)	6.27bc	7.97b	8.10b	8.20b	8.27b	8.23b	8.33b	8.27b	9.87bc	8.53b
CD	0.92	0.73	0.98	1.18	1.14	1.03	1.08	1.06	2.26	1.22
SEm±	0.31	0.24	0.33	0.40	0.38	0.35	0.36	0.36	0.76	0.41

The exchangeable Ca + Mg demonstrated a slight decline in all treatments, except for T3 and T4, at the surface layers **(Tables 30 and 31)**. Treatment T1 registered a decline of 9.60 – 5.40 meq/100 g soil (0-15 cm) and 5.53 – 7.03 meq/100 g soil (15-30 cm), at 45 DAS and 450 DAS. Similarly, T2 observed readings from 6.13 – 6.73 meq/100 g soil (0-15 cm) and 6.43 – 7.70 meq/100 g soil (15-30 cm), at 45 DAS and 450 DAS. In case of T3, the value increased from 6.74 – 8.60 meq/100 g soil (0-15 cm) and 8.60 – 10.80 meq/100 g soil (15-30 cm) at 45 DAS and 450 DAS. There were no significant changes in the T4 treatment in surface layer (10.03 – 10.67 meq/100 g soil at 45 – 450 DAS). However, a slight increase was observed in the subsurface layers for T4 (6.77 – 8.50 meq/100 g soil at 45 – 450 DAS). The remaining treatments T5, T6, T7, T8, T9 and T10 registered decline from 8.70 – 4.47 meq/100 g soil, 7.93 – 6.70 meq/100 g soil, 4.68 – 3.83 meq/100 g soil, 6.67 – 4.17 meq/100 g soil, 6.07 – 5.67 meq/100 g soil and 8.13 – 5.13 meq/100 g soil at 45 DAS to 450 DAS in the surface layers respectively. The subsurface layers indicated range from 5.13 – 5.97 meq/100 g soil, 5.67 – 6.73 meq/100 g soil, 6.10 – 4.43 meq/100 g soil, 5.40 – 4.67 meq/100 g soil, 6.30 – 6.90 meq/100 g soil and 6.27 – 8.53 meq/100 g soil at 45 and 450 DAS respectively. The Ex. Ca + Mg in the soil system tends to increase with depth, which might be a caused by leaching of the salts. Our results developed similar findings with Thomas *et al.,* 2007, which reported increased concentration of Ex. Ca + Mg at lower depths.

4.2 Soil Quality and Soil Health

4.2.1 Soil Organic Carbon (SOC) (g kg^{-1}):

Table 32: Effect of different agricultural practices on SOC (0-15cm)

Treatments	SOC (0-15cm) (g kg^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	3.87bc	4.13b	4.20bc	4.40de	4.27d	4.47cd	4.60cd	4.67d	4.77d	4.97cde
T2 (Straw Mulching)	4.93a	5.27a	5.43a	5.57a	5.63a	5.90a	5.93a	6.27a	6.63a	6.87a
T3 (Plastic Mulching)	4.13b	3.33cd	3.70cd	3.93de	4.17ef	4.27d	4.43d	4.63bd	4.97cd	5.23c
T4 (Minimum Tillage)	3.80ef	4.18b	4.53b	4.73bc	4.90bc	5.27b	5.47b	5.50b	6.03b	6.67a
T5 (Earthing up)	3.10de	2.95e	3.43d	3.97de	4.13efg	4.40cd	4.60cd	4.77d	5.07cd	5.13cd
T6 (Paired row)	3.63c	5.13ab	5.27a	5.17ab	5.30ab	5.63ab	5.60ab	5.70b	6.07b	5.93b
T7 (Broadcasting)	4.30b	4.70b	4.73b	4.73bc	4.53cd	4.43cd	4.57cd	4.43d	4.77d	4.70e
T8 (Ridge and Furrow)	3.07fg	3.45cd	3.57d	3.57e	3.70fg	3.80e	3.87e	3.97d	3.97e	4.23f
T9 (No weeding)	3.50cd	2.45f	3.13d	3.83e	4.30d	4.73c	4.90bc	5.17c	5.30c	4.80de
T10 (Weeding with weedicide)	3.27h	3.53c	3.57d	3.40e	3.60g	3.67e	3.63e	3.70e	3.97e	4.10f
CD	0.46	0.48	0.53	0.50	0.49	0.37	0.35	0.34	0.40	0.42
SEm±	0.16	0.16	0.18	0.17	0.16	0.13	0.12	0.11	0.13	0.14

Table 33: Effect of different agricultural practices on SOC (15-30 cm)

Treatments	SOC (15-30 cm) (g kg^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	2.87a	3.50a	3.57abc	3.63cd	4.03b	4.17b	4.13bcd	4.27bc	4.33bc	4.43cd
T2 (Straw Mulching)	2.77a	3.73a	4.10a	4.50a	4.57a	4.83a	4.93a	5.07a	5.33a	5.53a
T3 (Plastic Mulching)	2.27b	2.65cd	2.73ef	3.27ef	3.87bc	3.67cde	3.93bcd	4.03bc	4.17cd	4.30cd
T4 (Minimum Tillage)	2.44b	3.37ab	3.47bcd	3.73bc	4.07ab	4.17bc	4.33bc	4.23bc	4.57bc	5.17ab
T5 (Earthing up)	2.00b	2.55cd	2.97cde	3.43cde	3.73bcd	3.80bcd	3.97bcd	4.10bc	4.33bc	4.53cd
T6 (Paired row)	2.90a	3.77a	3.73ab	4.07b	4.20ab	4.37ab	4.40ab	4.47ab	4.87ab	5.17ab
T7 (Broadcasting)	2.57b	3.37ab	3.27bcde	3.20e	3.47cde	3.70cde	3.57de	3.63cd	3.63de	3.97de
T8 (Ridge and Furrow)	1.78b	2.73cd	3.03cde	3.37cde	3.33ef	3.57ef	3.77cd	3.63cd	4.33bc	4.73bc
T9 (No weeding)	2.00b	2.32d	2.30f	2.57f	2.63g	2.80g	2.73f	2.90e	3.17e	3.53e
T10 (Weeding with weedicide)	1.83b	2.92bc	2.93de	2.67f	2.97fg	3.13fg	3.07ef	3.13de	3.13e	3.43e
CD	0.51	0.45	0.57	0.33	0.50	0.56	0.58	0.63	0.59	0.58
SEm±	0.17	0.15	0.19	0.11	0.17	0.19	0.20	0.21	0.20	0.19

The soil organic carbon (SOC) is an indelible part of soil health. The different agricultural practices illustrated significant variations across the horizontal data distribution **(Tables 32and 33)**. The maximal distribution was distinguished in the organic mulching treatment (T2) and closely followed by T4 and T6 in both soil layers. Treatment T1 measured readings of 3.87 to 4.97 g kg^{-1} (surface) and 2.87 to 4.43 g kg^{-1} (subsurface) at 45 to 450 DAS The surface soil of T2 observed an increase in SOC content from 4.93 g kg^{-1} (45 DAS) to 6.87 g kg^{-1} (450 DAS). The subsurface soil indicated values from 2.77 g kg^{-1} at 45 DAS to 5.53 g kg^{-1} at the end of the experiment (450 DAS). The plastic mulching treatment (T3) demonstrated an increase from 4.13 to 5.23 g kg^{-1} (surface) and 2.27 to 4.30 g kg^{-1} (subsurface) from 45 DAS to 450 DAS. Another important treatment which showed an optimal increase in SOC was T4 and the values ranged at 3.80 to 6.67 g kg^{-1} at 0-15 cm and 2.44 to 5.17 g kg^{-1} at 15-30 cm respectively from 45 to 450 DAS. The remaining treatments T5, T6, T7, T8, T9 and T10 exuded a range from 3.10 – 5.13 g kg^{-1}, 3.63 – 5.93 g kg^{-1}, 4.30 – 4.70 g kg^{-1}, 3.07 – 4.23 g kg^{-1}, 3.50 – 4.80 g kg^{-1} and 3.27 – 4.10 g kg^{-1} at surface layers; 2.00 – 4.53 g kg^{-1}, 2.90 – 5.17 g kg^{-1}, 2.57 – 3.97 g kg^{-1}, 1.78 – 4.73 g kg^{-1}, 2.00 – 3.53 g kg^{-1} and 1.83 – 3.43 g kg^{-1} at subsurface layers from 45 DAS to 450 DAS respectively. An effective study for the change in SOC is also provided along with an interpolation data in **Fig (4a)**.

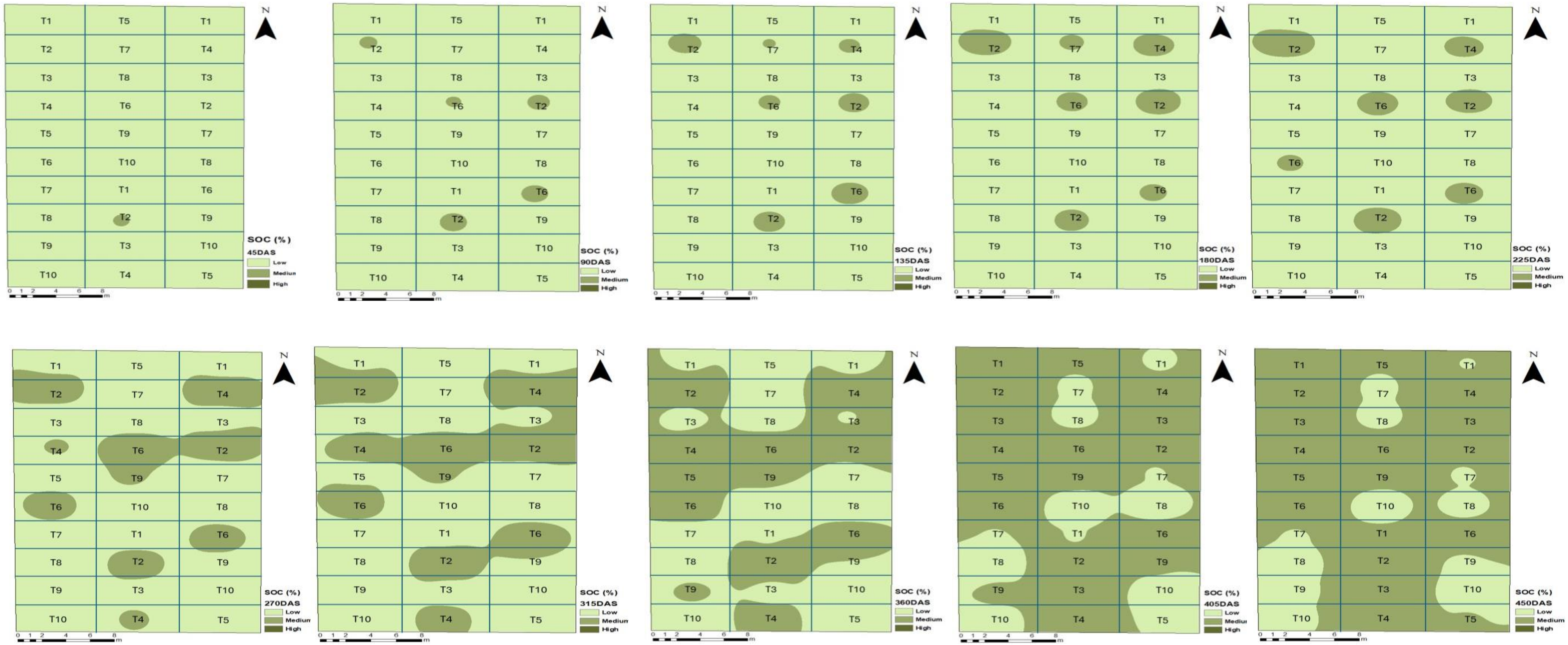
The different agricultural practices introduced significant effects on the functioning of soils, including the soil biogeochemical changes. The plastic mulching treatment may reduce the SOC through increased mineralization of organic matter and increased microbial activity (Li *et al.,* 2004; Zhou *et al.,* 2012). Other contrasting studies also confirmed that plastic mulch might increase SOC via increased crop root biomass and litter return to the soil (Gao *et al.,* 2014). Wang *et al.,* 2016 also suggested plastic mulch had positive effects on increasing the root biomass under maize crop. The increased biomass of the root system could have managed to develop alterations to the soil physico-chemical and biological properties. This would explain the initial decline in SOC and later develop an increase in the surface layers from the non-growing period in our experiment. Yang *et al.,* 2018 also observed a similar decline in SOC in plastic mulching during the initial phases. The plastic mulch treatment also developed similar

SOC levels in comparison to the other treatments at both soil depths. Straw mulching offered a conducive environment for the decomposition of the organic matter (OM). Increased microbial functions owing to optimum temperature conditions and soil moisture levels could have in the induced high SOC level in the soil system. Yang *et al.,* 2018 also instituted similar results whereby the SOC was higher in the straw mulching treatment than other conventional agricultural practices including plastic mulch. The subsurface soil however retained lesser SOC content. A study by Arora *et al.,* 2021 revealed that SOC was minimized under barren or fallow conditions owing to scarce vegetation and intense heat which further led to a higher decomposition rate. This is true for our experiment. However, the addition of vermicompost in all the treatments could have induced the gradual increase in SOC. The reduced tillage system generally conforms higher SOC than other conventional tillage practices (Conant *et al.,* 2007). The reduced soil disturbance, reduction in soil temperature and increased biomass could have led to certain interactions which increased SOC in minimum tillage (T4). Also, a reduction in the pace of decomposition in organic matter relatively to the other agricultural practices could have led to increased SOC in T4. Lilienfein *et al.,* 2000 also mentioned a higher organic matter content in minimum tillage system. Our result is also supported by the findings of Ernst and Emmerling, 2009 who suggested higher SOC in reduced tillage than other conventional systems.

It is a generally accepted concept that tillage operations expose the soil surfaces and higher surface area of the soil aggregates could lead to higher oxidation of organic carbon; thus, reducing the soil organic carbon. However, a study by Page *et al.,* 2020 found that tillage operations could increase the SOC under some circumstances. This could be the reason for increased SOC in our experiment in the other agricultural practices. The creation of a dome shape in the soil surface in treatments such as paired-row (T6), earthing up (T5) and ridge-furrow system (T8) could have delimited aeration and reduced the decomposition rate of organic matter, and therefore induced an increased SOC over time. The exposure of soil surfaces in conventional tillage systems reduces SOC. Therefore, the minimum tillage system and straw mulching system offers better deposition of SOC in the soil. Analogous findings were also observed by Zhao *et al.,* 2015.

The downward movement of SOC is very slow in nature (Wang *et al.,* 2020). This could be the reason for reduced SOC in the subsurface soil layers when compared to the surface layers. But the deposition of root biomass from the cropping system and decomposition over time could have increased the SOC in lower soil depths.

Fig 4a: Interpolation data of SOC at different DAS



4.2.2 Total Organic Carbon (TOC) (g kg^{-1}):

Table 34: Effect of different agricultural practices on TOC (0-15cm)

Treatments	TOC (0-15cm) (g kg^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	D1B (90)	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	D1H (360)	D1I (405)	D1J (450)
T1 (Fallow)	5.50cd	6.07cd	6.03de	6.13ef	5.90e	5.83g	6.30f	6.48fg	6.85de	7.30de
T2 (Straw Mulching)	6.80a	9.50a	9.50a	9.40a	9.60a	9.93a	9.90a	10.60a	12.00a	12.60a
T3 (Plastic Mulching)	6.50a	6.87c	7.03c	7.10de	7.11d	7.37cd	7.47de	8.20cd	9.30b	9.90b
T4 (Minimum Tillage)	5.20d	8.47b	8.67b	8.57ab	8.73b	9.20ab	9.60ab	9.90b	11.23a	12.67a
T5 (Earthing up)	6.37ab	5.33d	5.53e	5.70f	6.47de	6.87def	7.00ef	6.90efg	7.57cd	8.17cd
T6 (Paired row)	6.17abc	7.97b	7.87b	7.97bc	8.13bc	8.73b	8.80bc	9.00bc	9.60b	9.67b
T7 (Broadcasting)	6.47a	7.87b	7.97b	7.60cd	7.93c	7.90c	8.13cd	7.87cde	8.20c	8.37c
T8 (Ridge and Furrow)	4.90d	6.13cd	6.13de	6.23ef	6.34de	6.37efg	6.27f	6.47fg	6.94de	6.94e
T9 (No weeding)	5.60bcd	6.08cd	6.57cd	6.49	6.29de	7.08cde	7.40de	7.63def	7.97c	8.10cd
T10 (Weeding with weedicide)	5.13d	6.13cd	6.33cde	6.14ef	6.47de	6.17fg	6.20f	5.83g	6.53e	6.73e
CD	0.65	1.01	0.77	0.58	0.62	0.82	0.89	1.11	0.68	0.81
SEm±	0.22	0.34	0.26	0.20	0.21	0.27	0.30	0.38	0.23	0.27

Table 35: Effect of different agricultural practices on TOC (15-30 cm)

Treatments	TOC (15-30 cm) (g kg^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	3.83bc	5.50bcd	5.63d	5.50bc	5.33cde	5.40bcd	5.33def	5.50def	5.97d	6.10c
T2 (Straw Mulching)	4.30ab	6.23ab	6.57ab	6.87a	6.47a	6.70a	6.87b	7.43ab	7.57ab	8.77a
T3 (Plastic Mulching)	4.53a	6.07bc	5.77cd	6.07abc	5.47cd	5.97b	6.23bc	6.40c	6.87bc	7.10b
T4 (Minimum Tillage)	4.67a	6.85a	7.03a	6.85a	6.85a	7.63a	7.83a	7.85a	8.18a	9.02a
T5 (Earthing up)	4.50a	5.70bc	6.20bc	6.07abc	5.73bc	5.57bc	5.73cd	6.17cd	6.30cd	6.30c
T6 (Paired row)	4.57a	6.13abc	6.23bc	6.20ab	6.33ab	6.67a	6.63b	6.80bc	7.02bc	7.19b
T7 (Broadcasting)	4.17ab	5.63bc	5.60d	5.63bc	5.47cd	5.77b	5.63cde	5.63de	5.77d	6.03c
T8 (Ridge and Furrow)	3.47c	5.44cd	5.77cd	5.84abc	5.34cde	5.44bcd	5.50de	5.27ef	5.61de	6.10c
T9 (No weeding)	3.77bc	4.87de	4.93	5.10cd	4.80de	4.97de	5.00ef	4.93ef	4.93ef	5.83c
T10 (Weeding with weedicide)	3.57c	4.58e	4.77e	4.33d	4.70e	4.90e	4.67f	4.75f	4.83g	5.03d
CD	0.53	0.72	0.51	0.96	0.67	0.55	0.64	0.76	0.75	0.51
SEm±	0.18	0.24	0.17	0.32	0.23	0.19	0.22	0.26	0.25	017

The total organic carbon (TOC) is an inclusive parameter for the oxidizable carbons and other related carbon fractions. From the experiment, it was observed that TOC tends to increase under different agricultural practices albeit at different proportions **(Tables 34 and 35)**. The fallow treatment (T1) exhibited an increase from 5.50 – 7.30 g kg^{-1} (0 – 15 cm) and 3.83 – 6.10 g kg^{-1} (15 – 30 cm) from 45 to 450 DAS. The organic mulching treatment (T2) noted an exponential increase from 6.80 – 12.60 g kg^{-1} (0 – 15 cm) and 4.30 – 8.77 g kg^{-1} (15 – 30 cm) from 45 to 450 DAS. The plastic mulching treatment (T3) also followed similar inclinations, and its value ranged from 6.50 – 9.90 g kg^{-1} and 4.53 – 7.10 g kg^{-1} at 0 – 15 cm and 15 – 30 cm soil depths respectively. For the minimum tillage treatment (T4), the consecutive soil depths provided results ranging from 5.20 – 12.67 g kg^{-1} and 4.67 – 9.02 g kg^{-1} respectively at 45 and 450 DAS. The remaining treatments T5, T6, T7, T8, T9 and T10 elucidated a range from 6.37 – 8.17 g kg^{-1}, 6.17 – 9.67 g kg^{-1}, 6.47 – 8.37 g kg^{-1}, 4.90 – 6.94 g kg^{-1}, 5.60 – 8.10 g kg^{-1} and 5.13 – 6.73 g kg^{-1} in surface layers; 4.50 – 6.30 g kg^{-1}, 4.57 – 7.19 g kg^{-1}, 4.17 – 6.03 g kg^{-1}, 3.47 – 6.10 g kg^{-1}, 3.77 – 5.83 g kg^{-1} and 3.57 – 5.03 g kg^{-1} at subsurface layers.

The integration of 100% recommended dosage of fertilizers along with organic amendments seemed to magnify the TOC content in the soil. This could be the reason for the increase in TOC in the agricultural practices involved in our study. Analogous observations were recorded by Rudrappa *et al.,* 2006. However, the study of Rudrappa *et al.,* 2006 did not have any input of above ground biomass. In our study, incorporation of straw, plastic mulching and minimum tillage system led to an increase in the upper and lower surface biomass as compared to the other treatments. This could have induced higher TOC content in the soil layers. The biomass accumulation was more in the surface layers rather than the subsurface counterpart, and hence a higher TOC in the surface soil. Comparable findings were demonstrated by Zhou *et al.,* 2019. The TOC increased in surface layer of conservation agriculture systems rather than the conventional system due to higher accumulation of organic residues in conservation systems and encouraging carbon stabilization (Choudhury *et al.,* 2014; Jat *et al.,* 2019). This coincides with the results of our experiment.

At the subsurface layers, the mixing of crop residue in soil (Jat *et al.,* 2018), decomposition of the organic residues and root biomass over time and leaching down of organic carbon could have induced the increase in TOC (Nachimuthu and Hullugale, 2016). The findings are in sync with our results.

