EXPLORATION ON THE LINKS BETWEEN SOIL CARBON STORAGE AND ROOT BIOMASS AND ELUCIDATION OF DRIVERS OF CARBON STABILIZATION

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(2018-21-032)

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by

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(2018-21-032)

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DECLARATION

I, hereby declare that this thesis entitled **"EXPLORATION ON THE LINKS BETWEEN SOIL CARBON STORAGE AND ROOT BIOMASS AND ELUCIDATION OF DRIVERS OF CARBON STABILIZATION"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"EXPLORATION ON THE LINKS BETWEEN SOIL CARBON STORAGE AND ROOT BIOMASS AND ELUCIDATION OF DRIVERS OF CARBON STABILIZATION"** is a record of research work done independently by Ms. Geethu Jacob (2018-21-032) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

% - Per cent

@ - At the rate

C - At the rate

DOC - Dissolved Organic carbon DHA - Dehydrogenase Activity $dS\ m^{-1}$ - deci Siemens per meter

EC - Electrical Conductivity

EC - Electrical Conductivity

LC - Labile Carbon

LP - Labile Phosphorus

LRC - Linear Regression Curve

MBC - Microbial Biomass Carbon LRC - Linear Regression Curve $mg\ kg^{-1}$ - milligram per kilogram

N - Nitrogen

NLP - Non labile phosphorus

ON - Organic nitrogen

P - Phosphorus

SOC - Soil Organic C

TN - Total Nitrogen

TOC	-	Total Organic Carbon
TP	-	Total Phosphorus
$t\ ha^{-1}$	-	Tonnes per hectare

1. INTRODUCTION

Carbon is found in all living organisms and is the major building block of life on Earth. Carbon exists in many forms, predominantly as plant biomass, soil organic matter, and as the gas carbon dioxide (CO_2) in the atmosphere and dissolved in seawater. Carbon sequestration is the long term storage of carbon in oceans, soils, vegetation (especially forests), and geologic formations. Although oceans store most of the Earth's carbon, soils contain approximately 75 per cent of the carbon pool on land ie. three times more than the amount stored in living plants and animals (Huang *et al.*, 2020). Therefore, soils play a major role in maintaining a balanced global carbon cycle.

All the organic carbon present in the soil is mainly derived from plants either by humification after plant death or by rhizodeposition from roots during plant growth as well as sloughing of root hairs and fine roots. The first mode of carbon sequestration is well researched but carbon sequestration by plant roots is still under investigation (Kumar, 2018). The relative contribution of roots versus shoots to soil carbon pools is the prime factor that drives the fate of plant tissue carbon either as mineralized CO_2 or as stabilized organic matter. According to Rasse *et al.* (2005) root C had a longer residence time in soil than shoot C, contributing to more C stabilization and sequestration by roots. The greatest proportion of root biomass occurs in the top 30 cm of the soil surface and is the store house of many nutrients.

Root biomass along with extraneous matter act as a medium for storing nutrients and microorganisms which aids in the transfer of atmospheric carbon into the soil. The decomposition process and the release of carbon and nutrients from root biomass vary with the crop type and the adopted agricultural management practices. Root derived phenolic deposits are found to trigger legume rhizobium interactions and hence legumes should be included in cropping systems (Chavarria *et al.*, 2016). Similarly the mycorrhizal associations with plant roots promote the entry of atmospheric carbon to soil organic matter (SOM) pool by the activity of external hyphal mycelium (Godbold *et al.,* 2006). Thus root system of crops plays a vital role in improving soil organic carbon (SOC) levels and soil health.

The relative contribution to the soil organic C pool by roots against shoot tissues appears consistently greater than 1.0 and remarkably high which confirms the dominant role of plant root C in soils as suggested by several authors (Boone,1994; Norby and Cotrufo, 1998). Six *et al.* (2002) reported that the contribution of root tissues to the total particulate organic matter occluded within soil aggregates ranges between 1.2 to 6.1 times that of shoots.

Priming effects, variable aggregate formation, and root associations with mycorrhizae can effectively change the quantity and quality of below ground C inputs and SOM formation (Shahbaz *et al.,* 2016). Therefore plant root contribution to the accumulation of SOM needs to be better evaluated in order to device agricultural management practices that maximizes carbon storage throughout the entire depth of the root-zone soil profile.

The faulty agricultural management practices like excessive tillage, continuous use of inorganic fertilizers, herbicides, and fungicides, burning of crop residues etc. resulted in various problems to soil, plants, and human health, through their deleterious effect on soil quality, environmental pollution and human health (Yang *et al.,* 2004). Agricultural practices for more carbon sequestration like conservation tillage practices (reduced tillage and no till), cover cropping with legumes having well developed root systems in addition to N fixation capacity, retention of crop residues in fields etc. have to be adopted to ensure long term soil quality and sustainability.

Better fertility management through proper soil testing, precision farming, integrated nutrient management involving combinations of bio fertilizers, organic manures and chemical fertilizers etc. can also ensure better crop yields without having deleterious effect on soil quality and the ecosystem. The arbuscular mycorrhizal fungi (AMF) contribute predominantly to soil organic matter by creating a sink demand for plant C