4.2.3 Soil organic carbon stocks (SOCS) (Mg ha^{-1}):

Table 36: Effect of different agricultural practices on SOCS (0-15cm)

Treatments	SOCS (0-15cm) (Mgha^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	8.07bc	8.80b	8.82cd	9.42cd	9.09c	9.58d	9.73bc	9.80d	10.30cd	10.65cd
T2 (Straw Mulching)	10.07a	10.67a	11.09a	11.47a	11.49a	12.12a	12.28a	12.69a	13.53a	13.91a
T3 (Plastic Mulching)	8.56b	6.99cd	7.83de	8.38de	8.75cd	9.22d	9.38c	9.73d	10.28cd	10.76c
T4 (Minimum Tillage)	5.75ef	8.66b	9.66bc	10.01bc	10.51ab	11.22a	11.89a	11.80b	12.86ab	14.50a
T5 (Earthing up)	6.53de	6.06de	7.06e	8.27de	8.67cd	9.31d	9.73bc	9.79d	10.48cd	10.47cd
T6 (Paired row)	7.69bcd	10.63a	10.75ab	10.62ab	10.89a	11.66a	11.51a	11.54b	12.20b	12.01b
T7 (Broadcasting)	8.90b	9.94a	9.82bc	10.08bc	9.38bc	9.25d	9.53c	9.11d	10.01d	9.94cd
T8 (Ridge and Furrow)	5.07f	6.98cd	7.28e	7.33e	7.66d	7.98c	8.12d	8.39e	8.16e	8.64e
T9 (No weeding)	7.28cd	5.21e	6.67e	8.21e	9.36bc	10.09d	10.36b	10.70c	11.05c	9.80d
T10 (Weeding with weedicide)	4.75f	7.48c	7.65de	7.24e	7.67d	7.87c	7.74d	7.83e	8.27e	8.60e
CD	1.06	1.09	1.12	1.01	1.12	0.86	0.74	0.75	0.85	0.86
SEm±	0.36	0.37	0.38	0.34	0.38	0.29	0.25	0.25	0.29	0.29

Table 37: Effect of different agricultural practices on SOCS (15-30 cm)

Treatments	SOCS (15-30 cm) ($Mgha^{-1}$)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	8.14b	15.02a	15.42bc	15.59cd	17.54bc	18.00bcd	18.06bcd	18.90b	19.11bcd	20.04bc
T2 (Straw Mulching)	7.74b	16.23a	17.97a	19.98a	20.28a	21.17a	21.76a	21.73a	22.99a	24.35a
T3 (Plastic Mulching)	9.72b	11.29cd	11.72de	14.12d	16.94bcd	16.17cde	17.58bcd	17.78bc	18.50cd	19.10bc
T4 (Minimum Tillage)	8.92b	14.74ab	15.28bc	16.46bc	18.18ab	18.50bc	19.41abc	18.75b	20.69abc	23.30a
T5 (Earthing up)	8.70b	11.02cd	12.90cd	14.63d	16.35bcd	16.53cd	17.49bcd	18.31bc	19.11bcd	19.86bc
T6 (Paired row)	12.70a	16.37a	16.34ab	17.68b	18.38ab	19.53ab	19.48ab	19.54ab	21.60ab	23.34a
T7 (Broadcasting)	9.19b	14.75ab	14.39bc	14.30d	15.61cd	16.88cd	16.38d	16.02cd	16.48de	17.76cd
T8 (Ridge and Furrow)	7.85b	12.21cd	13.74cd	14.95cd	14.90de	15.72de	16.73cd	15.81cd	18.98bcd	20.58b
T9 (No weeding)	8.77b	10.27d	10.08e	11.47e	11.62f	12.43f	12.03e	12.84e	14.34e	15.82d
T10 (Weeding with weedicide)	8.12b	12.87bc	12.84cd	11.76e	13.00ef	13.89ef	13.80e	13.95de	14.00e	15.62d
CD	2.11	1.98	2.41	1.45	2.20	2.49	2.58	2.62	2.68	2.55
SEm±	0.71	0.67	0.81	0.49	0.74	0.84	0.87	0.88	0.90	0.86

The soil organic carbon stocks (SOCS) in the experimental field expressed significant variations along the horizontal data distribution **(Tables 36 and 37)**. It seemingly seems to increase along the increasing number of days (DAS) and the subsurface soil held more SOCS than its counterpart. Treatment T1 expressed SOCS in a range of 8.07 – 10.65 Mg ha^{-1} (0-15 cm) and 8.14 – 20.04 Mg ha^{-1} (15-30 cm) from 45 DAS to 450 DAS. T2 developed a variable range of 10.07 – 13.91 Mg ha^{-1} at surface soil and 7.74 – 24.35 Mg ha^{-1} at subsurface layers. The T3 treatment inculcated values of 8.56 – 10.76 Mg ha^{-1} (0-15 cm) and 9.72 – 19.10 Mg ha^{-1} (15-30 cm). The remaining treatments T4, T5, T6, T7, T8, T9 and T10 expressed 5.75 – 14.50 Mg ha^{-1}, 6.53 – 10.47 Mg ha^{-1}, 7.69 – 12.01 Mg ha^{-1}, 8.90 – 9.94 Mg ha^{-1}, 5.07 – 8.64 Mg ha^{-1}, 7.28 – 9.80 Mg ha^{-1} and 4.75 – 8.60 Mg ha^{-1} at surface layers; 11.10 – 23.30 Mg ha^{-1}, 9.57 – 19.86 Mg ha^{-1}, 12.70 – 23.34 Mg ha^{-1}, 8.92 – 23.30 Mg ha^{-1}, 8.70 – 19.86 Mg ha^{-1}, 12.70 – 23.34 Mg ha^{-1}, 9.19 – 17.76 Mg ha^{-1}, 7.85 – 20.58 Mg ha^{-1}, 8.77 – 15.82 Mg ha^{-1} and 8.12 – 15.62 Mg ha^{-1} for subsurface layers at 45 and 450 DAS respectively.

The SOCS in the surface soil showed significant variations and the highest was observed in the minimum tillage system (T4) and straw mulching treatment (T2). Bhattacharyya *et al.,* 2015 emphasized that implementation of conservation agricultural practices increases SOCS in the 0 – 15 cm soil layers. Luo *et al.,* 2010 also observed improvements in the SOCS in minimum tillage systems. Overall increase in SOCS irrespective of the agricultural practices were observed in our experiment albeit at different levels for the different soil depths. Analogous findings by Roy *et al.,* 2022 explained the increase in SOCS in conventional tillage systems at both soil depths.

For the subsurface soil, the increase in SOCS was phenomenal. Mixing of crop residues, stubbles and plant roots in subsurface soil could have induced increase in SOCS which were higher than the surface soil. Piccoli *et al.,* 2016 also derived that higher SOCS were noticed in the subsurface soil of conventional tillage systems. Any immediate modifications in the SOCS could develop tremendous influence on the Greenhouse gas equilibrium and climate change scenario. A study by Wang *et al.,* 2020 purported the variations in SOCS due to different tillage practices. At 0-20 cm soil depths, SOCS were found to be more in minimum tillage than the other conventional tillage systems. However, at 20-40 cm soil depth, SOCS developed significant increase in the conventional tillage system. This is in agreement with our results whereby a significant increase was noted in T5 (earthing up), T6 (paired row) and T8 (ridge and furrow) followed by the other treatments. Also, the initial incorporation of vermicompost at the start of our experiment could have induced an increase in the SOCS at both soil depths. This could be verified through the findings of Li *et al.,* 2018 who suggested that organic manure incorporation seemingly generates an increase in SOC and SOCS.

4.2.4 Lability Index (LI):

Table 38: Effect of different agricultural practices on lability index (0-15cm)

Treatments	Lability Index (0-15cm)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	1.62a	1.45a	1.48a	1.54ab	1.65a	1.69a	1.55a	1.48a	1.39a	1.31ab
T2 (Straw Mulching)	1.70a	1.06b	1.12c	1.16de	1.14c	1.18de	1.10cde	1.04cd	0.96cd	0.92de
T3 (Plastic Mulching)	1.49a	0.92b	1.00c	1.04e	1.07c	1.10e	1.00e	0.95d	0.88d	0.85e
T4 (Minimum Tillage)	1.21b	1.03b	1.09c	1.16de	1.09c	1.11e	1.05de	1.01cd	0.91d	0.86e
T5 (Earthing up)	1.14b	1.36a	1.45ab	1.59a	1.42b	1.44bc	1.34ab	1.29ab	1.27ab	1.15bc
T6 (Paired row)	1.57a	1.41a	1.45ab	1.42abc	1.44b	1.40bc	1.35ab	1.30ab	1.25ab	1.23ab
T7 (Broadcasting)	1.64a	1.33a	1.30b	1.38abcd	1.38b	1.33c	1.29bc	1.31ab	1.31ab	1.26ab
T8 (Ridge and Furrow)	1.22b	1.46a	1.45ab	1.45abc	1.41b	1.49b	1.53a	1.43a	1.34a	1.39a
T9 (No weeding)	1.51a	1.02b	1.03c	1.25cde	1.27bc	1.28cd	1.21bcd	1.16bc	1.12bc	1.06cd
T10 (Weeding with weedicide)	1.01b	1.32a	1.30b	1.34bcd	1.25bc	1.43bc	1.41ab	1.42a	1.29ab	1.24ab
CD	0.23	0.22	0.16	0.18	0.19	0.14	0.19	0.18	0.19	0.15
SEm±	0.08	0.07	0.05	0.06	0.07	0.05	0.06	0.05	0.06	0.05

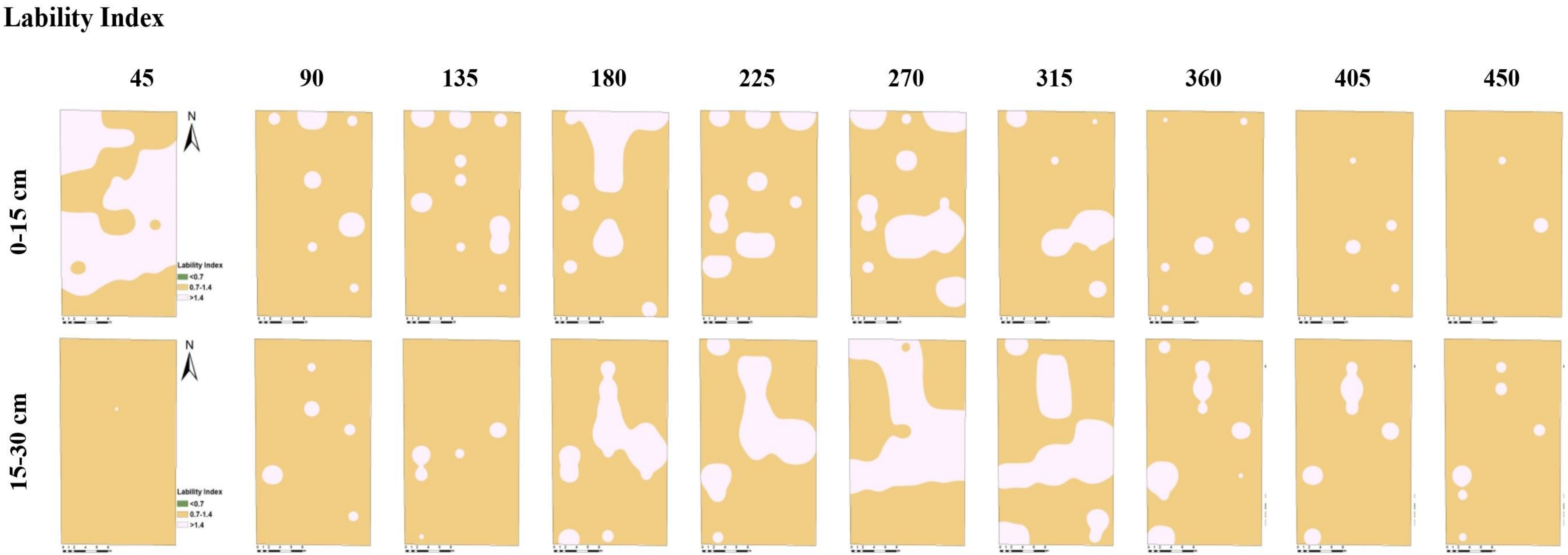
Table 39: Effect of different agricultural practices on lability index (15-30 cm)

Treatments	Lability Index (15-30 cm)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	1.18ab	1.21bc	1.23b	1.31abc	1.36bcd	1.49ab	1.40ab	1.36bc	1.25bc	1.28bc
T2 (Straw Mulching)	0.98b	1.16c	1.13bc	1.20bcd	1.27bcde	1.34bcd	1.30bc	1.15de	1.16c	1.00d
T3 (Plastic Mulching)	1.17ab	0.82d	0.91d	1.00d	1.12e	1.18de	1.10c	0.99e	0.92d	0.95d
T4 (Minimum Tillage)	0.97b	1.06c	1.02cd	1.18bcd	1.14de	1.09e	1.09c	0.98e	0.97d	0.95d
T5 (Earthing up)	1.05b	1.00cd	1.01cd	1.14cd	1.19cde	1.34bcd	1.38ab	1.20cd	1.23bc	1.26c
T6 (Paired row)	1.35a	1.42ab	1.42a	1.48a	1.38bc	1.46abc	1.49ab	1.41ab	1.39ab	1.40ab
T7 (Broadcasting)	1.12b	1.51a	1.46a	1.48a	1.60a	1.63a	1.57a	1.57a	1.50a	1.49a
T8 (Ridge and Furrow)	1.13b	1.21bc	1.22b	1.43ab	1.47ab	1.54a	1.51a	1.40ab	1.45a	1.39ab
T9 (No weeding)	1.19ab	1.10c	1.14bc	1.34abc	1.36bcd	1.28cd	1.13c	1.16de	1.24bc	1.06d
T10 (Weeding with weedicide)	1.08b	1.39ab	1.41a	1.42ab	1.40abc	1.46abc	1.57a	1.43ab	1.39ab	1.41a
CD	0.19	0.22	0.16	0.24	0.21	0.15	0.20	0.16	0.16	0.13
SEm±	0.06	0.07	0.05	0.08	0.07	0.05	0.07	0.06	0.05	0.04

The lability index (LI) is an important determining factor for the soil quality and soil health. Lower the lability index, greater is the soil quality. The values from the horizontal data distribution indicates significant variation among the treatments with the increasing number of days **(Tables 38 and 39)**. Further investigation discerned that lability index increases during the non- growing period for both soil layers. Treatment T1 indicates LI of 1.62 (45 DAS), increasing to 1.69 (270 DAS) and finally reducing to 1.31 (450 DAS) in surface layers. For the subsurface layer, it was 1.18 at 45 DAS, increasing to 1.49 at 270 DAS and decreasing to 1.28 by 450 DAS. The organic mulch treatment (T2) noted readings of 1.70 (45 DAS), increasing towards 1.18 at 270 DAS and reducing to 0.92 by 450 DAS in surface soil. The subsurface soil indicated values of 0.98 (45 DAS), 1.34 (270 DAS) and 1.00 (450 DAS). Treatment T3 observed values of 1.49 (45 DAS) and gradually reducing to 0.85 (450 DAS) at 0-15 cm soil depth and 1.17 (45 DAS) to 0.95 (450 DAS) at 15-30 cm soil depth. In case of T4, the values were 1.21 (45 DAS) reducing to 0.86 (450 DAS) in surface layers which was at par with both T2 and T3. The subsurface layers observed values of 0.97 (45 DAS), increasing to 1.18 (180 DAS) and finally 0.95 (450 DAS). The surface layers of the remaining treatments T5, T6, T7, T8, T9 and T10 determined a range of 1.14 – 1.15, 1.57 – 1.23, 1.64 – 1.26, 1.22 – 1.39, 1.51 – 1.06 and 1.01 – 1.24 respectively at 45 to 450 DAS. The treatments T6, T7 and T8 offered reduction in LI from 1st trial to 2nd trial period. In case of subsurface layers, we could see a spike in LI in the remaining treatments T5, T6, T7, T8 and T10 except for T9 from 45 to 450 DAS. The indicated values were 1.05 – 1.26, 1.35 – 1.40, 1.12 – 1.49, 1.13 – 1.39, 1.08 – 1.41 and 1.19 – 1.06 respectively. For better understanding in the variations of LI, the change in LI associated with the treatments and the increasing number of days is represented with the help of IDW interpolation in **Fig (4b)**.

According to Basak *et al.,* 2021, the lability index (LI) of new alluvial soil were observed around 1.74 and those with vegetation cover were around 1.54. The considerable changes observed in LI at both soil layers could be due to modifications in the tillage systems and residue management. The lability index is a very sensitive indicator which might differ substantially due to any changes in land use and different soil depths (Majumder *et al.,* 2007). Under the findings of Hadke *et al.,* 2020, LI was reported to be higher in a cropping system than the non-cropped treatment. LI increases with the increase in the quantities of labile carbon fractions and also with changes in crop residues and biomass. The LI decreases with increase in soil depth. This could be due to an increase in BD and non-availability of readily decomposable biomass (Meetei *et al.,* 2020). Many researchers found that LI increases in the conservation agricultural practices (mulching, reduced tillage) (Sharma *et al.,* 2017; da Silva Rodrigues Pinto *et al.,* 2022) rather than the other conventionally practised tillage systems. In contrast to their findings, our experiment showed decreased LI in the mulching (T2, T3), minimum tillage (T4) and no weeding treatment (T9); but an increase in LI in the other remaining treatments T1, T5, T6, T7, T8, T9, T10 at both soil depths were observed. Decrease in LI could be an indication towards the increase in dwelling time of SOC and a decrease in its turnover rate. Also, the transformation rate from labile to recalcitrant pools also increased. This denotes an improvement in the C-sequestration potential in the soil system (De Clercq *et al.,* 2015; Basak *et al.,* 2021). A study by Yadav *et al.,* 2021 also recorded lesser levels of LI in a reduced tillage system and mulching tillage system at both soil depths.

Fig 4b: Lability Index along the variation in DAS



4.3 Soil Biological Properties

4.3.1 Soil microbial biomass carbon (SMBC) (μ g^{-1}):

Table 40: Effect of different agricultural practices on SMBC (0-15cm)

Treatments	SMBC (0-15cm) (μg g^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	104.29i	96.37i	102.97f	99.01e	93.73e	95.71e	102.31c	107.59de	118.15h	120.13f
T2 (Straw Mulching)	252.15c	308.91b	209.31b	145.21a	133.99a	128.71a	133.33a	137.95a	275.91b	346.54b
T3 (Plastic Mulching)	306.93a	331.35a	211.29b	144.55a	134.65a	129.37a	134.65a	137.29a	326.07a	372.28a
T4 (Minimum Tillage)	168.32g	269.97c	155.84c	124.75b	129.37ab	127.39ab	129.37a	133.33ab	182.84f	230.36cd
T5 (Earthing up)	278.55b	227.72e	120.13e	115.51cd	132.67a	119.47bcd	104.29c	104.95e	221.12d	228.38cd
T6 (Paired row)	237.62d	187.46f	127.39de	125.41b	126.07bc	112.21d	114.85b	113.53cd	232.34c	205.94d
T7 (Broadcasting)	195.38f	148.52g	135.31d	125.41b	114.85d	113.53d	110.23bc	116.83c	211.22e	215.18d
T8 (Ridge and Furrow)	176.90g	130.03h	130.69de	124.09bc	122.77c	116.83cd	116.83b	127.39b	215.18de	231.02cd
T9 (No weeding)	205.28e	256.11d	234.98a	132.67b	128.05abc	122.77abc	114.85b	118.81c	229.70c	246.87c
T10 (Weeding with weedicide)	137.95h	124.09h	128.71de	110.89d	110.89d	111.55d	108.91bc	107.59de	150.50g	170.96e
CD	8.18	9.82	10.27	7.10	5.22	5.87	7.11	8.14	5.24	23.23
SEm±	2.75	3.31	3.46	2.39	1.76	1.98	2.39	2.74	1.76	7.82

Table 41: Effect of different agricultural practices on SMBC (15-30 cm)

Treatments	SMBC (15-30 cm) (µg g^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	76.57h	89.11h	93.07f	89.77f	86.47f	89.11e	77.23e	88.45d	102.31e	98.35e
T2 (Straw Mulching)	184.16cd	205.94b	119.84cd	110.23bc	112.21bc	108.91b	116.83b	115.51b	191.42b	231.02b
T3 (Plastic Mulching)	173.60d	195.38c	128.78bc	104.29bcde	108.25cd	105.61bc	113.53b	111.55bc	194.72b	233.66b
T4 (Minimum Tillage)	231.68a	275.25a	134.72b	137.29a	135.97a	128.71a	127.39a	130.69a	231.68a	275.25a
T5 (Earthing up)	198.02b	137.29e	114.85d	98.35def	118.81b	102.31bcd	77.23e	78.55e	140.59c	159.74c
T6 (Paired row)	191.42bc	140.59e	115.51d	107.59bcd	102.97de	97.03d	101.65c	108.91bc	143.89c	130.03d
T7 (Broadcasting)	118.15f	115.51f	108.25de	112.87b	113.53bc	108.25bc	98.35cd	104.95c	142.57c	135.97d
T8 (Ridge and Furrow)	62.71i	103.63g	102.97ef	97.03ef	96.37e	96.37d	90.43d	88.45d	125.41d	120.79d
T9 (No weeding)	153.80e	170.30d	169.64a	108.91bc	104.95d	105.61bc	103.63c	107.59bc	148.52c	136.63d
T10 (Weeding with weedicide)	96.37g	106.27fg	108.91de	101.65cde	102.97de	101.65cd	104.95c	103.63c	128.05d	125.41d
CD	11.17	10.12	11.51	6.75	6.93	5.44	7.85	8.86	7.03	14.80
SEm±	3.76	3.41	3.87	2.27	2.33	1.83	2.64	2.98	2.37	4.98

The soil microbial biomass carbon (SMBC) is a major determining parameter for the amount of C contained in the microbial community (both bacteria and fungi) in a given soil. The decomposition process of biomass by the microorganisms will induce release of CO_2 and available plant nutrients. The study emphasized that the microbial biomass carbon induction was high during the crop growing period (or trial periods) and there was less activity of microbes during the non-growing period **(Tables 40 and 41)**. Treatment T1 indicated SMBC values of 104.29 µg g^{-1} (45 DAS), reducing to 93.73 µg g^{-1} (225 DAS) and increasing to 120.13 µg g^{-1} (450 DAS) at surface soil. A range of 76.57 µg g^{-1} (45 DAS) to 98.35 µg g^{-1} was observed in the subsurface layers. Treatment T2 noted values of 252.15 µg g^{-1} (45 DAS), reducing to 128.71 µg g^{-1} (270 DAS) and a further increase to 346.54 µg g^{-1} (450 DAS) at 0-15 cm soil depth. At 15-30 cm soil depth, the recorded values were 181.16 µg g^{-1} (45 DAS), 108.91 µg g^{-1} (270 DAS) and an increase to 231.02 µg g^{-1} (450 DAS). The maximum microbial biomass carbon amongst all treatments in the surface was in treatment T3. The recorded values were 306.93 µg g^{-1} (45 DAS), 129.37 µg g^{-1} (270 DAS) and 372.28 µg g^{-1} (450 DAS). The subsurface soil noted readings of 173.60 µg g^{-1} (45 DAS), 105.61 µg g^{-1} (270 DAS) and 233.66 µg g^{-1} (450 DAS), which was at par with T2. Readings of T4 at surface layers indicated 168.32 µg g^{-1} (45 DAS), 155. 84 µg g^{-1} (180 DAS) and increasing to 230.36 µg g^{-1} (450 DAS). Maximum significant variation of SMBC in subsurface layer was observed in T4 with recorded values of 231. 68 µg g^{-1} (45 DAS), 127.39 µg g^{-1} (315 DAS) and increasing to 275.25 µg g^{-1} (450 DAS). The treatments T5 and T6 noted a decline in SMBC from 45 to 450 DAS at both surface layers. The range of T5 was recorded as 278.55 – 228.38 µg g^{-1} (surface) and 198.02 – 159.74 µg g^{-1} (subsurface). In case of T6, the values were 237.62 – 205.95 µg g^{-1} (surface) and 191.42 – 130.97 µg g^{-1} (subsurface). The remaining treatments T7, T8, T9 and T10 recorded an increased SMBC from 45 to 450 DAS in the soil layers. The values were ranged at 195.38 – 215.18 µg g^{-1}, 176.90 – 231.02 µg g^{-1}, 205.28 – 246.87 µg g^{-1} and 137.95 – 170. 96 µg g^{-1} in surface soil; whilst it was 118.15 – 135.97 µg g^{-1}, 62.71 – 120.79 µg g^{-1}, 153.80 – 136.63 µg g^{-1} and 96.37 – 125.41 µg g^{-1} in subsurface soil respectively.

Soil Microbial Biomass Carbon (SMBC) is an important parameter which could indicate the quality of soils and it is strongly associated with soil fertility (Das *et al.,* 2014). The

SMBC decreases along the increasing soil depth in every land use system. It was found to be highest during the rainy season and lowest during summer months and winter (Lepcha and Devi, 2020; Arora *et al.,* 2021). The differences observed in the SMBC in different agriculture systems could be due to the diverse agricultural practices involved, accessibility to resources and crop arrangement (Van Leeuwen et at., 2017). In comparison to the conventional tillage system, the straw mulch (T2) and plastic mulch (T3) offered a better composition of SMBC in the upper soil layers. However, less significant differences could be observed in the subsurface soils. Similar readings were suggested by Yang *et al.,* 2018. This could be an inference to the higher moisture retention in the topsoil and temperature regulation in the mulching system leading to changes in SMBC in semi-arid regions (Liu *et al.,* 2013). The highest SMBC in the plastic mulching (T3) treatment could be a function of regulating and improving the soil hydrothermal conditions. This was also described by Wang *et al.,* 2014.

Likewise, Roldán *et al.,* 2003 suggested that SMBC could be positively related to the various tillage systems and residue management practices in maize crops. Incidentally, the amount of biomass incorporation is also a driving factor for controlling the amount of SMBC as plant biomass could turn as a huge energy source for the soil microbes. Higher organic residue retention increases the SMBC when compared to the other treatments. Govaerts *et al.,* 2007 deduced that residue incorporation and retention could significantly affect the SMBC in surface soils as compared to non-residue incorporation. The microbial communities could obtain their energy sources directly from the C obtained from crop residues. Our treatments T2, T3 and T9 offered a significant increase in SMBC during the cropping period, which could be due to the above reason.

SMBC was also significantly more in the minimum tillage (T4) in comparison to the other conventional tillage systems in the long run. The initial higher SMBC in the other agricultural practices apart from T2, T3 and T9 could be due to higher N-mineralization in soil. Availability of N is highly positively correlated with the amount of SMBC in a soil system. Yadav *et al.,* 2017 also found an increased SMBC in minimum tillage practices in comparison to conventional practices. It was also observed that increase in tillage could negatively impact the SMBC and induce its reduction, which was relevant with our study.

4.3.2 Dehydrogenase activity (DHA) (µg g^{-1} day^{-1}):

Table 42: Effect of different agricultural practices on DHA (0-15cm)

Treatments	DHA (0-15cm) (µg g^{-1} day^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	20.58d	15.47e	14.39e	8.75c	9.31e	10.92e	12.66e	16.24g	27.63e	26.10f
T2 (Straw Mulching)	33.91a	40.90a	29.80a	11.59b	11.38b	15.00ab	21.71b	27.57a	43.83b	44.33bc
T3 (Plastic Mulching)	30.07b	41.34a	31.64a	13.46a	11.57ab	12.47d	17.52d	23.18c	47.49a	45.27ab
T4 (Minimum Tillage)	29.23b	43.70a	29.98a	13.06a	12.18a	16.13a	21.09c	25.36b	48.83a	47.94a
T5 (Earthing up)	22.29cd	32.08c	21.39cd	10.72b	10.92bc	14.25b	17.19d	21.17de	31.14d	42.14c
T6 (Paired row)	22.71cd	32.33c	23.63b	11.14b	11.07b	14.63b	21.86b	23.68c	32.66d	38.46d
T7 (Broadcasting)	21.42cd	29.70c	21.30cd	10.82b	10.01de	12.97cd	25.62a	20.14ef	43.39b	28.29ef
T8 (Ridge and Furrow)	23.50cd	30.52c	21.92bc	11.22b	11.39b	14.08bc	21.26c	22.13d	40.25c	29.33e
T9 (No weeding)	24.69c	35.69b	24.07b	11.10b	11.30b	12.00de	17.29d	19.14f	38.47c	37.54d
T10 (Weeding with weedicide)	21.17d	20.91d	19.33d	9.23c	10.21cd	10.91e	11.14f	15.99g	38.08c	29.64e
CD	2.87	2.82	1.68	0.92	0.73	1.14	0.33	1.04	1.69	2.35
SEm±	0.97	0.95	0.57	0.31	0.25	0.38	0.11	0.35	0.57	0.79

Table 43: Effect of different agricultural practices on DHA (15-30 cm)

Treatments	DHA (15-30 cm) (μg g^{-1} day^{-1})									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	12.22e	16.46de	12.93f	6.17f	6.04e	6.41f	8.32f	8.48e	18.83f	20.82e
T2 (Straw Mulching)	23.13ab	28.17a	25.66a	9.58b	8.47b	11.66b	13.56a	13.41a	30.39b	29.81c
T3 (Plastic Mulching)	25.64a	25.58b	26.19a	9.34b	8.02b	12.20a	11.40b	12.78b	35.06a	34.88a
T4 (Minimum Tillage)	24.80a	27.70ab	24.48a	10.30a	9.49a	11.42b	10.95c	13.00ab	35.51a	35.33a
T5 (Earthing up)	20.56bc	22.03c	18.39bc	7.59cd	8.10b	9.81c	9.93d	11.94c	33.54a	33.78ab
T6 (Paired row)	20.68bc	21.31c	16.92cd	7.30de	8.25b	9.23d	9.20e	9.58d	22.01e	20.51e
T7 (Broadcasting)	15.51d	14.49e	14.57ef	6.80ef	7.55c	8.29e	8.11f	8.42e	17.81f	19.42e
T8 (Ridge and Furrow)	18.79c	21.79c	19.19b	7.55cde	8.12b	10.22c	11.03bc	13.51a	24.83d	26.10d
T9 (No weeding)	20.92bc	21.19c	19.16b	7.39cde	7.25c	10.00c	10.03d	12.55b	28.37c	31.42bc
T10 (Weeding with weedicide)	13.47de	16.94d	15.96de	8.16c	6.77d	9.09d	9.24e	9.56d	21.60e	25.16d
CD	2.04	2.23	1.89	0.64	0.34	0.42	0.29	0.55	1.93	2.39
SEm±	0.69	0.75	0.64	0.22	0.12	0.14	0.10	0.19	0.65	0.81

The soil dehydrogenase activity (DHA) expresses the range in oxidation of organic matter by microorganisms, and it could be a good indicator of microbial activity in soils. During the experiment, DHA was high during both crop growing periods, but it decreased during the non-growing period **(Tables 42 and 43)**. The maximum decrease in all treatments were observed at 225 DAS. The range of DHA in the surface soil for the fallow treatment (T1) developed a range from 20.58 µg g^{-1} day^{-1} at 45 DAS with a maximum decrease to 9.31 µg g^{-1} day^{-1} at 225 DAS and increasing to 26.10 µg g^{-1} day^{-1} by 450 DAS. Straw mulching treatment (T2) developed similar trend from 33.91 µg g^{-1} day^{-1} at 45 DAS to 11.38 µg g^{-1} day^{-1} at 225 DAS and increasing to 44.33 µg g^{-1} day^{-1} by 450 DAS. Similarly, the plastic mulching treatment (T3), minimum tillage (T4) and earthing up treatment (T5) noted a range of 30.07– 11.57 – 45.27 µg g^{-1} day^{-1}, 29.23 – 12.18 – 47.94 µg g^{-1} day^{-1} and 22.29 – 10.92 – 42.14 µg g^{-1} day^{-1} respectively at 45 DAS – 225 DAS – 450 DAS. The remaining treatments also developed similar variability denoted in the range: T6 (22.71 – 11.07 – 38.46 µg g^{-1} day^{-1}), T7 (21.42 – 10.01 – 28.29 µg g^{-1} day^{-1}), T8 (23.50 – 11.39 – 29.33 µg g^{-1} day^{-1}), T9 (24.69 – 11.30 – 37.54 µg g^{-1} day^{-1}) and T10 (21.17 – 10.21 – 29.64 µg g^{-1} day^{-1}) at 45 DAS – 225 DAS – 450 DAS respectively. The subsurface layers also indicated a similar form albeit at different value ranges which has been provided as under: indicated values of T1 (12.22 – 6.04 – 20.82 µg g^{-1} day^{-1}), T2 (23.12 – 8.47 – 29.81 µg g^{-1} day^{-1}), T3 (25.64 – 8.02 – 34.88 µg g^{-1} day^{-1}), T4 (24.80 – 9.49 – 35.33 µg g^{-1} day^{-1}), T5 (20.56 – 8.10 – 33.78 µg g^{-1} day^{-1}), T6 (20.68 – 8.25 – 20.51 µg g^{-1} day^{-1}), T7 (15.51 – 7.55 – 19.42 µg g^{-1} day^{-1}), T8 (18.79 – 8.12 – 26.10 µg g^{-1} day^{-1}), T9 (20.92 – 7.25 – 31.42 µg g^{-1} day^{-1}) and T10 (13.47 – 6.77 – 25.16 µg g^{-1} day^{-1}) at 45 DAS – 225 DAS – 450 DAS respectively.

Amalgamation of higher organic residues on the surface soil stimulates the functionality of Dehydrogenase enzyme by providing essential substrates to the microbes (Maini *et al.,* 2020). Variation in DHA was observed with the changes in the agricultural practices employed. DHA declines rapidly during the summer and winter months; however, it was found to be highest during the rainy season. Least amount of Dehydrogenase activity was observed in a barren land use system and higher in cultivated systems (Arora *et al.,* 2021). This could be the justification for increase in DHA during the two-cropping period and reduction during the non-growing period. The reasoning is completely in agreement with our findings during the experimentation.

Minimum tillage (T4) offered the highest variation in DHA compared to the other practices. This could be result of higher SMBC in the reduced tillage system in relation to other conventional tillage systems (Pandey *et al.,* 2014). Similar observations were recorded by Adak *et al.,* 2023 whereby a reduced tillage condition observed maximum increase in DHA than other conventional tillage systems in the surface layers. It was also observed that addition and retention of organic residues enhanced the DHA more the surface layers than subsurface layers. This could be the reason for higher DHA in straw mulching (T2) and plastic mulching (T3). Also, the DHA in subsurface soil in all the treatments were lesser the surface soils. Synthetic chemicals are known to negatively affect the soil enzymes and DHA is reduced (Devi *et al.,* 2018) which could be the reason for decreased enzymatic activity in T10.

4.3.3 Bacterial count (× 10^6):

Table 44: Effect of different agricultural practices on bacterial count (0-15 cm)

Treatments	Bacterial Count (× 10^6) (0-15 cm)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	D1B (90)	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	D1H (360)	D1I (405)	D1J (450)
T1 (Fallow)	19.67f	21.00d	18.67e	17.33f	17.00e	18.00d	17.67cd	16.00e	20.67g	21.33e
T2 (Straw Mulching)	24.67c	27.00bc	24.67bc	22.00bc	22.33ab	21.00bc	21.33ab	22.33ab	25.33bcd	26.33bcd
T3 (Plastic Mulching)	28.67a	30.67a	30.00a	26.33a	22.33ab	22.67ab	21.67a	22.67a	30.67a	32.67a
T4 (Minimum Tillage)	27.00b	28.33ab	28.67ab	23.67b	24.00a	23.67a	22.00a	21.00abc	27.67b	28.67b
T5 (Earthing up)	24.67c	26.00bc	21.67cde	19.67cdef	20.33bcd	19.33cd	19.00abcd	19.33bcd	24.67cde	26.00bcd
T6 (Paired row)	23.33cd	24.00cd	23.67cd	21.67bcd	21.33abc	21.00bc	20.67abc	21.33abc	24.00cde	26.33bcd
T7 (Broadcasting)	22.33de	20.33d	19.00de	18.33ef	18.00de	18.67cd	18.00cd	16.33de	22.67fg	24.00d
T8 (Ridge and Furrow)	24.33c	25.33bc	22.00cde	19.33def	18.67cde	19.00cd	18.33bcd	19.00cde	25.67bc	27.33b
T9 (No weeding)	24.00c	24.67bc	22.00cde	20.00cde	19.33cde	18.67cd	18.00cd	18.67cde	26.00bc	27.00bc
T10 (Weeding with weedicide)	21.33e	20.33d	19.33de	18.33ef	17.67de	18.00d	17.00d	17.33de	23.00efg	24.33cd
CD	1.32	3.44	4.47	2.29	2.52	2.33	2.80	2.79	2.31	2.57
SEm±	0.45	1.16	1.51	0.77	0.85	0.79	0.94	0.93	0.78	0.87

Table 45: Effect of different agricultural practices on bacterial count (15-30 cm)

Treatments	Bacterial Count (× 10^6) (15-30 cm)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	D2B (90)	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	D2H (360)	D2I (405)	D2J (450)
T1 (Fallow)	15.67f	14.67e	14.33d	14.67e	14.00e	14.33c	14.67a	15.00b	15.67e	15.00f
T2 (Straw Mulching)	19.67abcd	22.00a	21.00a	20.67ab	21.00ab	18.33ab	18.67a	18.33ab	20.67b	22.33ab
T3 (Plastic Mulching)	21.67a	21.33abc	21.00a	20.67ab	19.67abc	18.00ab	17.33a	18.67ab	22.67a	23.33a
T4 (Minimum Tillage)	20.67ab	21.67ab	21.33a	21.67a	21.33a	19.00a	18.33a	19.00a	20.67b	22.00abc
T5 (Earthing up)	18.67bcde	19.00bcd	19.00abc	19.33abc	18.67bc	17.00abc	17.33a	17.67ab	19.00bcd	19.67bcde
T6 (Paired row)	18.00cdef	17.00de	16.67cd	16.33de	18.00cd	18.67ab	18.33a	18.33ab	19.33bcd	17.67def
T7 (Broadcasting)	17.33def	17.00de	16.67cd	16.67cde	15.67de	15.67abc	16.33a	15.33ab	18.33cd	18.67cde
T8 (Ridge and Furrow)	19.33abcd	18.67cd	18.00bc	18.33bcd	17.67cd	16.67abc	17.67a	17.67ab	20.00bc	19.67bcde
T9 (No weeding)	20.00abc	20.67abc	19.67ab	19.33abc	18.33c	17.33abc	17.33a	17.33ab	20.00bc	21.00abcd
T10 (Weeding with weedicide)	16.33ef	15.67e	15.00d	14.33e	14.67e	15.33bc	15.00a	15.33ab	17.33de	17.00ef
CD	2.25	2.70	2.55	2.68	2.39	2.84	3.49	3.39	1.91	3.16
SEm±	0.76	0.91	0.86	0.90	0.81	0.96	1.17	1.14	0.64	1.06

The bacterial count is an indication of the microbial health present in the soil, and it can be included as a good parameter for evaluating soil health. Significant variations were observed in all the treatments and across the horizontal data distribution. A slight increase was observed at 90 DAS and later developed a decline during the non-growing periods on both soil depths **(Tables 44 and 45)**. The fallow treatment (T1) followed an increase of 19.67 – 21.00 from 45 DAS – 90 DAS and later monitored maximum declined to 16.00 at 360 DAS which was however increased to 21.33 at 450 DAS. The bacterial count in straw mulching treatment (T2) increased from 24.67 to 27.00 at 90 DAS; declined to 22.33 at 225 DAS and increased until 26.33 at 450 DAS. For the plastic mulching treatment (T3), observable range were 28.67 – 30.67 at 90 DAS; maximal decline to 21.67 at 315 DAS and increased to 32.67 at 450 DAS. The minimum tillage (T4) established an increase from 27.00 to 28.33 at 90 DAS; falling to 21.00 at 360 DAS and inclining to 28.67 at 450 DAS. For earthing up treatment (T6), the increase was 24.67 – 26.00 at 90 DAS; reducing to 19.00 at 315 DAS and gaining increase to 26.00 at the end of the experiment. The remaining treatments also entailed a similar trend which corresponded to paired row treatment (T6) developing a bacterial count from 23.33 – 24.00 at 90 DAS; declining to 20.67 at 315 DAS and increasing to 26.33 at 450 DAS. For broadcasting treatment (T7), it was 25.00 – 28.00 at 90 DAS; reduction to 20.67 at 270 DAS and inclining to 29.67 at 450 DAS. The ridge and furrow treatment developed an increase from 24.67 – 27.67 at 90 DAS; declining to 20.00 at 225 DAS and increasing to 27.67 at 450 DAS. For no weeding treatment (T9), it was an increase from 19.67 – 23.00 at 90 DAS; declining to 18.33 at 225 DAS and increasing to 27.33 at 450 DAS. For the weeding with weedicide treatment (T10), there was no significant change from 45 to 90 DAS; however, a decline to 18.67 was observed at 225 DAS which was increased to 23.33 at 450 DAS. The maximum variation was seen under T3 which was closely followed by T9 and T2. Following the surface layers, the subsurface soil established significant variations in the bacterial count. Similar to the surface soil, it also developed a decline during the non-growing period. Treatments T2 and T5 obtained maximum decline at 270 DAS; treatment T1 at 225 DAS; T3, T4, T9 and T10 developing maximum reduction at 315 DAS while it was 180 DAS T10 for T6 and T7 and 270 DAS for T8. The subsurface soil recorded values of T1 (15.67 – 15.00), T2 (19.67 – 22.33), T3 (21.67 – 23.33), T4 (20.67 – 22.00), T5 (18.67 – 19.67), T6 (18.00

– 17.67), T7 (17.33 – 18.67), T8 (19.33 – 19.67), T9 (20.00 – 21.00) and T10 (16.33 – 17.00) from 45 to 450 DAS respectively. Maximum variation was noted in T3 which is closely followed by T2 and T4.

The soil biological parameters are a necessity to stipulate the quality of soil in relation to the agricultural practices involved. Different tillage practices and residue management system tend to have a paramount effect on the soil microbial population (Das *et al.,* 2021). The microbial communities are also responsible for maintaining crop production and also the fertility condition of soil (Fan *et al.,* 2020). Mulching could improve the soil biogeochemical properties and also enhances the soil microbial activity (Zhou *et al.,* 2012). Several studies have been carried out to study the influence of straw and plastic mulching on the soil biota. However, differences in climatic conditions, temperature and soil created certain differences in the study (Wang *et al.,* 2020).

In comparison to the other tillage systems, plastic film mulching had a relatively higher abundance in the bacterial population in a maize-wheat crop rotation system (Chen *et al.,* 2021). This could be an inference to the higher bacterial population in our plastic mulching treatment (T3). Addition of straw had also shown an increase in the bacterial count during the initial phases. However, its relative abundance seemed to decrease with time (Su *et al.,* 2020). This is in agreement with our straw mulching treatment (T2). Surface mulching invigorate a conductive environment for nitrification under the mulched system, by increasing the soil-water content and retention, supplying of energy through C produced from the biomass. It helps in the proliferation of microbial population and increasing the microbial activities in an anaerobic micro-environment. Application of 100% recommended dose of fertilizers along with organic amendments also increases the bacterial and fungal count (Walia *et al.,* 2024). This could be the reason for the slight increases in bacterial count in the other treatments. The bacterial population was higher in the surface soils and there were less significant differences in the subsurface layers.

4.3.4 Fungal count (× 10^6):

Table 46: Effect of different agricultural practices on fungal count (0-15 cm)

Treatments	Fungal Count (× 10^3) (0-15 cm)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D1A (45)	**D1B (90)**	D1C (135)	D1D (180)	D1E (225)	D1F (270)	D1G (315)	**D1H (360)**	**D1I (405)**	**D1J (450)**
T1 (Fallow)	18.33f	19.00d	18.33e	18.00d	17.67c	18.00d	18.33c	19.33c	20.33d	21.33e
T2 (Straw Mulching)	27.67b	28.67b	26.33b	23.67ab	22.00a	22.67a	23.00a	23.00ab	27.33bc	28.67cd
T3 (Plastic Mulching)	27.00bc	28.33b	26.00bc	23.00ab	21.00ab	22.33ab	23.33a	23.67a	29.00b	32.33ab
T4 (Minimum Tillage)	27.33bc	28.00b	26.00bc	23.33ab	21.33a	21.67abc	22.67ab	23.00ab	28.33b	30.33bc
T5 (Earthing up)	31.33a	34.33a	30.33a	25.00a	22.00a	21.00abc	21.33abc	21.67abc	31.67a	34.33a
T6 (Paired row)	27.33bc	30.67b	26.33b	23.67ab	22.00a	22.33ab	23.00a	23.67a	29.67ab	30.67bc
T7 (Broadcasting)	25.00cd	28.00b	24.00bc	22.33ab	21.00ab	20.67abcd	21.33abc	21.00abc	28.00b	29.67cd
T8 (Ridge and Furrow)	24.67d	27.67b	23.67c	21.33bc	20.00abc	20.33abcd	21.00abc	21.67abc	27.67bc	27.67d
T9 (No weeding)	19.67f	23.00c	18.67e	18.67cd	18.33c	19.67bcd	20.33abc	20.67bc	25.33c	27.33d
T10 (Weeding with weedicide)	22.33e	23.33c	21.33d	19.00cd	18.67bc	19.33cd	19.67bc	20.67bc	21.67d	23.33e
CD	2.30	2.94	2.22	2.66	1.83	2.42	2.57	2.01	2.20	2.41
SEm±	0.78	0.99	0.75	0.90	0.62	0.81	0.86	0.68	0.74	0.81

Table 47: Effect of different agricultural practices on fungal count (15-30 cm)

Treatments	Fungal Count (× 10^3) (15-30 cm)									
	1ST TRIAL		Non-Growing Period					2ND TRIAL		
	D2A (45)	**D2B (90)**	D2C (135)	D2D (180)	D2E (225)	D2F (270)	D2G (315)	**D2H (360)**	**D2I (405)**	**D2J (450)**
T1 (Fallow)	15.67c	15.33d	14.67c	14.67c	14.00c	14.33c	14.00c	14.67c	15.00e	15.33e
T2 (Straw Mulching)	21.33a	22.67ab	20.67ab	19.67ab	19.33ab	18.33ab	18.67a	19.33a	21.67ab	23.33ab
T3 (Plastic Mulching)	22.00a	23.00a	22.33a	20.33a	19.67a	18.67a	19.00a	19.67a	23.00a	25.00a
T4 (Minimum Tillage)	20.33ab	21.67ab	21.33a	20.00a	19.33ab	18.00ab	18.00ab	18.33ab	20.67abcd	22.33bc
T5 (Earthing up)	21.00a	22.33ab	21.33a	20.00a	18.67ab	17.67ab	18.33ab	19.00a	21.33abc	22.67bc
T6 (Paired row)	19.33ab	20.33abc	19.67	18.33ab	18.67ab	18.00ab	18.33ab	19.00a	19.67abcd	20.67cd
T7 (Broadcasting)	18.67abc	20.33abc	19.33ab	18.00ab	18.67ab	18.33ab	19.33a	19.33a	17.67cde	20.67cd
T8 (Ridge and Furrow)	19.67ab	20.67abc	20.00ab	19.00ab	16.67bc	15.67bc	15.00c	16.00bc	18.67bcde	20.33cd
T9 (No weeding)	18.67abc	19.67bc	19.33ab	18.33ab	17.67ab	16.67abc	16.33abc	17.00abc	18.67bcde	21.33bc
T10 (Weeding with weedicide)	17.67bc	18.33c	17.67b	16.67bc	16.67bc	15.67bc	15.33bc	15.00c	17.00de	18.67d
CD	3.07	3.06	2.85	2.91	2.73	2.66	2.91	2.53	3.46	2.34
SEm±	1.03	1.03	0.96	0.98	0.92	0.90	0.98	0.85	1.17	0.79

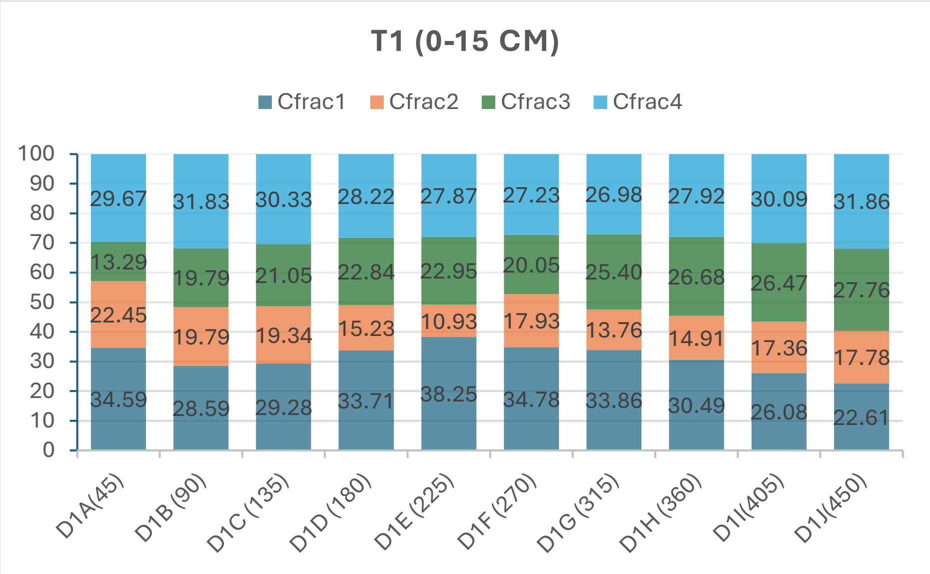
Similar to the bacterial count, the fungal count denotes the microbial activity in soil, and it is also an important parameter for assessing soil quality and soil health. Similar to bacterial count, a sharp decline was observed in fungal count during the non-growing periods at both soil depths. The recorded values of fungal count at the surface soil were: the fallow treatment (T1) developed a decline from 18.33 – 17.67 from 45 DAS to 225 DAS and increasing to 21.33 at 450 DAS). The straw mulching treatment (T2) observed a decline from 27.67 – 21.00 at 225 DAS and increasing to 28.67 at 450 DAS. Similarly, plastic mulching (T3) and minimum tillage (T4) developed the values of (27.00 – 21.00 – 32.33) and 27.33 – 21.33 – 30.33) at 45 DAS – 225 DAS – 450 DAS respectively. The earthing up treatment (T5) and broadcasting treatment (T7) managed values of 31.33 – 21.00 – 34.33 and 25.00 – 20.67 – 29.67 at 45 DAS – 270 DAS – 450 DAS respectively. The variations observed in the remaining treatments were: T6 (27.33 – 22.00 – 30.67), T8 (24.67 – 20.00 – 27.67), T9 (19.67 – 18.33 – 27.33) and T10 (22.33 – 18.67 – 23.33) at 45DAS – 225 DAS – 450 DAS respectively. Significant variations were observed at T3, T4, T2 and T9 in order. The subsurface layer noted readings of T1 (15.67 – 15.33), T2 (21.33 – 23.33), T3 (22.00 – 25.00), T4 (20.33 – 22.33), T5 (21.00 – 22.67), T6 (19.33 – 20.67), T7 (18.67 – 20.67), T8 (19.67 – 20.33), T9 (18.67 – 21.33) and T10 (17.67 – 21.33) from 45 to 450 DAS respectively **(Tables 46 and 47)**.

Agricultural practices could impose significant effects on the microbial communities (Govaerts *et al.,* 2007). An increased microbial diversity was identified in a conservation-based agriculture system owing to the presence of crop residues on the surface layers of soil (Choudhary *et al.,* 2018). This was in agreement with our current findings. Addition of straws could develop increase in the fungal population during the decomposition stages of straw (Su *et al.,* 2020) and this could be the reason for increase in fungal count in our straw mulching treatment (T2). The reduced disturbances in a minimum tillage system could increase the fungal population due to proliferation of extensive hyphal networks. Bailey *et al.,* 2002 also established a fungal dominated ecosystem under a reduced tillage condition and reduced tillage often bear the closest similarity to a natural ecosystem. The crop residue decomposition and nutrient cycling processes are the major driving factors for an increase in fungal population (Choudhary *et al.,* 2018).

4.4 Effect of different agricultural practices on soil carbon fractions:

Upon analysis of the different carbon fractions (C_{frac1}, C_{frac2}, C_{frac3} and C_{frac4}), significant variations in all the treatments and along the increasing DAS were observed. It could also be noted that the non-labile carbon fractions (C_{frac3} + C_{frac4}) were the highest irrelevant of the different agricultural practices employed.

4.4.1 T1 (Fallow):



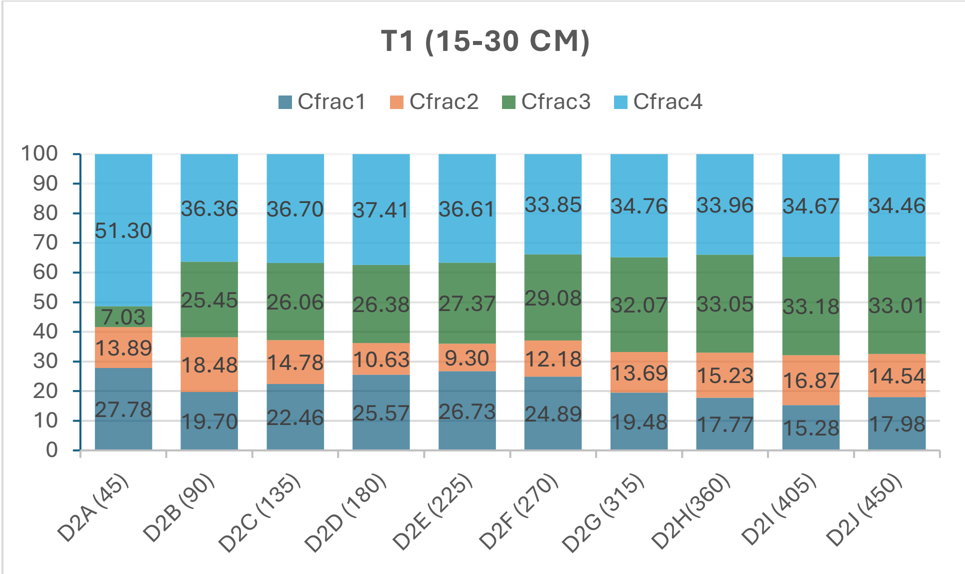
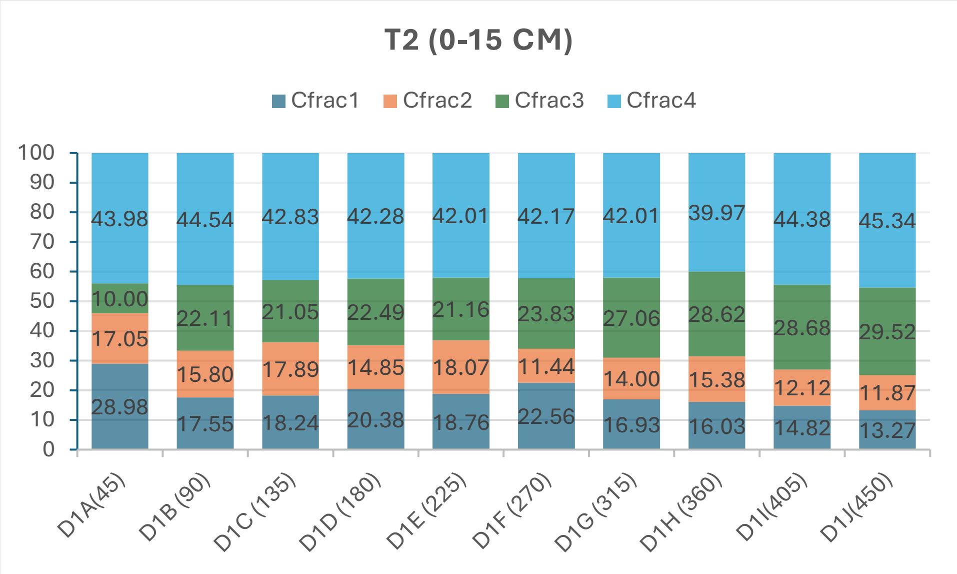


Fig 5a: Carbon pools for T1 (0-15 cm)

Fig 5b: Carbon pools for T1 (15-30 cm)

In treatment T1 (Fallow), the most labile C fraction (C_{frac1}) was observed in a range from 22.61% to 38.25% in the surface soil (0-15 cm) and 17.77% to 27.78% in subsurface soil (15-30 cm). The maximum was recorded at 225 DAS (38.25%) while the minimum was indicated at 450 DAS (22.61%) for surface soil. In case of subsurface soil, 45 DAS (27.79%) was the highest and 360 DAS (17.77%) was the lowest. The fluctuation in C_{frac1} could be a result of difference in organic matter decomposition in the soil. Labile pools (C_{frac2}) also showed variations from 10.39% to 22.45% in surface soils while it was 9.30% to 13.89% in the subsurface soil. The C_{frac1} and C_{frac2} pools are labile in nature, and it can be a source of nutrition for the microbial communities in soil. The less labile pools were observed to be increasing from 45 DAS upto 450 DAS in both surface and subsurface layers. At 0-15 cm, the increase was indicated from 13.29 % (45 DAS) to 27.76% (450 DAS). Similarly, at 15- 30 cm soil depth, the development was 7.03% at 45 DAS and 33.01% at 450 DAS. The recalcitrant pool also shows fluctuations from 29.67% at 45 DAS, a slight decrease to 26.98% at 315 DAS and an increase up to 31.86% at 450 DAS in surface soil. For the subsurface soil, there was a decline in recalcitrant pools from 45 DAS (51.30%) to 90 DAS (36.36%). This could be a result of the oxidization of carbon due to tillage practices. Other than this, negligible changes were observed until the end of the experiment at 450 DAS (34.46%). The C_{frac3} and C_{frac4} are generally non- labile in nature and persist in the soil system for a long period. They are considered as good indicators for carbon in soil. The C_{frac3} and C_{frac4} are increasing when the agriculture land is kept fallow, and this could be an indication towards healing the soil. The relative variation in the carbon fractions have been shown in **Fig 5a and 5b**.

4.4.2 T2 (Straw mulching):



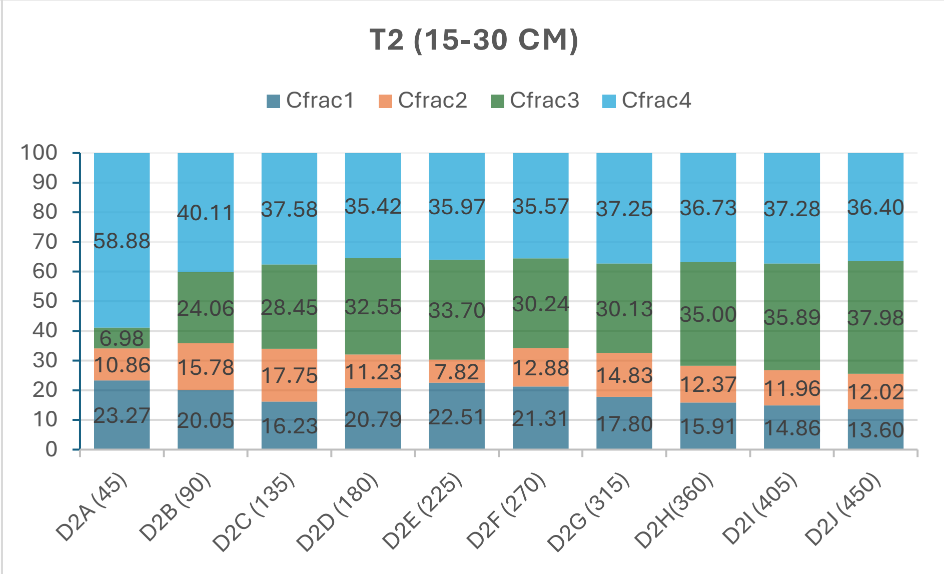


Fig 6a: Carbon pools for T2 (0-15 cm)

Fig 6b: Carbon pools for T2 (15-30 cm)

The most labile carbon fraction (C_{frac1}) was observed within a range of 13.27% to 28.98% in surface soil and 13.6% to 23.27% in the subsurface soil. Maximum value was estimated at 45 DAS and minimum was observed at 450 DAS. The labile fraction (C_{frac2}) also discerned variable changes along the increasing time period. The highest and lowest values for surface soil were 17.05% at 45 DAS and 11.44% at 270 DAS, 11.87% at 450 DAS. The values at subsurface soil fluctuated from 10.88% at 45 DAS, decreasing to 7.82% at 225 DAS and improving to 12.02% at 450 DAS. The combined labile pools (C_{frac1} and C_{frac2}) at 0-15 cm soil depth seems to be higher than the 15-30 cm soil depth. The presence of organic biomass (straw mulch in this case) and its decomposition at surface soil attributed for the variation. There was less biomass in the subsurface soil as compared to its surface counterpart. The less labile fraction (C_{frac4}) seems to be increasing in both cases. The surface soil observed an increase from 10.00% at 45 DAS to 29.52% at 450 DAS. Similar variations were also made out in subsurface soil with an increase from 10.86% at 45 DAS to 37.98% at 450 DAS. The recalcitrant fraction displayed minimal changes from 43.98% at 45 DAS to 45.34% at 450 DAS in surface soils. However, a slight dip from 58.88% at 45 DAS to 40.11% at 90 DAS in subsurface soil was observed. This could be a resulted from the disruption of soil system during tillage operations. At any rate, the combined non-labile pools (C_{frac3} and C_{frac4}) were noticed to be increasing along the timeline. As previously mentioned, it is an indication of clear enhancement in the soil quality when organic mulching was incorporated in the experiment. The relative variation in the carbon fractions have been shown in **Fig 6a and 6b**.

4.4.3 T3 (Plastic mulch)

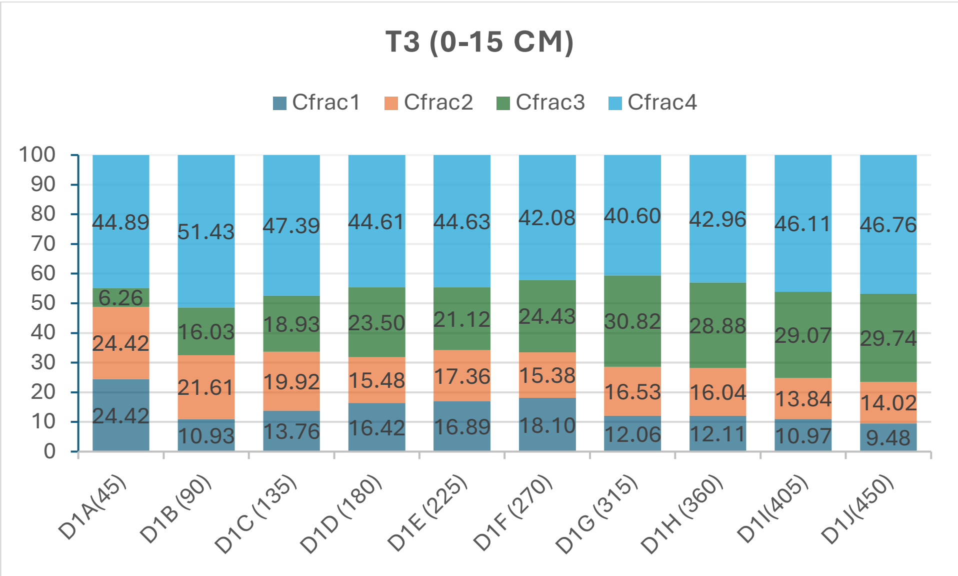


Fig 7a: Carbon pools for T3 (0-15 cm)

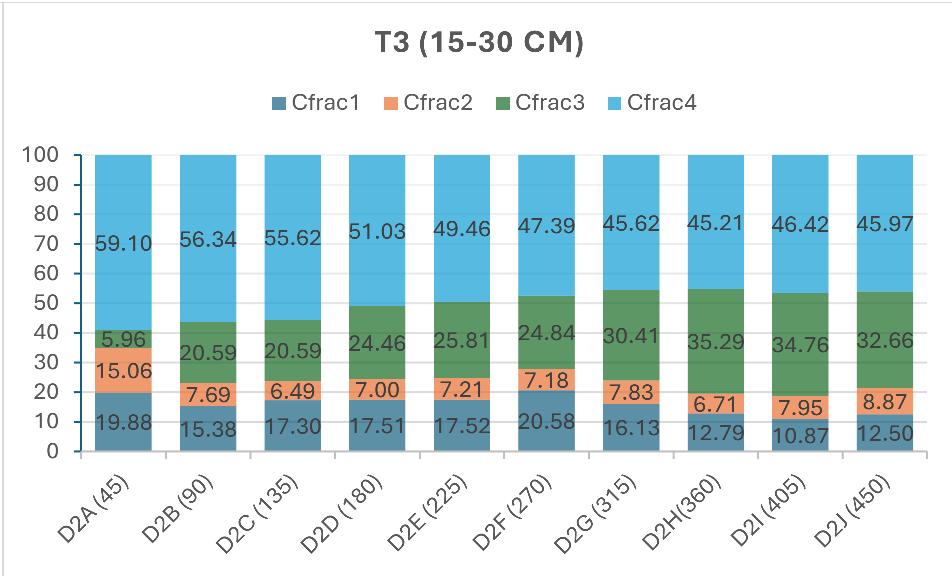


Fig 7b: Carbon pools for T3 (15-30 cm)

The variation in C_{frac1} in surface soil for plastic mulch treatment had minimum observation at 450 DAS (9.48%) while the maximum was at 45 DAS (24.42%). C_{frac1} in the subsurface soil was lower than the surface soil with values ranging from 19.88% at 45 DAS to 12.50% at 450 DAS. The C_{frac2} also followed a similar disposition in both soil layers. At 0-15 cm soil depth, C_{frac2} ranged from 24.42% at 45 DAS to 14.02% at 450 DAS. Similar observations were made in 15-30 cm soil depth where the range was 15.06% at 45 DAS to 8.87% at 450 DAS. It could be clearly seen from **Fig 7a and Fig 7b** that the labile pools (C_{frac1} and C_{frac2}) were larger in the surface soil. It was perhaps the decomposition of plant biomass inside the plastic mulch, which led to higher labile pools in the above soil layers. The less labile pools (C_{frac3}), however, had a dramatic increase along the timeline. At surface layers, it increases from 6.26% at 45 DAS to 29.74% at 450 DAS. In a similar approach, the subsurface layer also procured an increase from 6.96% at 45 DAS to 32.66% at 450 DAS. The recalcitrant pools (C_{frac4}) in the surface soil had minimal changes. The value of C_{frac4} at 45 DAS was 44.89% of the total proportion, which increased to 51.43% at 1st harvest (90 DAS). It had slight variation in value along the timeline and finally settled at 46.76% at 450 DAS. In the subsurface layers, the range was observed at 59.10% at 45DAS to 45.97% at 450 DAS. The non-labile pools (C_{frac3} and C_{frac4}) distinctively contrasted with the labile pools, and it exhibited higher deposition in the subsurface soil layers.

4.4.4 T4 (Minimum tillage):

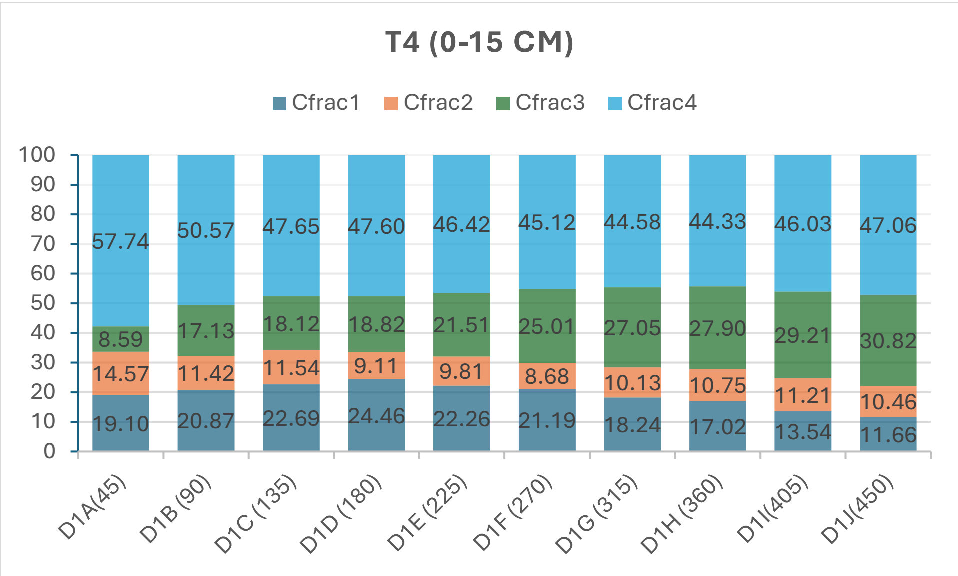


Fig 8a: Carbon pools for T4 (0-15 cm)

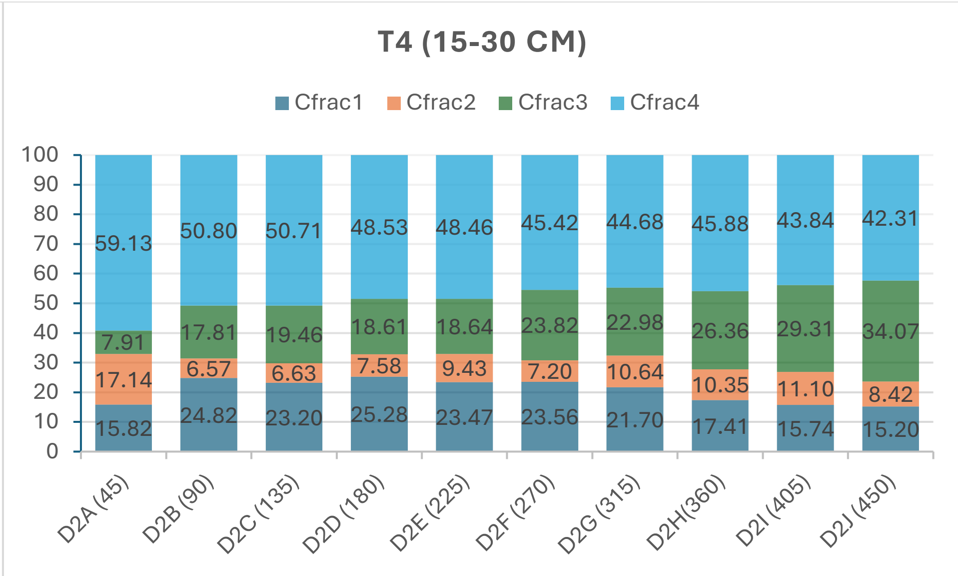


Fig 8b: Carbon pools for T4 (15-30 cm)

The C_{frac1} in the minimum tillage operation fluctuated in both the soil layers. In the surface layer, the values had a gradual increased from 19.10% at 45 DAS to a maximum of 24.46% at 180 DAS declining to 11.66% at 450 DAS. At the subsurface layers, the values increased from 15.82% at 45 DAS to 25.28% at 180 DAS reducing to 15.20 by 450 DAS. The changes observed in labile pools (Cf_{rac2}) were sub optimal in both soil layers. The range in the surface layers were 14.57% at 45 DAS to 10.46% at 450 DAS. For subsurface soil, it was 17.14% at 45 DAS to 8.42% at 450 DAS. The labile pools (C_{frac1} and C_{frac2}) were noticeably smaller from the other treatments. This could probably be a result of minimal disturbance to the soil layers throughout the experimental period. In the instance of less labile fraction (C_{frac3}), both the soil layers exhibited increment in values during the time period, which could be a possible indication of capturing and trapping the carbon inside the soil system. The values magnified from 8.59% to 30.82% and 7.91% to 34.07% at 45 DAS and 450 DAS in the surface and subsurface soils respectively. The recalcitrant fraction (C_{frac4}) ranged from 57.74% at 45 DAS to 47.06% at 450 DAS in surface layers and 59.13% to 42.31% in subsurface layers. The non labile pools (C_{frac3} and C_{frac4}) were higher in the subsurface layers and there were visible higher indications in comparison to the other treatments. Perhaps, minimal soil disturbance could provide a positive outlook for maximizing the quality of soil. The relative variation in the carbon fractions have been shown in **Fig 8a and 8b**.

4.4.5 T5 (Earthing up):

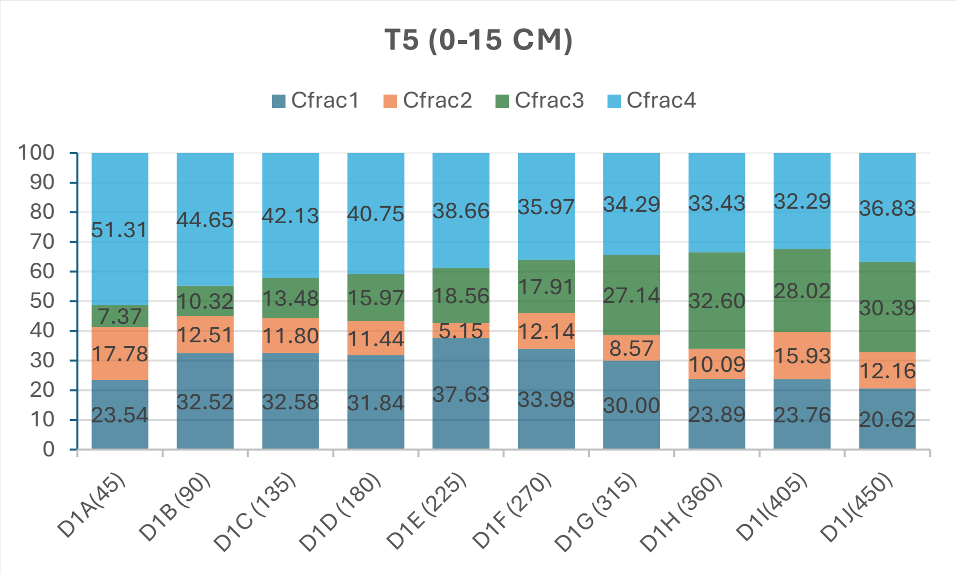


Fig 9a: Carbon pools for T5 (0-15 cm)

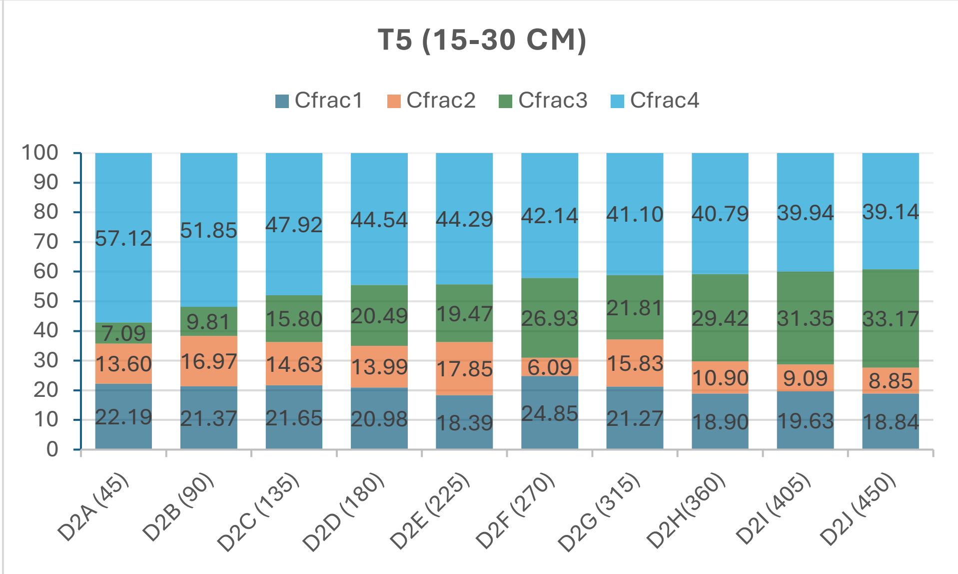
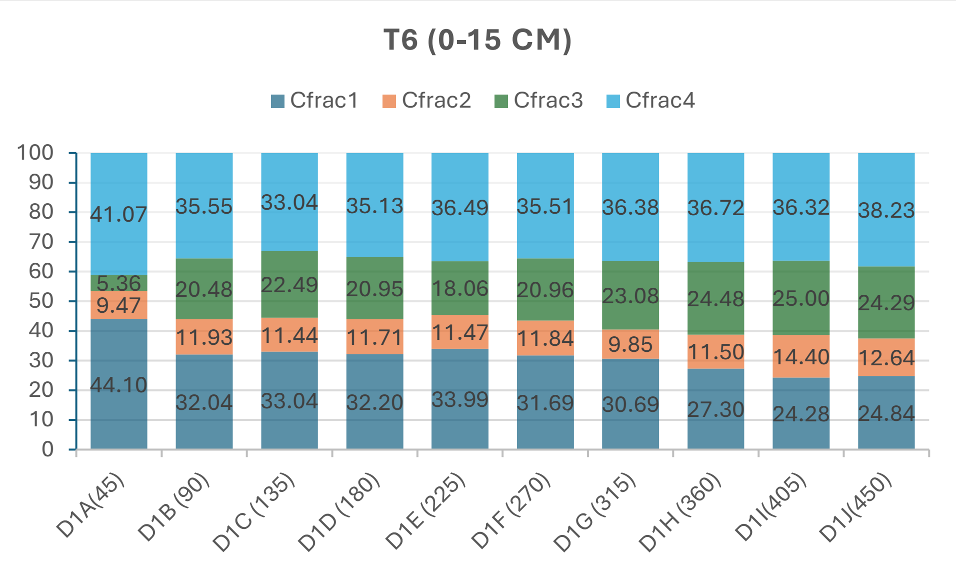


Fig 9b: Carbon pools for T5 (15-30 cm)

The agricultural practice employed for T5 (Earthing up) described significant variations among the carbon pools. The most labile fraction (C_{frac1}) was 23.54% at 45 DAS which escalated to 37.63% at 225 DAS and further depreciated to 20.62% at 450 DAS in the surface soil. The changes in the subsurface soil were below par in comparison to the surface layer. It was 22.19% at 45 DAS, attaining a highest of 24.85% at 270 DAS and 18.84% at 450 DAS. In case of labile fraction (C_{frac2}), the observed values were 23.54% at 45 DAS, lowering to 5.15% at 225 DAS and finally 12.16% at 450 DAS in the surface layers. At 15-30 cm soil depth, the range was 13.60% at 45 DAS to 8.85% at 450 DAS. The labile fractions (C_{frac1} and C_{frac2}) at the surface soil layer were comparatively higher than the previous treatments T1, T2, T3 and T4. Perhaps the introduction of earthing up to the crops had a positive effect on the labile carbon fractions and it could enhance the productivity functions in soil. The non labile fractions were however lower than the previous treatments. The range of the less labile fraction (C_{frac4}) was 7.37% - 30.39% and 7.09% - 33.17% during 45DAS and 450 DAS at 0-15 cm and 15-30 cm soil depth. The recalcitrant fraction (C_{frac4}) observed a value ranging from 51.31% to 36.83% in the surface layers and 57.12% to 39.14% in the subsurface layers at 45 DAS and 450 DAS respectively. The relative variation in the carbon fractions have been shown in **Fig 9a and 9b**.

4.4.6 T6 (Paired Row):



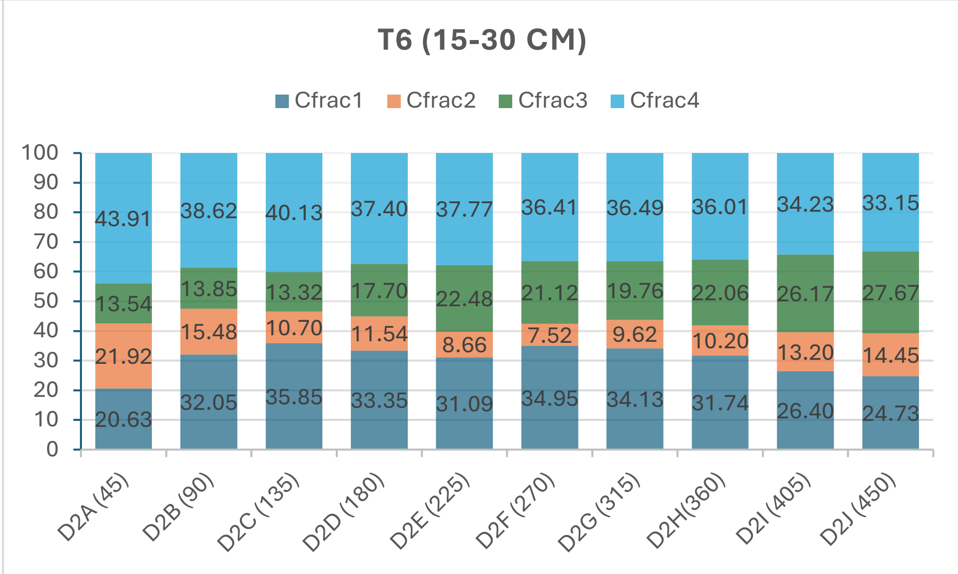


Fig 10a: Carbon pools for T6 (0-15 cm)

Fig 10b: Carbon pools for T6 (15-30 cm)

The paired row treatment induced a high value of the most labile carbon fraction (C_{frac1}). It exhibited values of 44.10%, 32.04%, 33.04%, 32.20%, 33.99%, 31.69%, 30.69%, 27.30%, 24.28%, 24.84% in surface soil and 20.63%, 32.05%, 35.85%, 33.35%, 31.09%, 34.95%, 34.13%, 31.74%, 26.40% and 24.73% in subsurface soils at 45, 90, 135, 180, 225, 270, 315, 360, 40 and 450 DAS respectively. The C_{frac2} ranged from 9.47% to 12.64% and 21.92% to 14.45% in the surface and subsurface layers at 45 DAS to 450 DAS. The less labile carbon fractions (C_{frac3}) maintained a value range of 9.47% at 45 DAS to 24.29% at 450 DAS in 0-15 cm soil depth. The 15-30 cm soil depth exhibited value range of 13.54% at 45 DAS to 27.67% at 450 DAS. The increase in the less labile fraction along the time period is relatively lower than treatments T1, T2, T3 and T4. Additionally, the recalcitrant fraction (C_{frac4}) demonstrated minimal changes. Values were ranged at 41.07% to 38.23% and 43.91% to 33.15% at 45 DAS to 450 DAS for the surface and subsurface soil layers respectively. The relative variation in the carbon fractions have been shown in **Fig 10a and 10b**.

4.4.7 T7 (Broadcasting):

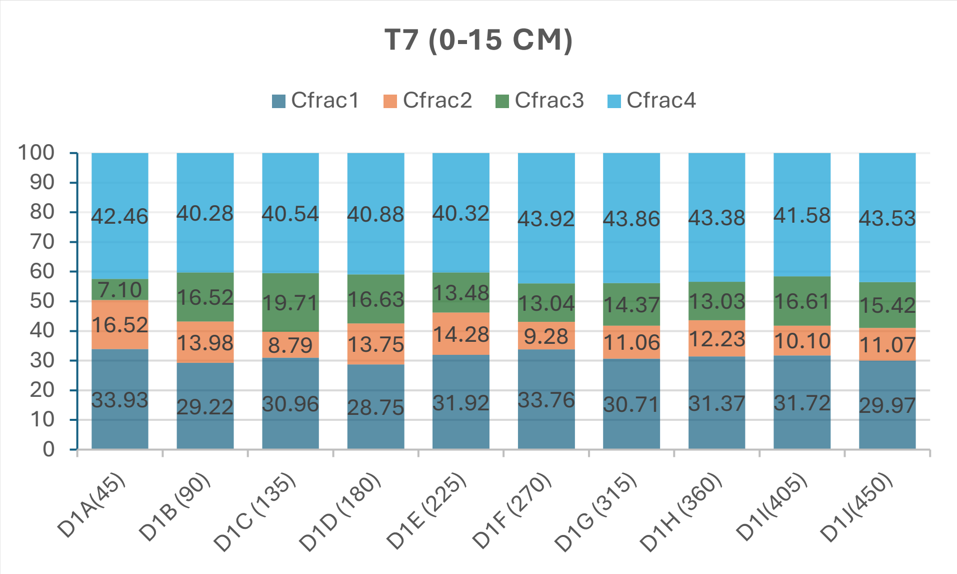


Fig 11a: Carbon pools for T7 (0-15 cm)

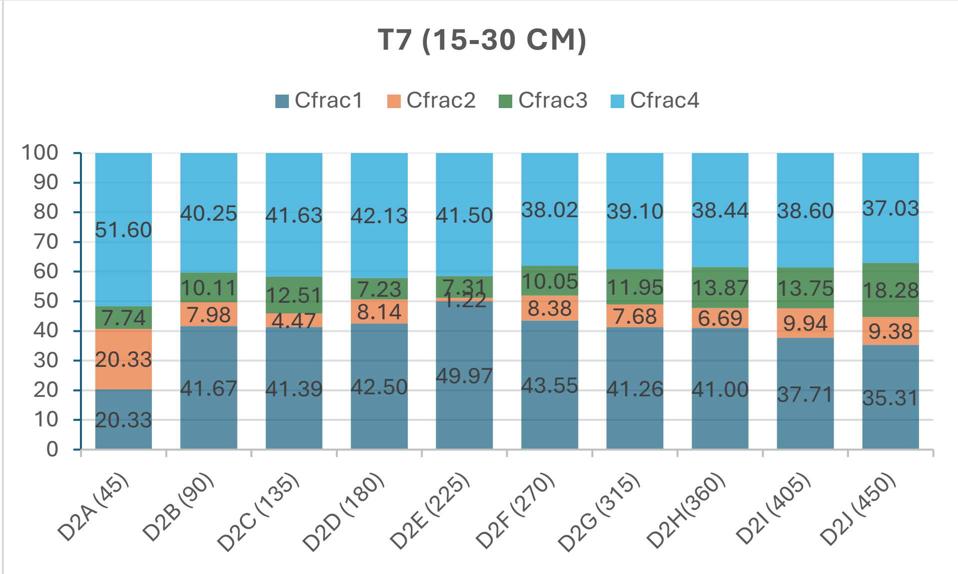


Fig 11b: Carbon pools for T7 (15-30 cm)

The most labile carbon fraction (C_{frac1}) remains almost consistent along the increasing DAS in surface soil for the broadcasting treatment. It ranged from 33.93% at 45 DAS to 29.97% at 450 DAS. In the subsurface layers, the values increased from 20.33 DAS at 45 DAS to a maximum of 49.93% at 225 DAS minimizing to 35.31% at 450 DAS. C_{frac2} was associated in surface layers with a range from 16.52% to 11.07% and 20.33% to 9.38% in subsurface layers at 45 DAS and 450 DAS respectively. The combined labile pools (C_{frac1} and C_{frac2}) in both the layers were relatively high in comparison to the other treatments. Since these carbon fractions are generally labile in nature, it can be easily lost to the surrounding environment. It could also affect the lability index to a certain degree. Minimal changes were observed in the less labile fraction (C_{frac3}). The associated changes at surface and subsurface soil ranged at 7.10% to 15.42% and 7.74% to 18.28% respectively at 45 DAS and 450 DAS. Conjunctively, the recalcitrant pool (C_{frac4}) observed minimal variation in the surface soils. It ranged from 42.46% to 43.53% and 51.60% to 37.03% at 45 DAS and 450 DAS in the surface and subsurface soil layers respectively. The relative variation in the carbon fractions have been shown in **Fig 11a and 11b**.

4.4.8 T8 (Ridge and furrow):

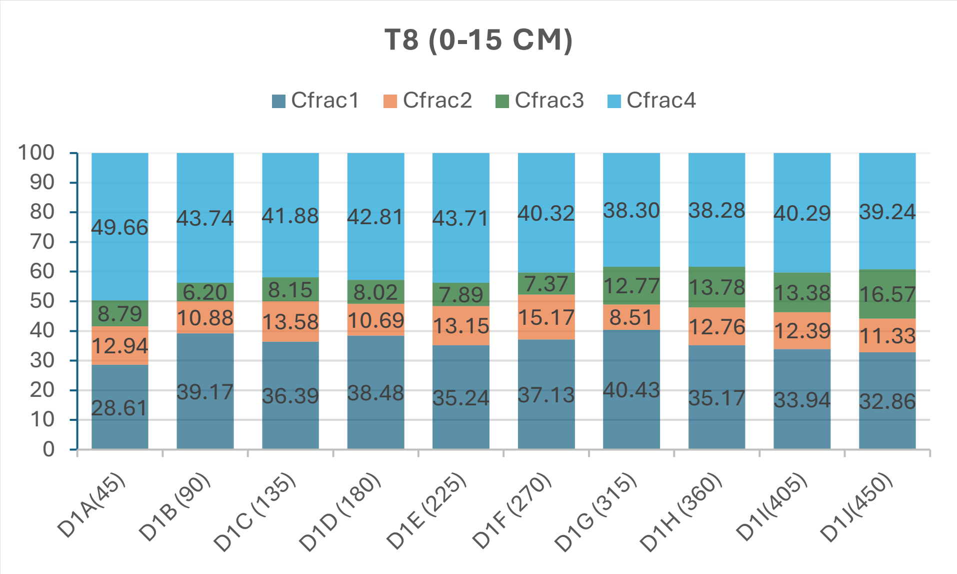


Fig 12a: Carbon pools for T8 (0-15 cm)

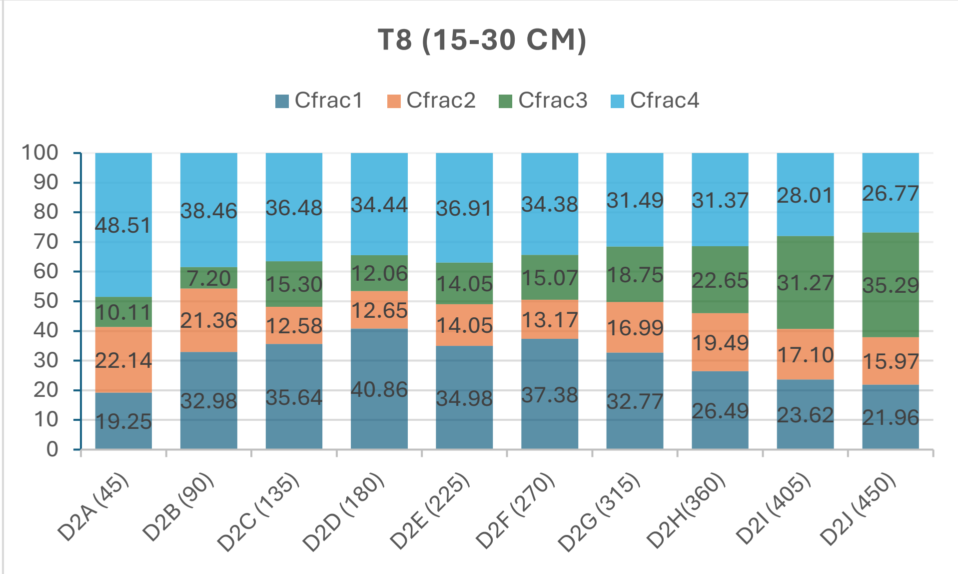


Fig 12b: Carbon pools for T8 (15-30 cm)

The ridge and furrow treatment recorded an increase in C_{frac1} varying from 28.61% at 45 DAS and peaking at 40.43% at 315 DAS, ultimately reducing to 32.86% in 450 DAS at 0-15 cm soil depth. At 15-30 cm soil depth, the values obtained were 19.25% at 45 DAS, peaking to 40.86% at 180 DAS and reducing to 21.96% at 450 DAS. There were sub optimal changes in C_{frac2} in the surface soil. Values ranged at 12.94% at 45 DAS to 11.33% at 450 DAS for surface layers and 22.14% to 15.97% at 45 DAS and 450 DAS respectively at subsurface layers. Similar to T7, the highly labile carbon fractions are liable to loss into the atmosphere. The less labile carbon fractions (C_{frac3}) had little variation in the surface soil. Comparatively, the subsurface soil exhibited a higher change. Changes observed were 8.79% to 16.57% and 10.11% to 35.29% at 45 DAS and 450 DAS respectively at surface and subsurface layers. The C_{frac4} values varied from 49.66% to 39.24% at 0-15 cm soil depth and 48.51% to 26.77% at subsurface layers. The relative variation in the carbon fractions have been shown in **Fig 12a and 12b**.

4.4.9 T9 (No weeding):

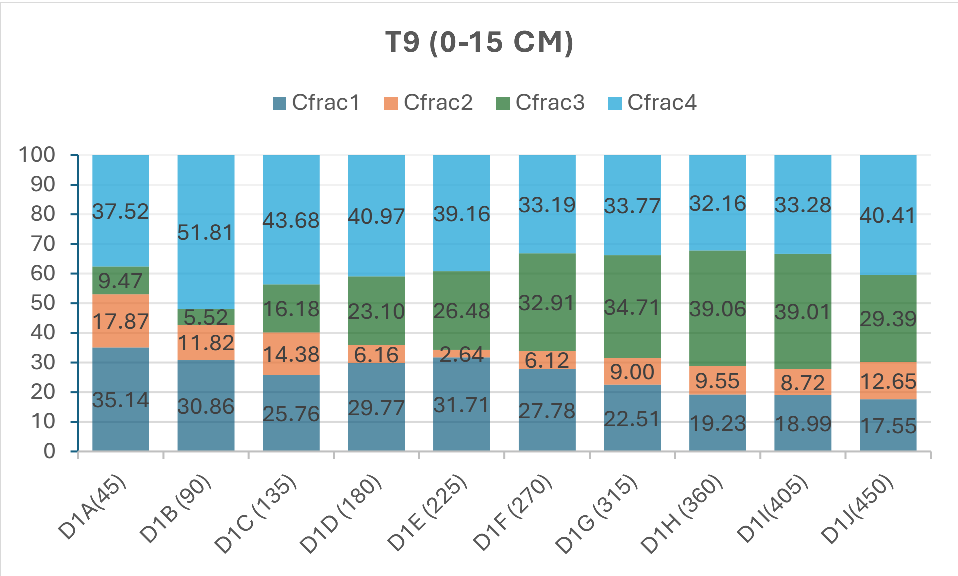


Fig 13a: Carbon pools for T9 (0-15 cm)

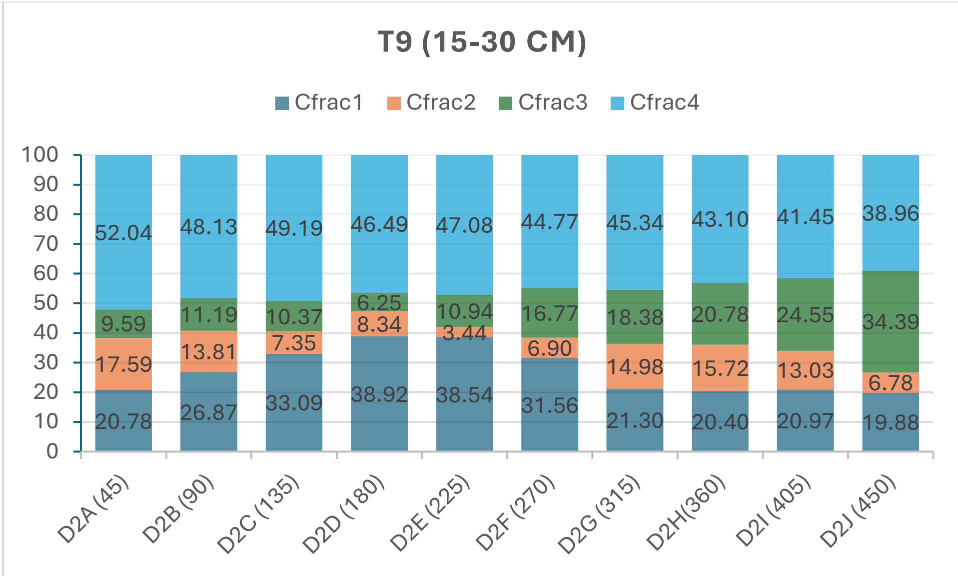


Fig 13b: Carbon pools for T9 (15-30 cm)

The no weeding treatment expressed comparatively lower C_{frac1} pools than the previous treatments T7 and T8. However, it was comparably higher than T1, T2, T3 and T4. In the surface layers, the C_{frac1} value started off with 35.14% at 45 DAS to 17.55% at 450 DAS. in the subsurface layers, the range was 20.78% at 45 DAS, maximizing to 38.92% at 180 DAS and declining to 19.88% at 450 DAS. C_{frac2} ranged from 17.87% to 12.65% and 17.59% to 6.78% at 45 DAS and 450 DAS respectively for surface and subsurface layers. The combined labile pool (C_{frac1} and C_{frac2}) was significantly high, and this could perhaps be a result of plant biomass incorporation from the weeds and standing crops. The less labile carbon pool (C_{frac3}) reduced from 9.47% at 45 DAS to 5.52% at 90 DAS, which further increased to 39.01% at 405 DAS and 29.39% at 450 DAS in the surface soil. in the subsurface layers, it reduced from 9.59% at 45 DAS to 6.25% at 180 DAS and maximising 34.39% at 450 DAS. The range of the recalcitrant pool were 37.52% to 40.41% and 52.04% to 38.96% at 45 DAS and 450 DAS respectively. The relative variation in the carbon fractions have been shown in **Fig 13a and 13b**.

4.4.10 T10 (Weeding with weedicide):

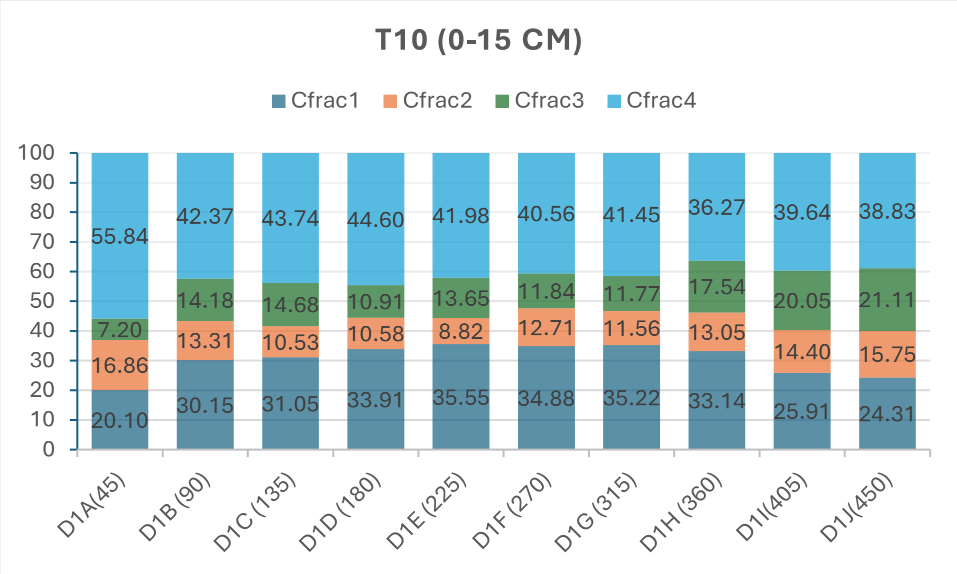


Fig 14a: Carbon pools for T10 (0-15 cm)

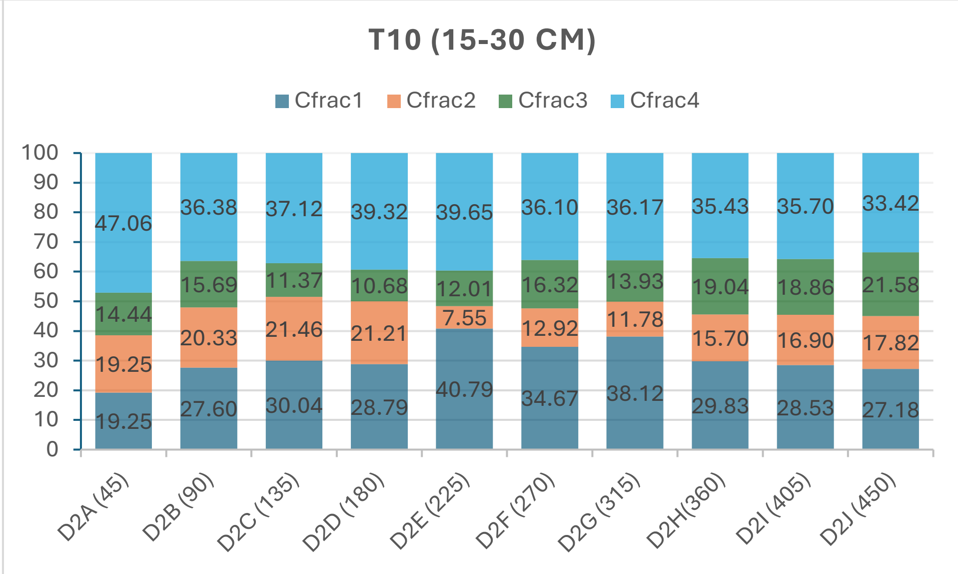


Fig 14b: Carbon pools for T10 (15-30 cm)

The weeding with weedicide treatment exhibited higher scale of C_{frac1} during the non-growing period from 135 to 315 DAS in both soil layers. This could be an indication of high lability of the carbon lost into the atmosphere. It is also probable that less biomass was exuded during the cropping season due to the effects of weedicide. The C_{frac1} scaled from 20.10% at 45 DAS to 35.55% at 225 DAS and reducing to 24.31% at 450 DAS in surface layers. It ranged from 19.25% at 45 DAS maximising to 40.79% at 225 DAS and finally 27.18% at 450 DAS. The labile fraction (C_{frac2}) varied from 16.86% to 15.75% and 19.25% to 17.82% at 45 DAS and 450 Das in the surface and subsurface layers respectively. The C_{frac3} indicated slight variations. It ranged from 7.20% to 21.11% and 14.44% to 21.58% for the both the soil layers. The recalcitrant pool was 55.84% at 45 DAS and 38.83% at 450 DAS for surface layers; 47.06% to 33.42% for the subsurface layers at 45 DAS and 450 DAS respectively. The relative variation in the carbon fractions have been shown in **Fig 14a and 14b**.

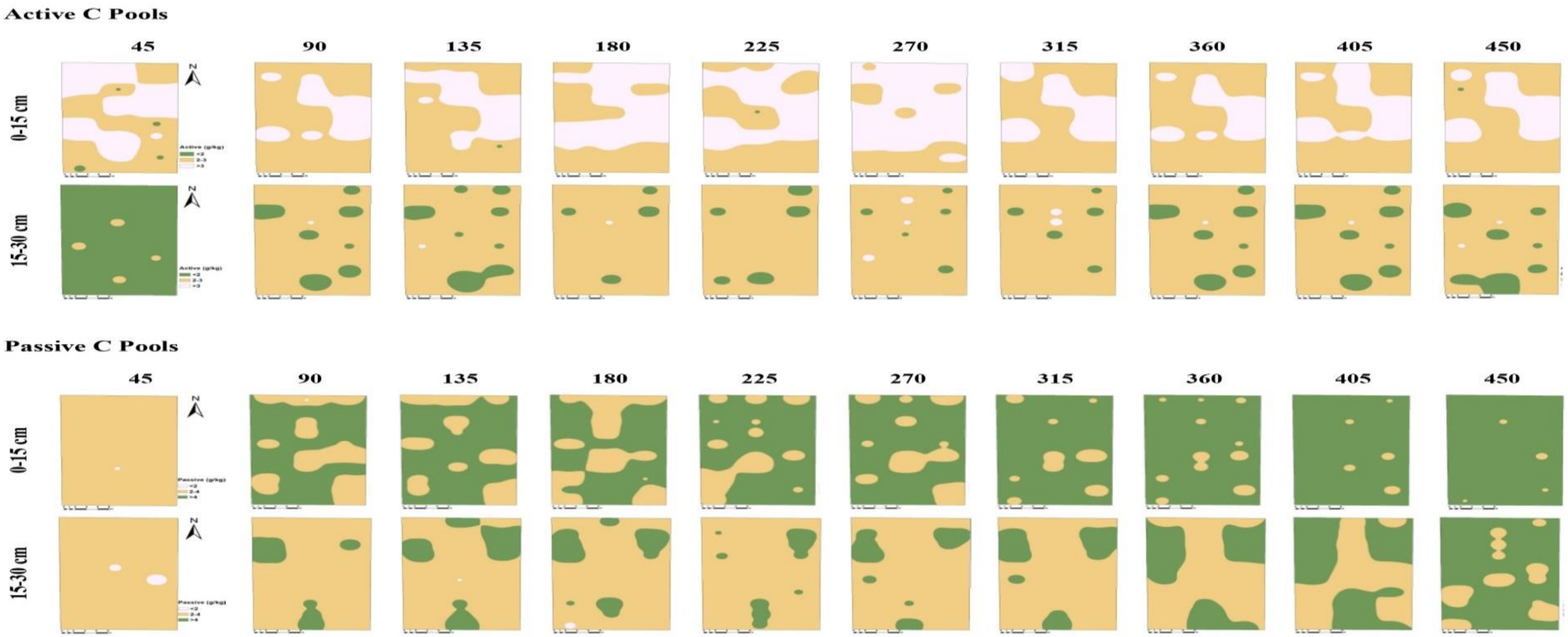


Fig 15: Interpolation data for the active and passive carbon pools across different soil depths and increasing DAS

4.5 Contribution of soil quality indicators to the principal components

The principal component analysis (PCA) was used for determining the correlation between the variables (25 in numbers). Through PCA, the contribution of the soil quality indicators was designated into corrplots **(Fig 16)**. The different indicators were assigned with coloured circles to define the contribution of each indicator towards the correlation. A large circle size and strength of the colour relates to higher contribution of an indicator towards the PCA. The corrplots were perpetually assigned to the increasing number of days after sowing (DAS) at a 45-day interval. For both the soil depths (0-15 cm and 15-30 cm), corrplots were allocated at 45, 90, 135, 180, 225, 270, 315, 360, 405 and at 450 DAS.

4.5.1 Contribution of soil quality indicators for soil depth (0-15 cm):

For soil depth 0-15 cm, the first corrplot at 45 DAS had its principal components (RC) rotated 5 times. The correlation analysis showed a value range from -0.94 to 0.96. According to the size of the circle and strength of the colour, the study of the first PC (RC1) revealed that SOC contributed the maximum positive correlation. Other significant correlations were demonstrated in soil quality functions viz. the active pools, SOCS, Cfrac1, LI, TOC, pH, EC. In RC2, high positive correlation was observed in the biological soil functions (fungal count > SMBC > bacterial count). Av. N was negatively correlated with the other indicators in RC2. Following the correlation in RC3, highest positive contribution was observed in the soil physical function (clay) while negative loadings were observed in sand and silt. For RC4, high positive loadings were distinguished in the soil fertility functions (Av. S > Av. K) and biological indicators (DHA > bacterial count). A relatively small negative loading was observed in BD followed by C_{frac4}. Following RC5, highest positive loading was detected in soil fertility indicator (Av. K) while the maximum negative contribution was observed in Ex. Ca + Mg.

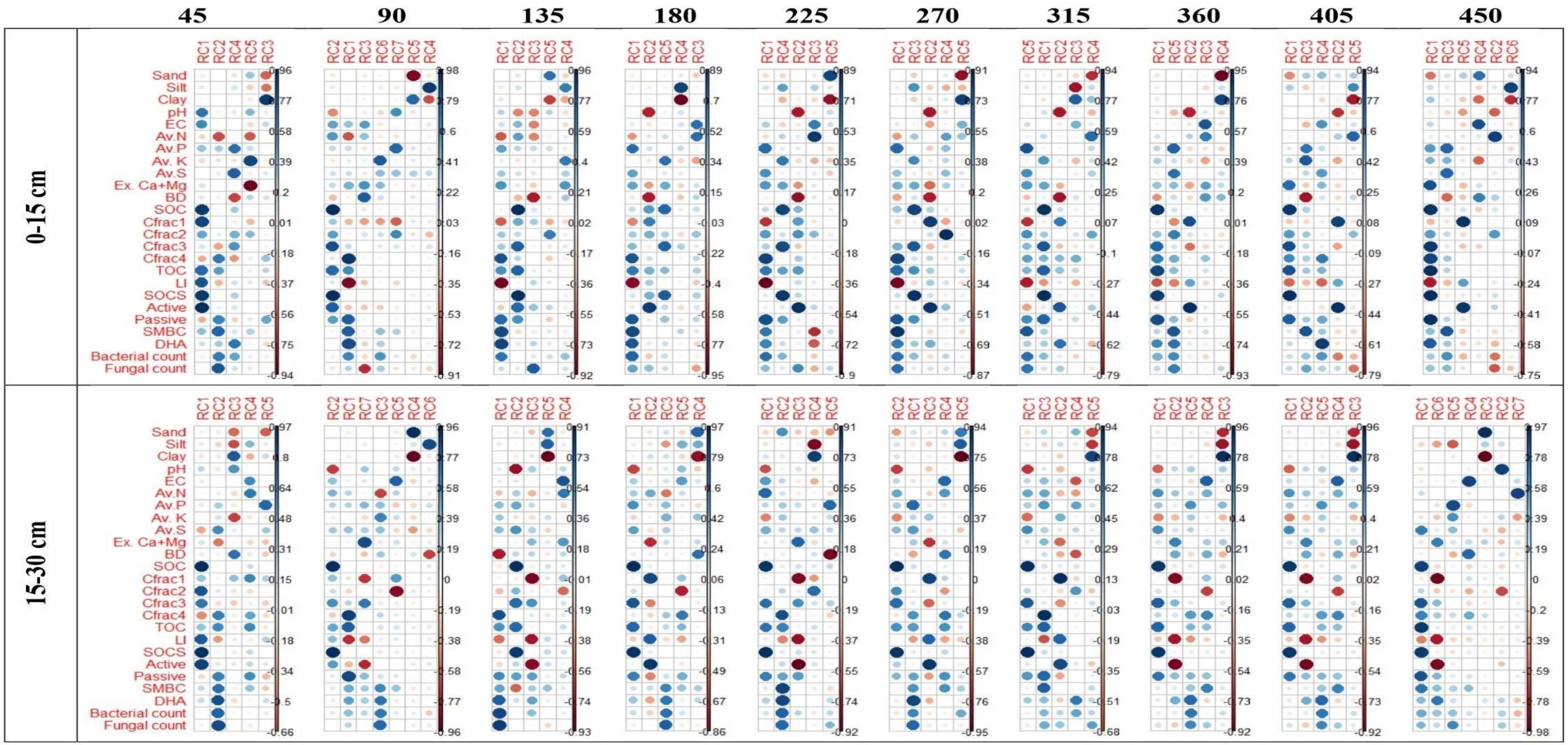


Fig 16: Contribution of soil quality indicators to each principal component of surface (0-15 cm) and sub-surface (15-30cm) soil. Note: The larger the circle size and more the strength of the colour, the higher the contribution

At 90 DAS, the PCs' were rotated for at least 7 times. Since harvesting for 1st season was performed at 90 DAS, the 7 rotations were meant to invigorate and analyse the contributions of the indicators extensively. In the first PC (RC1), the highest indication of positive correlation was observed in a soil quality parameter (C_{frac4}) which were followed by other biological and quality indicators (DHA> SMBC> passive pools> bacterial count> TOC). Lability index (LI), which is a land induced soil quality parameter, was observed to indicate maximum negative correlation in RC1 followed by fungal count. For RC2, maximum positive contribution to the correlation were indicated in the soil quality functions SOC and SOCS which were subsequently followed by the active pools, C_{frac3}, C_{frac2}, Av. N, passive pools and EC. Negative loadings was observed in the pH. In RC3, RC4, RC5, RC6 and RC7, dominant positive contribution in the corrplot were the soil physical and fertility functions viz BD, silt, clay, Av. K and Av. P respectively. Negative contribution for the same were observed under soil biological and physical functions namely fungal count, clay, sand and C_{frac1} respectively.

At 135 DAS, the PCs' were rotated for 5 times. Studying the first principal component (RC1) resulted in high positive contribution from the soil biological, quality and fertility functions recorded in the order: DHA> SMBC> C_{frac4}> passive pools> bacterial count> Ex. Ca + Mg> Av. N. Negative loadings were observed under LI> C_{frac1}> Av. N. For RC2, maximum positive contribution was seen in SOC and SOCS followed by C_{frac3}, TOC, active pools, passive pools and EC. Negative contribution was observed on soil buffering indicator (pH). For RC3, RC4 and RC5, maximum positive contribution was observed under soil biological function (fungal count), soil physical indicators (silt) and sand respectively. Maximal negative contributions were related to soil physical indicators (BD and clay) respectively.

At 180 DAS, RC1 observed positive contribution from soil biological indicators (SMBC, DHA, bacterial count), soil quality functions (passive pools, C_{frac4}, TOC) and soil fertility functions (Av. P) in order. Negative loading was observed under LI. For principal components RC2, RC3, RC4 and RC5, highest positive loadings were observed under active pools, EC, silt and SOCS respectively. Maximal negative loading from the indicators were observed under pH, fungal count, clay respectively.

At 225 DAS, RC1 retained maximum positive contribution from soil quality functions (C_{frac4}, passive pools) and soil fertility functions (Av. P). Negative loadings were observed under LI and C_{frac1}. For RC2, RC3, RC4 and RC5, high value in the correlation were seen under active pools, Av. N, SOC and sand respectively. Following suite, high negative values were found under BD, SMBC and clay respectively.

At 270 DAS, study of RC1 revealed the maximum positive contribution in soil biological function (SMBC) and soil quality function (C_{frac4}) subsequently followed by passive pools and TOC. Negative contributions were observed in the soil induced quality function (LI). The remaining principal components RC2, RC3, RC4 and RC5 noted maximum positive contributions in C_{frac1}, SOC, C_{frac2} and clay.

At 315 DAS, variations in RC1 showed maximum contribution from SOC, SOCS, C_{frac3}, TOC and passive pools in order. Negative correlation was retained in LI. For the remaining principal components RC2, RC3, RC4 and RC5, maximum contribution was observed in active pools, EC, clay and SMBC respectively. Negative maximal correlation was observed under BD, silt, sand and LI in order.

The second cropping season was started at 360 DAS. Analysis of the principal components at revealed 5 PCs'. Under the 1^{st} principal component (RC1), the soil quality functions had maximum contribution to the corrplot (SOC> SOCS> TOC> passive pools). Negative loading was also observed under LI. RC2 retained the active pools and Cfrac1 with maximum contribution and soil pH had negative contribution. The other PCs' RC3, RC4 and RC5 had provided maximum contribution soil buffering function (EC), soil physical function (clay) and soil biological function (SMBC) respectively. Also, the negatively loaded contributions were Av. K, sand and LI.

At 405 DAS, RC1 observed a positive contribution from soil quality functions (SOCS> SOC> TOC> C_{frac3}) and Ex. Ca + Mg. Negative loadings were observed in LI and sand. C_{frac1} and active pools had positive contribution in RC2; soil fertility functions (Av. K and Av. P) and soil biological function (SMBC) under RC3 observed positive contributions. In RC4 and RC5, DHA and Av. N respective gave positive contribution in the corrplot. Negative contribution in RC2, RC3, RC4 and RC5 were observed in soil pH, BD, LI and clay respectively.

The harvesting for 2nd season was performed at 450 DAS and therefore, the rotation for the PCA was performed at least 6 times. The correlation showed a range from -0.75 to +0.94. Analysis of the 1st principal component (RC1) resulted in maximum positive contribution from the soil quality functions (SOC, SOCS, C_{frac3}, C_{frac4}, TOC, passive pools), Ex. Ca + Mg and soil biological function (DHA) respectively. Negative loadings were also observed under LI and sand. RC2 demonstrated positive loading under soil fertility function (Av. N) and a negative loading under soil pH. The remaining principal components RC3 maintained positive contribution in soil biological function (SMBC) and soil fertility functions (Av. P and Av. S) with negative loading observed on BD and LI. Maximum positive contribution from RC4, RC5 and RC6 were retained in EC, active pools and silt respectively.

4.5.2 Contribution of soil quality indicators for soil depth (15-30 cm):

Similar to the analysis for correlation at surface soil, PCA was also undertaken for subsurface soils (15-30 cm). The corrplot in **Fig 16** illustrates the complete contribution of the soil quality indicators from 45 DAS to 450 DAS. At 45 DAS, the correlation varied from -0.66 to +0.97. The 1st principal component (RC1) demonstrated maximum positive contribution with SOC, which were significantly correlated with other soil quality functions (SOCS, active pools, LI, C_{frac2} and C_{frac3}). Soil fertility function (Av. S) was negatively correlated with the other variables. For RC2, the soil biological functions exuded positive contributions (fungal count> bacterial count> DHA> SMBC) along with soil quality functions (passive pools> C_{frac4}> TOC) while negative contribution was disclosed in Ex. Ca + Mg. Positive contribution for RC3 (clay, BD, pH), RC4 (Av. N, EC, C_{frac1}, TOC, passive pools) and RC5 (Av. P) were also observed. Maximum negative contribution was seen under Av. K, clay, and sand for RC3, RC4 and RC5 respectively.

At 90 DAS, seven rotations were performed with the PCA. The first PC (RC1) disclosed positive correlation in soil quality functions (passive pools, C_{frac4}, TOC) and negative in LI. Maximum positive contributions were observed for RC2 (SOC, SOCS), RC3 (fungal count, bacterial count, DHA, SMBC and Av. K), RC4 (sand), RC5 (EC, C_{frac1}), RC6 (silt) and RC7 (Ex. Ca + Mg, C_{frac3}). Negative correlations with the other variables were seen for RC2 (pH), RC3 (Av. N), RC4 (clay), RC5 (C_{frac2}), RC6 (BD) and RC7 (C_{frac1}, active pools, LI). The variables in each PC were significantly correlated with each other.

At 135 DAS, positive loadings for RC1 were seen in soil biological functions (fungal count, bacterial count, DHA, SMBC) and soil quality functions (C_{frac4}, passive pools) while negative loading was seen in soil physical function (BD). For RC2, the soil quality function (SOC, SOCS, TOC, C_{frac2}) positively contributed to the corrplot while soil pH and SMBC contributed negatively. Remaining PCs' RC3, RC4 and RC5 showed maximum positive loadings in C_{frac3}, EC and silt while negative loadings were displayed under C_{frac1}, C_{frac2} and clay respectively.

At 180 DAS, maximum positive loadings were: RC1 (SOC, SOCS), RC2 (C_{frac1}, active pools), RC3 (C_{frac3}), RC4 (sand) and RC5 (C_{frac4}). Negative loadings were observed under RC1 (pH), RC2 (Ex. Ca + Mg), RC3 (silt), RC4 (clay) and RC5 (C_{frac2}). At 225 DAS, effective positive correlation was described under RC1 (SOC, SOCS, Av. N, C_{frac3}, TOC and EC), RC2 (SMBC, DHA, bacterial count, fungal count, sand, C_{frac4} and TOC), RC3 (Ex. Ca + Mg, C_{frac3} and passive pools), RC4 (clay and C_{frac2}) and RC5 (Av. P). High negative loadings were described under RC1 (pH and Av. K), RC2 (LI), RC3 (C_{frac1}, active pools and LI), RC4 (silt) and RC5 (BD).

At 270 DAS, high positive contribution to the corrplot were observed under RC1 (DHA, fungal count, SMBC, passive pools, Av. P), RC2 (SOC, SOCS, C_{frac3}, C_{frac2} and TOC), RC3 (C_{frac1}, active pools), RC4 (EC, C_{frac4}, TOC and passive pools) and RC5 (sand, silt). Negative loadings which were described under RC1 (LI, BD), RC2 (pH, sand), RC3 (Ex. Ca + Mg), RC4 (LI) and RC5 (clay). At 315 DAS, positive contributions were recorded under RC1 (SOC, SOCS, C_{frac3}), RC2 (C_{frac1}, active pools), RC3 (C_{frac4}, passive pools, SMBC), RC4 (DHA) and RC5 (clay).

The second cropping season started at 360 DAS. The principal component analysis revealed 5 PCs' with correlation value ranging from -0.92 to +0.96. The 1st PC (RC1) noted high positive contribution from the soil quality functions (SOC, SOCS, C_{frac3} and TOC) with negative contribution from the soil buffering function (pH). For RC2, positive loadings were observed in Ex. Ca + Mg and BD with negative loading from active pools, C_{frac1} and LI. The remaining PCs' described positive contributions in RC3 (clay), RC4 (DHA), RC5 (DHA, bacterial count, fungal count) and negative contribution in RC3 (sand, silt), RC4 (C_{frac2}) and RC5 (LI).

At 450 DAS, RC1 described positive contribution under soil quality functions (SOC, SOCS, C_{frac3}, TOC, passive pools and Av. N) and negative loadings under soil pH. The remaining PCs' contributed positively for RC2 (Av. S, Ex. Ca + Mg, SMBC), RC3 (clay), RC4 (EC), RC5 (DHA, bacterial count, fungal count, Av. P) and it negatively loaded for RC2 (C_{frac2}, active pools, LI), RC3 (sand, silt), RC4 (C_{frac2}) and RC5 (LI).

Analysis of the PCs' at 450 DAS recorded significant contributions from the variables. The correlation ranged in a value of -0.98 to +0.97. The principal components were rotated at least 7 times. RC1 recorded positive contributions from the soil quality functions (SOC, SOCS, TOC, passive pools, C_{frac4}), soil fertility function (Av. S) and soil biological functions (SMBC, bacterial count) with maximum negative loading in LI. RC2 demonstrated negative contribution from C_{frac2}. The highest contributing variables from the remaining principal components were RC3 (sand), RC4 (EC), RC5 (Av. P), RC6 (DHA, Ex. Ca + Mg) and RC7 (Av. N). These contributions were positively correlated with the other indicators. Negative contributions were observed under RC3 (clay), RC4 (C_{frac2}), RC5 (silt) and RC6 (C_{frac1}, LI).

4.6 Identification of key soil indicators through PCA for 1st Harvest

Overall soil indicator sensitivity is described by the PCA. The variation in soil qualities was expressed through the principal components (PCs') with high eigen values. From the analysis of the 1st harvest data at soil depth 0-15 cm, 7 PCs' possessing eigen value > 1 (ranging from 1.645 to 5.717) were drawn out with varimax rotation from the dataset. The cumulative variance from the selected PCs' accounted for 86.25% of the total variance. The 1st PC or PC1 expressed 22.86% of the total variance and SOC (0.977) developed the highest loading factor. It was selected as the key indicator for the 1st group and incorporated in the selection for MDS. The next PC2 expressed a variance of 22.80% and C_{frac4} (0.938) was recorded as the highest loading factor. It was also incorporated into factor selection for development of the MDS. PC3 involved a total of 9.97% of the total variance and BD (0.805) had the maximum factor loading in the group. It was thus selected for the MDS dataset. PC4, PC5, PC6 and PC7 composed a variance of 8.52%, 8.49%, 7.01% and 6.58% respectively of the total variance. Based upon the communalities, maximum weight was assigned to SOC followed by C_{frac4}, silt, sand, BD, Av. P and Av. K **(Table 48)**. The maximum factor loading was seen in Av. K (0.815), Av. P (0.756), sand (-0.912) and silt (0.930) in the cases of PC4, PC5, PC6 and PC7 respectively. They were selected for supplementing the MDS. A total of 7 indicators was, therefore, selected from a total of 25 soil and its derived parameters; it was processed for the development of SQI for the soil depth 0-15 cm during the 1st harvest period.

The variability of the 7 PCs' for the soil depth 15-30 cm contributed 84.75% of the entirety variance. The eigen values ranged from 1.49 to 4.24 for the entire PCA. PC1 accounted for 16.95% variance and SOC (0.964) was noted for the maximum positive loading factor. PC2 noted a variance of 15.67% and C_{frac4} (0.893) was observed to accumulate the highest positive factor loading. Ex. Ca + Mg (0.848) was demonstrated as the highest factor loading in PC3 with a variance of 13.94%. The remaining PC4, PC5, PC6 and PC7 accumulated a variance of 13.65%, 9.27%, 9.26% and 5.98% respectively. The highest weightage in the communalities were observed in SOC subsequently followed by C_{frac4}, clay content, DHA, C_{frac2}, Ex. Ca + Mg and silt content **(Table 49)**. The highest factor loadings were acknowledged as DHA (0.712), C_{frac1} (-0.869), clay (-0.960) and silt (0.854) in PC4, PC5, PC6 and PC7 respectively. A total of 7 factors were loaded for the MDS and further attaining the SQI for soil depth 15-30 cm at the 1st harvest season.

Harvest- 1

Table 48: Identification of most sensitive soil health attributes through PCA analysis for 1st harvest (0-15cm)

Principal components	PC1	PC2	PC3	PC4	PC5	PC6	PC7	Communality
Eigen value	5.717	5.700	2.493	2.131	2.124	1.755	1.645	
Percent	22.866	22.800	9.970	8.524	8.494	7.019	6.580	
Cumulative percent	22.866	45.666	55.636	64.160	72.655	79.674	86.253	
Eigen vectors								
Sand	-.138	.029	-.112	-.076	.046	**-.912**	-.148	.895
Silt	.128	.040	.054	.089	-.119	.053	**.930**	.910
Clay	.016	-.058	.053	-.007	.057	.755	-.634	.982
pH	-.465	-.004	.104	-.211	.602	-.172	.009	.664
EC	.511	.387	.540	-.137	.019	-.043	-.153	.747
Av.N	.548	-.623	.394	-.110	-.150	-.016	.067	.883
Av.P	.248	.233	-.148	-.055	**.756**	.158	-.090	.746
Av. K	-.122	.121	.096	**.815**	-.058	.132	.075	.730
Av.S	.206	.225	-.117	.392	.390	.297	.259	.568
Ex. Ca+Mg	.244	.453	.581	.425	-.080	-.137	-.077	.815
BD	-.300	-.081	**.805**	.206	-.047	.161	-.024	.816
SOC	**.977**	-.003	-.126	-.050	.057	.055	.045	.981
Cfrac1	.361	-.329	-.405	-.411	-.590	.140	.104	.949
Cfrac2	.532	.063	.181	.213	.630	-.170	-.300	.882
Cfrac3	.856	.231	.029	.131	.174	.078	.177	.872
Cfrac4	.152	**.938**	.059	-.063	-.016	.041	.062	.915
TOC	.762	.602	-.048	-.074	.028	.064	.071	.961
LI	.159	-.899	-.280	-.056	-.205	.015	-.037	.958
SOCS	.975	-.040	-.017	-.034	-.010	.087	.066	.966
Active	.794	-.288	-.273	-.254	-.106	.008	-.132	.881
Passive	.537	.797	.057	.020	.075	.069	.134	.956
SMBC	-.073	.811	-.073	.394	.305	-.088	-.025	.924
DHA	.042	.867	-.221	.296	.034	-.027	-.063	.896
Bacterial count	-.096	.627	-.194	.574	.154	-.208	.056	.840
Fungal count	.137	.295	-.721	.334	-.162	-.123	-.222	.828

Table 49: Identification of most sensitive soil health attributes through PCA analysis for 1st harvest (15-30cm)

Principal components	PC1	PC2	PC3	PC4	PC5	PC6	PC7	Communality
Eigen value	4.240	3.919	3.486	3.414	2.320	2.315	1.495	
Percent	16.959	15.676	13.946	13.656	9.278	9.260	5.980	
Cumulative percent	16.959	32.634	46.580	60.235	69.514	78.774	84.755	
Eigen vectors								
Sand	.022	.095	.014	.022	-.134	.959	-.061	.951
Silt	-.013	.024	-.115	.003	.073	.194	**.854**	.786
Clay	-.018	-.096	.013	-.021	.111	**-.960**	-.143	.965
pH	-.664	-.055	.359	-.018	.256	.127	.108	.667
EC	.390	.074	.135	-.006	.780	-.210	.114	.841
Av.N	.444	.265	.043	-.646	.271	.021	.092	.768
Av.P	.287	.278	.409	.399	-.254	-.197	.216	.636
Av. K	-.094	.033	-.191	.629	.218	-.184	.070	.529
Av.S	.352	.364	.303	.394	-.205	-.405	-.183	.743
Ex. Ca+Mg	-.033	.063	**.848**	.144	.207	.057	.106	.802
BD	-.221	-.026	-.284	.341	.061	.192	-.663	.726
SOC	**.964**	-.034	-.036	-.080	.078	.019	.158	.969
Cfrac1	.368	-.166	-.699	.071	.534	.023	.109	.955
Cfrac2	.206	-.214	-.035	-.123	**-.869**	.121	.061	.879
Cfrac3	.585	.266	.684	-.083	.110	-.079	.030	.907
Cfrac4	-.241	**.893**	.000	.293	.127	.099	.018	.968
TOC	.502	.785	-.027	.205	.173	.104	.134	.970
LI	.400	-.717	-.520	-.122	.137	-.021	.093	.986
SOCS	.961	-.047	.005	-.126	.119	.075	.025	.961
Active	.512	-.311	-.740	-.008	-.022	.103	.152	.942
Passive	.148	.860	.396	.184	.164	.032	.031	.981
SMBC	.156	.456	.342	.616	.374	.114	-.097	.891
DHA	.117	.506	.316	**.712**	-.120	.087	.012	.900
Bacterial count	-.129	.395	.279	.684	.127	.103	-.242	.804
Fungal count	-.046	.271	-.008	.752	.020	.087	-.111	.662

4.7 Identification of key soil indicators through PCA for 2nd Harvest:

The extent of variation explained by the PCA accounted for 84.78% cumulative variance for the soil depth 0-15cm during the 2nd harvest season. The eigen values had a range from 1.50-8.53 for the entire PCA. The principal components were rotated for a total of 6 times. PC1 with an eigen value of 8.53 was associated with 34.12% of the total variance. Ex. Ca + Mg (0.806), C_{frac3} (0.898), C_{frac4} (0.860), TOC (0.938), SOCS (0.934) and passive pools (0.927) were among the factors with high loading capacity. A significant correlation between TOC and other soil health attributes with higher factor loading were discerned. TOC (0.938) possessed the highest factor loading; it was therefore selected as the representative for PC1 and assembling the MDS. For PC2, a total variance of 13.67% was noted with an eigen value of 3.42. Av. P (0.747), Av. S (0.740), and SMBC (0.792) were the highly loaded factors in the group. SMBC (0.792) was significantly correlated with the other soil attributes, and it scored the highest factor loading; thus, it was retained as the representative of group 2 for assembling the MDS. PC3 managed 11.62% of the total variance with an eigen value of 2.90. The high loading factors in the group were C_{frac1} (0.913) and active pools (0.907). Since C_{frac1} had the higher value, it was retained as the representative factor for group 3. Following this trend, PC4, PC5 and PC6 managed a variance of 9.77%, 9.53% and 6.02% respectively. EC (0.823), Av. N (0.871) and silt (0.869) were the highest loading factors in PC4, PC5 and PC6 respectively and they were retained for the MDS. Dependent on the communalities, the maximum weightage was accredited to TOC followed by C_{frac1}, silt content, SMBC, Av. N and EC **(Table 50)**.

From the **Table 51**, it was distinguished that a cumulative variance of 87.36% was observed in the PCA for soil depth 15-30 cm during 2nd harvest season. The eigen values ranged from 1.41 to 6.38. A total of 7 rotations were performed during the entire operations. Principal component 1 or PC1 was assigned with a variance of 25.54% and eigen value of 6.38. The highest loading factor in the group was TOC (0.931) and it was retained for the MDS. A variance of 18.18% and eigen value of 4.54 was observed in PC2. The highest loading factor in the group were the active pools (-0.925) and it was reserved for forming the MDS. The remaining PC3, PC4, PC5, PC6 and PC7 had variances of 2.67%, 2.32%, 2.09% and 1.41% respectively. The highest levels of factor loading were described in Av. P (0.866), EC (0.895), clay (-0.978) pH (0.915) and Av. N (0.893) respectively for PC3, PC4, PC5, PC6 and PC7. All the 7 highest loading factors were selected and included in assembling the MDS and later used for development of the SQI. On the basis of communalities, highest weightage was attributed to clay content which were subsequently followed by TOC, active pools, EC, pH, Av. N and Av. P.

Harvest- 2

Table 50: Identification of most sensitive soil health attributes through PCA analysis for 2nd harvest (0-15cm)

Principal components	PC1	PC2	PC3	PC4	PC5	PC6	Communalities
Eigen value	8.532	3.424	2.907	2.443	2.384	1.506	
Percent	34.127	13.697	11.629	9.771	9.537	6.026	
Cumulative percent	34.127	47.825	59.453	69.225	78.762	84.788	
Eigen vectors							
Sand	-.499	.175	.295	.690	-.017	.210	.886
Silt	.224	-.132	-.041	-.212	.144	**.869**	.891
Clay	.343	-.089	-.256	-.530	-.067	-.700	.967
pH	-.097	-.199	-.410	.025	-.554	.001	.524
EC	.250	-.015	-.215	**.823**	.057	-.145	.810
Av.N	.100	-.103	.162	.149	**.871**	.100	.837
Av.P	.520	**.747**	-.122	-.087	.039	-.176	.883
Av. K	.427	.421	-.130	-.554	.068	.191	.724
Av.S	.096	**.740**	.085	-.016	.119	.050	.581
Ex. Ca+Mg	**.806**	.056	-.283	.204	-.079	.038	.782
BD	.012	-.544	-.262	.642	.287	.057	.862
SOC	**.912**	.148	.171	-.230	.173	-.014	.966
Cfrac1	-.302	-.145	**.913**	-.037	-.065	.043	.954
Cfrac2	.525	.246	-.189	.011	.528	-.047	.653
Cfrac3	**.898**	.147	-.270	-.210	.037	-.023	.947
Cfrac4	**.860**	.346	-.056	.041	-.038	.015	.867
TOC	**.938**	.281	.040	-.075	.052	.003	.969
LI	-.750	-.297	.512	-.023	.124	.042	.930
SOCS	**.934**	-.100	.120	.098	.201	.068	.951
Active	.006	-.001	**.907**	-.034	.277	.017	.901
Passive	**.927**	.279	-.153	-.067	-.007	.000	.964
SMBC	.382	**.792**	-.240	-.079	-.193	-.075	.881

DHA	.778	.343	-.209	-.159	-.304	-.075	.890
Bacterial count	.337	.572	-.313	.140	-.507	-.099	.825
Fungal count	.373	.405	.163	-.021	-.586	-.278	.751

Table 51: Identification of most sensitive soil health attributes through PCA analysis for 2nd harvest (15-30cm)

Principal components	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**Communality**
Eigen value	6.387	4.545	2.673	2.382	2.342	2.093	1.419	
Percent	25.549	18.180	10.691	9.527	9.369	8.374	5.676	
Cumulative percent	25.549	43.729	54.419	63.947	73.316	81.690	87.366	
Eigen vectors								
Sand	-.008	.067	-.029	-.010	.975	.055	-.010	.958
Silt	-.202	-.400	-.603	-.013	.296	.231	-.041	.708
Clay	.038	-.005	.117	.012	**-.978**	-.087	.016	.979
pH	-.167	-.024	-.003	-.083	.088	**.915**	.011	.881
EC	.081	-.058	.088	**.895**	-.084	-.083	.236	.888
Av.N	.222	-.012	-.027	.120	-.042	.009	**.893**	.863
Av.P	-.001	.172	**.866**	-.192	.004	.001	.077	.823
Av. K	-.155	-.267	.581	.067	-.112	.284	-.416	.704
Av.S	.675	.134	.403	.039	-.218	-.326	-.114	.805
Ex. Ca+Mg	.124	.670	.175	.243	.293	-.296	.183	.762
BD	-.074	.014	-.341	.764	.014	.183	-.141	.759
SOC	.902	-.182	-.060	-.225	-.097	-.198	.135	.968
Cfrac1	-.105	-.933	-.005	.215	.113	.134	.003	.958
Cfrac2	.270	-.254	-.148	-.360	-.113	-.646	.081	.725
Cfrac3	.831	.421	.000	-.198	-.113	-.020	.099	.930
Cfrac4	.636	.339	.234	.496	.221	.005	.091	.878
TOC	**.931**	.116	.118	.193	.088	-.110	.137	.970
LI	-.478	-.787	-.198	-.198	-.090	-.111	-.107	.958
SOCS	.928	-.091	-.169	-.118	-.063	-.151	.073	.944
Active	.070	**-.925**	-.091	-.032	.028	-.266	.050	.943
Passive	.841	.436	.142	.191	.072	-.008	.110	.972
SMBC	.705	.409	.316	.412	.122	-.012	-.053	.952
DHA	.409	.700	.207	.009	.178	.280	-.279	.888
Bacterial count	.485	.378	.391	.198	-.126	.298	-.333	.785
Fungal count	.445	.249	.635	.156	.027	.344	-.185	.839

4.8 Relationship among the soil quality indicators:

4.8.1 1st Harvest:

The correlation between the different variables were illustrated with the application of the principal component variable correlation plots **(Fig. 17)**. For soil depth 0-15 cm at 1st harvest season, the PC1 (Dim1) showed a variation of 28%. The soil attributes represented through coloured lines exemplified the contribution of each soil quality indicators. Soil fertility factors viz. Av. K, Av. S, Av. P, had the same positive loading along Dim1. The biological soil functions (bacterial count, fungal count, SMBC, DHA) also exhibited similar positive loading along with active pools, passive pools, Ex. Ca + Mg, C_{frac2}, C_{frac3}, C_{frac4}, EC, TOC, silt, SOC and SOCS **(Fig 17)**. High contributions to the variance, denoted by longer arrows, were observed in SOC, SOCS, SMBC, TOC, passive pools and LI respectively in order. The soil pH, BD, sand, LI, clay, C_{frac1} and Av. N were negatively loaded along Dim1. Along PC2 (Dim2) which encased a variance of 22.3%, the passive pools, Av. P, C_{frac2}, EC, TOC, C_{frac3}, silt, SOC, SOCS, active pools, clay, Av. N C_{frac1} and LI were positively correlated while BD, pH, sand, Av. K, bacterial count, SMBC, DHA, Ex. Ca+ Mg, C_{frac4} and fungal count had negative factor loadings.

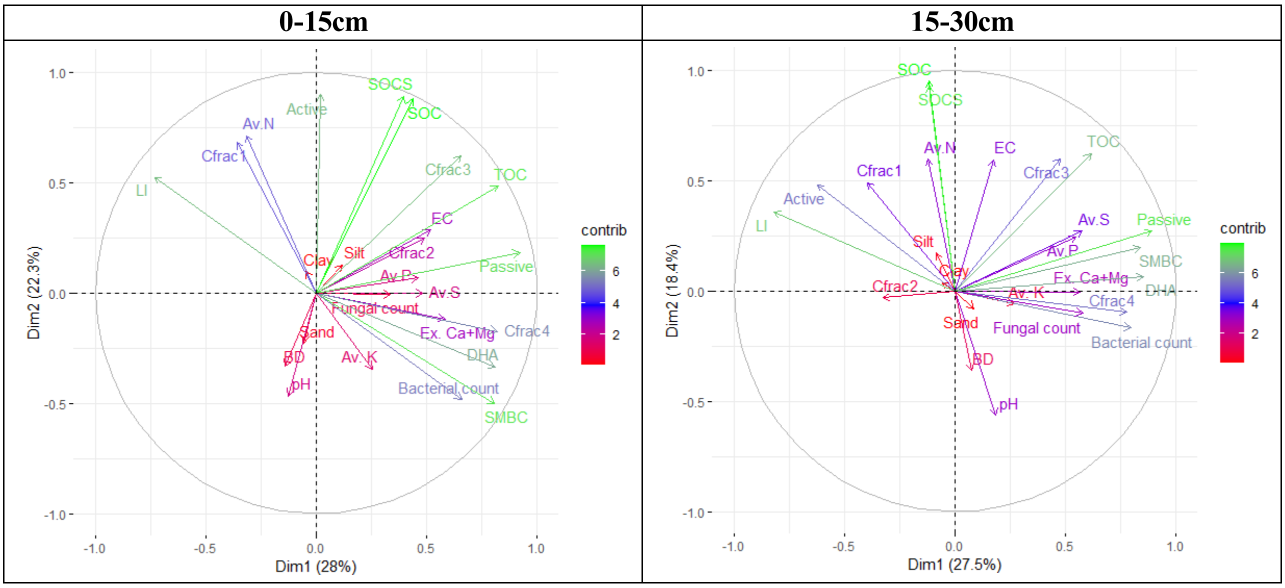


Fig 17: Principal component variable correlation circle diagram. X–Y axis corresponds to principal component 2 (Dim 2) principal component 1 (Dim 1). The different colors represent the percentage of contribution of each variable (soil quality indicators) to data variance.

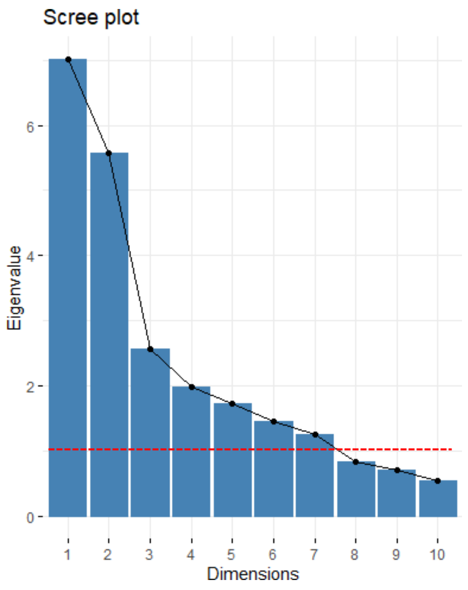
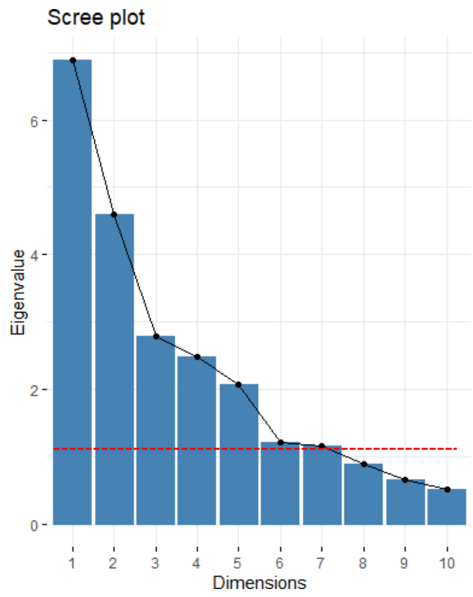
0-15cm	15-30cm
	

Fig 18: Scree plot for 1st harvest

For soil depth 15-30 cm, the soil attributes sand, BD, pH, fungal count, bacterial count, Av. K, C_{frac4}, DHA, Ex. Ca + Mg, SMBC, passive pools, Av. P, Av. S, TOC C_{frac3} and EC demonstrated positively correlation and were regarded as positive factor loadings along PC1 (Dim1). Dim 1 had a variation of 27.5%. The negative factor loadings along Dim1 were observed in Av. N, SOCS, SOC, clay, silt, C_{frac1}, active pools, LI and C_{frac2} **(Fig 17)**. High contribution in the correlation were observed in SOC, SOCS, passive pools, LI, SMBC and DHA. Upon studying the variance in PC2 (Dim2), which had a variation of 18.4%, the soil attributes Ex. Ca + Mg, SMBC, passive pools, Av. P, Av. S, TOC C_{frac3}, EC, Av. N, SOCS, SOC, clay, silt, C_{frac1}, active pools and LI were positively loaded along Dim2. C_{frac2}, sand, BD, pH, fungal count, bacterial count, Av. K and C_{frac4} showcased negative loadings along Dim2.

4.8.2 2nd Harvest:

The principal component 1 (Dim1) and principal component 2 (Dim2) delineates the variability of the different soil attributes and its contribution towards soil quality. In one particular PC, higher the angle between two soil attributes, their correlation is larger. In case of Dim1 which represented a variability of 41.9%, the soil attributes for biological functions viz. fungal count, bacterial count, DHA and SMBC were positively correlated with other soil health attributes (clay, Av. S, Av. P, Av. K, Ex. Ca + Mg, C_{frac3}, passive pools, C_{frac4}, TOC, SOC, SOCS, EC, C_{frac2} and silt). They have been represented with positive factor loading along Dim1. The negative factor loadings along Dim1 were determined in soil attributes Av. N, active pools, BD, Cfrac1, LI, sand and pH. High contribution to the variability were obtained in TOC, SOC, SOCS, passive pools, C_{frac3}, LI, DHA, Av. N and bacterial count **(Fig 19)**. In the same figure, PC2 (Dim2) showed a variability of 13.3%. The soil attributes which were positively loaded along Dim2 were Ex. Ca + Mg, C_{frac3}, passive pools, C_{frac4}, TOC, SOC, SOCS, EC, C_{frac2}, silt, Av. N, active pools, BD, C_{frac1}, LI and sand. Negative loadings were observed in pH, fungal count, bacterial count, clay, Av. S, Av. P, Av. K, SMBC and DHA.

For soil depth 15-30 cm, PC1 (Dim1) illustrated a variability of 35% with positive factor loadings in sand, Av. P, Ex. Ca + Mg, C_{frac4}, EC, passive pools, C_{frac3}, Av. S, TOC, SOCS, SOC, Av. N, clay. Negative loadings were observed in C_{frac2}, active pools, C_{frac1}, LI, silt, BD, Av. K and pH.

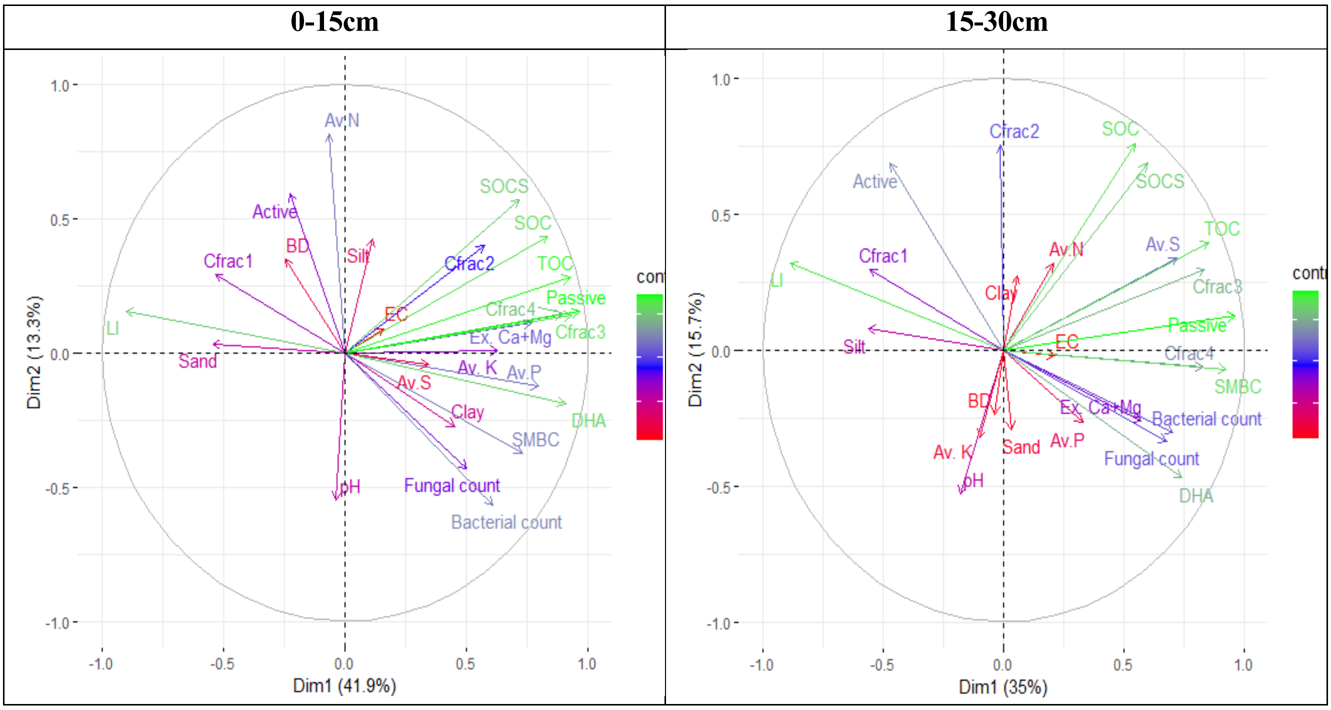


Fig 19: Quality of representation correlation circle of variables to PC 1 and PC 2. The colour gradient indicates the quality of representation of the variables

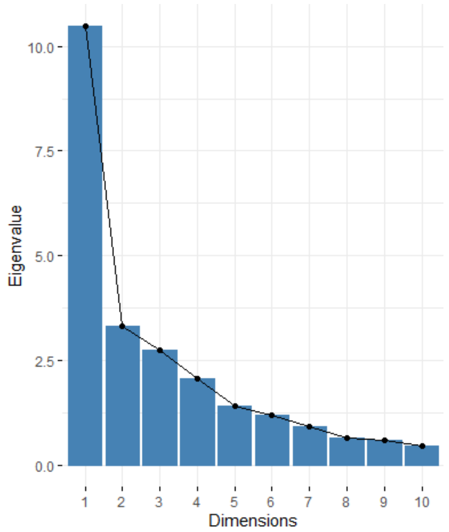
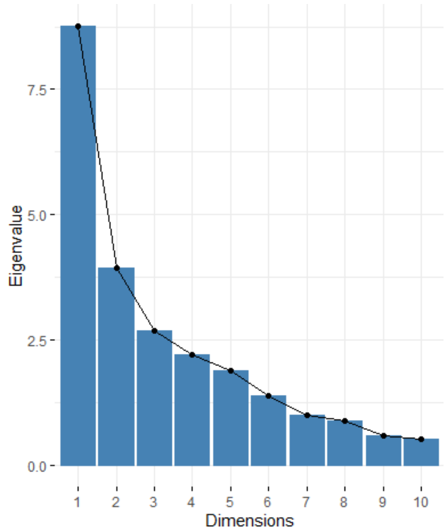
0-15cm	15-30cm
	

Fig 20: Scree plot for 2nd harvest

4.9 Developing Soil Quality Index (SQI):

4.9.1 1st Harvest

4.9.1.1 Surface soil (0-15 cm soil depth)

The analysis of variance for the seven PCs' in the surface soil (0-15 cm) indicated the weight assigned to the sensitive indictors. The weight of each PC was calculated through the percentage of variance to the total variance and ranged from 0.149 – 0.234. The maximum weight was assigned to SOC (0.234) and minimum was assigned to sand (0.149) and silt (0.152). This will indicate the highest and lowest contribution of the PC in the SQI respectively. The analysis showed distinctive improvements of the SQI from the different agricultural land use practices employed **(Fig 21)**. It was observed that T2 (organic/ straw mulching treatment) manifested the highest SQI value (0.957). An increase of 15.85% was recorded in T2 in comparison to T1 (Fallow, SQI: 0.826). Lowest SQI value (0.813) resulted in treatment T5 (Earthing up) with a decrease of 1.57% from T1. The variations in the SQI values for the remaining treatments were T4 (Minimum tillage, SQI: 0.903) > T7 (Broadcasting, SQI: 0.879) > T6 (Paired row, SQI: 0.877) > T3 (Plastic mulching, SQI: 0.859) > T8 (Ridge and Furrow, SQI: 0.829) > T9 (No weeding, SQI: 0.820) > T10 (Weeding with weedicide, SQI: 0.818). The significant increase in SQI in treatment T4, T7, T6 and T3 compared to T1 could be attributed to an increase in soil quality from the different agricultural land use practices.

Table 52: Weights assigned to sensitive indicators for 1st harvest

	0-15cm		15-30cm	
Sl No	Indicators	Weight	Indicators	Weight
1	SOC	0.234241	SOC	0.154570
2	Cfrac4	0.218481	Cfrac4	0.154411
3	BD	0.194842	Ex. Ca+Mg	0.127931
4	Av. K	0.174308	DHA	0.143564
5	Av.P	0.178128	Cfrac2	0.140214
6	Sand	0.149341	Clay	0.153932
7	Silt	0.151844	Silt	0.125379

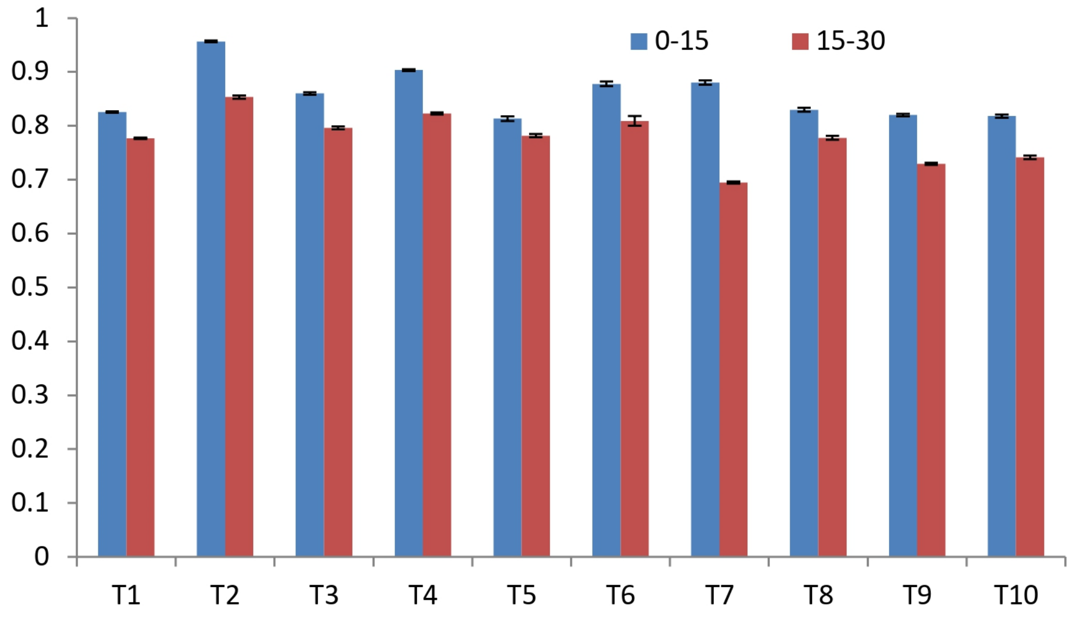


Fig 21: Soil quality index (SQI-1)

4.9.1.2 Sub-surface soil (15-30 cm soil depth):

Following the same principles from the analysis in surface soils, SQI for the subsurface soil was also developed **(Fig 21)**. The weight assigned to the sensitive indicators ranged from 0.125 – 0.156. The weights assigned to the indicators were PC1 (SOC, weight: 0.156), PC2 (C_{frac4}, weight: 0.154), PC3 (Ex. Ca + Mg, weight: 0.127), PC4 (DHA, weight: 0.143), PC5 (C_{frac2}, weight: 0.140), PC6 (clay, weight:0.153) and PC7 (silt, weight: 0.125). The assigned weights are contributions of the indicators towards developing the SQI. The organic mulched agriculture land use system (T2) exhibited the highest SQI value (0.853) and lowest was observed in the conventional agriculture system (T7) with a value of SQI: 0.695. In comparison to T1 (Fallow, SQI: 0.777), T2 intensified the SQI value by 9.78% and the lowest T7 decreased by 10.55%. Other agriculture land use systems had range from 0.730 – 0.823 in the SQI values. The recorded values of SQI for the other treatments were T4 (0.823) > T6 (0.809) > T3 (0.796) > T5 (0.782) > T8 (0.778) > T10 (0.742) > T9 (0.730). Overall, the subsurface soil expressed lower SQI in comparison to the surface soils.

4.9.2 2nd Harvest:

4.9.2.1 Surface soil (0-15 cm soil depth)

The MDS for surface soil in the 2nd harvest had a total of 6 indicators **(Fig 22)**. The assigned weights to indicators from the PCA were PC1 (TOC, weight: 0.181), PC2 (SMBC, weight: 0.164), PC3 (C_{frac1}, weight: 0.178), PC4 (EC, weight: 0.151), PC5 (Av. N, weight, 0.156) and PC6 (silt, weight: 0.166). As previously mentioned, these assigned weights infer significant contribution of the indicators towards the SQI. Treatment T2 expressed the maximum SQI value (0.811) and minimum SQI (0.600) was described in T9. T2 showed a variable increase of 21.23% from T1 (Fallow, SQI: 0.669) and T9 had a declined by 10.16%. The remaining treatments exhibited SQI values ranging from 0.737 – 0.607. Recorded values for SQI in the remaining treatments were T6 (0.737) > T7 (0.688) > T8 (0.687) > T4 (0.673) > T3 (0.670) > T5 (0.642) > T10 (0.607).

4.9.2.2 Subsurface soil (15-30 cm soil depth)

A total of 7 indicators with weights ranging from 0.129 – 0.152 were assigned for analysis in the subsurface soil **(Fig 22)**. The variable weights assigned to the indicators were PC1 (TOC, weight: 0.152), PC2 (Active pools, weight: 0.148), PC3 (Av. P, weight: 0.129), PC4 (EC, weight: 0.139), PC5 (clay, weight: 0.154), PC6 (pH, weight: 0.138) and PC7 (Av. N, weight: 0.135). The highest SQI value (0.848) was inferred to T6 and lowest was allocated to T9 (SQI: 0.703). An increase of 8.16% was observed in T6 compared to T1 (Fallow, SQI: 0.784) and a decrease of 10.20% in SQI was measured in T9. The remaining treatments revealed significant SQI values which were recorded as T2 (0.816) > T8 (0.805) > T4 (0.783) > T3 (0.781) > T7 (0.772) > T5 (0.749) > T10 (0.719).

Table 53: Weights assigned to sensitive indicators for 2nd harvest

0-15cm			15-30cm	
Sl No	Indicators	Weight	Indicators	Weight
1	TOC	0.181393	TOC	0.152828
2	SMBC	0.16492	Active	0.148574
3	Cfrac1	0.178585	Av.P	0.129668
4	EC	0.151629	EC	0.139909
5	Av.N	0.156683	Clay	0.154246
6	Silt	0.166791	pH	0.138806
7	-	-	Av.N	0.13597

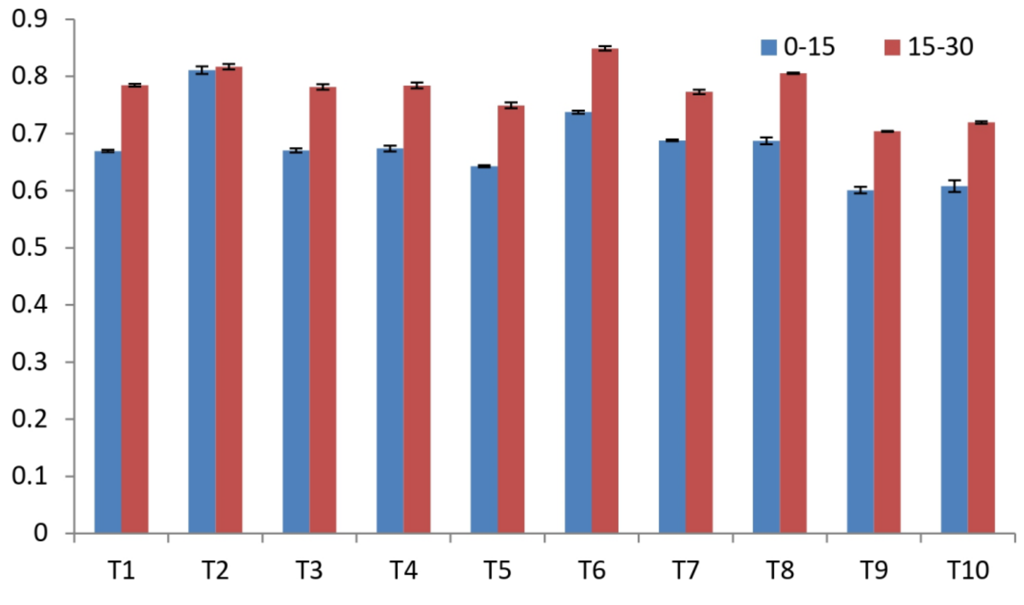


Fig 22: Fig: Soil quality index (SQI-2)

4.10 Yield of Maize

Table 54: Yield of maize under different agricultural practices for two trials

Treatments	1ST TRIAL (2022-2023) (t ha^{-1})	2nd TRIAL (2023-2024) (t ha^{-1})
T1 (Fallow)	-	-
T2 (Organic Mulching)	5.03a	5.76a
T3 (Plastic Mulching)	3.68de	4.47d
T4 (Minimum Tillage)	3.38e	4.10e
T5 (Earthing up)	3.82cd	4.69c
T6 (Paired row)	4.28b	5.44b
T7 (Broadcasting)	3.59de	4.56cd
T8 (Ridge and Furrow)	4.16bc	5.41b
T9 (No weeding)	2.87f	3.54f
T10 (Weeding with weedicide)	3.48de	4.40d
CD	0.372	0.176
SEm±	0.125	0.059

The harvest in both the trials exhibited significant variations amongst the different agricultural practices **(Table 54)**. For the 1st trial, the highest yield was noted in the straw mulch treatment (T2) with an indicated reading of 5.03 tha^{-1}. It was subsequently followed by the paired row treatment (T6: 4.28 tha^{-1}) which was statistically at par with the ridge and furrow treatment (T8: 4.16 tha^{-1}). The earthing up treatment (T5) maintained a yield of 3.82 tha^{-1} which was at par with plastic mulching treatment (T3: 3.68 tha^{-1}), broadcasting treatment (T7: 3.59 tha^{-1}) and weeding with weedicide treatment (T10: 3.48 tha^{-1}). The minimum tillage treatment (T4) exhibited yield of 3.38 tha^{-1}. The lowest yield was discerned in the no weeding treatment (T9: 2.87 tha^{-1}).

In the 2nd trial, a variable increase in yield was observed across all the agricultural practices. It could be due to the increase in the soil quality and fertility due to variable changes in the SOC and its related components. Maximum yield was observed in the straw mulching treatment (T2) with a recorded value of 5.76 t ha^{-1}. It was closely followed by the paired row treatment (T6: 5.44 tha^{-1}) which was found to be statistically at par with the ridge and furrow treatment (T8: 5.41 tha^{-1}). Subsequently, the earthing up treatment (T5) observed yield of 4.69 tha^{-1} and it was statistically at par with the broadcasting treatment (T7: 4.56 tha^{-1}). The plastic mulch treatment (T3) indicated a yield of 4.47 tha^{-1} and weeding with weedicide recorded 4.40 tha^{-1}. The minimum tillage (T4) recorded yield of 4.10 tha^{-1} and the minimum yield recorded was at no weeding treatment (T10) with a recorded yield of 3.54 tha^{-1}.

Chapter 5: Summary and conclusion

The findings of the experiment denoted certain notable variances in the different soil functions viz. physical properties, chemical properties and biological properties. The different agricultural practices employed during the experiment responded differently due to diversity of the treatments. In case of the soil physical functions, the textural triangle classified the type of soil in our experimental field as sandy loam in both soil layers. The sand fractions enveloped the highest proportions followed by silt and clay. There were little to no variances during in the soil texture during the entirety of the experimental period.

The soil buffering function pH is one of the most important parameters for indicating the soil reactions. Certain treatments such as straw mulching treatment (T2) saw a decline in the soil pH at both soil depths while the other remaining treatments increased the pH. The range of pH observed ranged from normal to slightly alkaline during the experiment.

The Electrical conductivity (EC) also showed variations in each agricultural practice during the experiment. Most treatments had a tendency for a slight decline in the EC in the surface soil and subsurface soil. This could be attributed to the application of vermicompost during the initial phase of our experiment and also leaching down of the ions or running off with the irrigation water. The range of EC was found to be normal during the entire experiment.

The bulk density (BD) developed no significant changes both during the two trial periods and the non-growing period. The treatments had no significant effect on the bulk density of soil. A slight decline in BD in the surface soil of T2 could be attributed to the accumulation of more organic biomass and increasing the porosity of the soil. The subsurface, however, observed an increase in BD during the experiment.

The available nitrogen (Av. N) showed an increase during the initial period of the two trials. The application of fertilizers and vermicompost could have amplified the availability of N in the soil layers. The increase in Av. N over time could be due to the slow-release nature of the vermicompost provided alongside the decomposition of biomass in the same area. Higher Av. N was observed in the straw mulching treatment (T2) which could be a result of biomass decomposition and release of nutreints in the soil. The Av. N in the subsurface soils were lower than the surface soils.

The available phosphorus (Av. P) indicated a slight increase across all the treatments during the experimental period. This could be attributed to the application of fertilizers and vermicompost. Also, the organic acid release during decomposition of residues and P-solubilization in the mulched plots (T2 and T3) could have further enhanced the availability of P in the mulching treatments. The Av. P also increased in the subsurface soil layers. Leaching down of nutrients could have attributed to such changes. Notably, the Av. P was higher in the surface soils.

The available potassium (Av. K) observed a decline in the surface layers during the non-growing period. However, it was examined to increasing in the subsurface layers during the experimental period.

The application of different agricultural practices determined an increasing potential, however slight, in Av. S at both soil depths. The highest increase of Av. S was however observed in the organic mulching treatment (T2) which could be due to the decomposition of biomass ensuring release of Av. S in the soil.

The exchangeable calcium and magnesium (Ex. Ca + Mg) were registered to be declining from the 1st trial period into the non-growing period which could be due to leaching down of salts from the upper to the lower soil depths.

The soil health and quality function described SOC as one of its primary parameters. The SOC was found to be the highest in the straw mulching treatment (T2) and closely followed by minimum tillage treatment (T4) at both soil depths. Higher biomass accumulation aligning with optimal temperature and moisture increased the mineralization of the organic matter, thus increasing the SOC concentration. Other treatments such as paired row treatment (T5) and plastic mulching treatment (T3) also developed similar increases. Increasing in SOC is a much essential criterion for maintaining the soil sustainability and productivity potential.

The amendment of 100% recommended dose of fertilizers along with vermicompost provided an ideal condition for increasing the total organic carbon (TOC) in soil. The additional incorporation of straw mulches in T2 and its relative decomposition further enhanced the TOC content in T2. The accumulation of TOC was higher in the surface layers as compared to the subsurface soil.

Soil organic carbon stocks (SOCS) are regarded as an important function for soil health sustainability. Any changes in the SOC stocks could lead to changes in the greenhouse gas emissions and affect the global climate change scenario. The SOCS were highly retained in the minimum tillage system (T4) which could be due to less disturbance of the natural soil and higher crop biomass concentration. The straw mulch treatment (T2) and plastic mulch (T3) were also acknowledged to retain higher SOCS. The subsurface soil held higher SOCS comparatively to surface layers.

The different agriculture practices generated certain variances in the lability index (LI). The treatments T2 and T3 indicated a lower LI along the increasing DAS. This could signify a higher retention time and decreased turnover rate of SOC, denoting an increase in the soil quality.

The soil microbial biomass carbon (SMBC) and Dehydrogenase activity (DHA) were highly correlated to the activity of soil fauna and climatic factors. Higher SMBC and DHA could be observed during when the soil became wet. However, the dry and cold conditions declined the functions of soil microbes leading to decline in SMBC, DHA during the non-growing period. The bacterial and fungal count also maintained similarity with the observations of SMBC and DHA.

The different carbon fractions (C_{frac1}, C_{frac2}, C_{frac3} and C_{frac4}) developed significant variances across the different treatments and increase in DAS. The C_{frac1} are highly labile in nature and any changes in the tillage system significantly affected its availability. The C_{frac1} + C_{frac2} were collectively conferred as the active pools while C_{frac3} + C_{frac4} were the passive pools. There was an increase in the passive pools in most treatments, which could be an inference to the increasing the quality and health of soil.

The PCA discussed the important parameters which were used for development of the soil quality index (SQI) at 1st harvest and 2nd harvest. The highly loaded factors from each principal component (PC) were utilized to develop the minimum dataset for determining the SQI of the soils. The highest SQI for both surface and subsurface soil were observed in the straw mulching treatment (T2) for 1st harvest. Similarly, the different SQI for the other treatments were also determined. Higher SQI distinguished itself by better soil functioning properties including soil quality and soil health. Lowest SQI was observed under T10 for surface soils and T9 in the subsurface soil for the 1st harvest. In case of 2nd harvest, T2 signified the highest SQI at 0-15 cm soil depth and T6 at 15-30 cm soil depth.

The yield at 1st harvest and 2nd harvest were observed to be maximum under straw mulching treatment (T2) subsequently followed by the paired row treatment (T6). The no weeding treatment (T9) attained minimum yield in both cases.

Summarizing the above findings, it can be concluded that that addition of straw mulches could enhance the soil functions while also maintaining the fertility and productivity of crops as indicated by straw mulching treatment (T2). The biological activity of soils also developed significant positive correlation with T2. The SQI also indicated higher soil quality being accumulated in the straw mulching treatment (T2). The paired row treatment (T6) also invigorated high amendments towards the soil quality and productivity. The minimum tillage (T4), no weeding (T9) and plastic mulching (T3) also maintained the quality and fertility status. However, it was less responsive to the productivity factor. The major perspective of the experiment was to interrelate all the major objectives and determine the most suitable agricultural practice which could improve soil quality, retain the SOC and its different fractions, increase soil fertility and its productivity. The treatment which could improve the productivity status while increasing the soil quality could be the most effective and sustainable for the future. On this basis, the straw mulching treatment T2 was considered as the best agricultural practice which should be highly recommended and adopted.

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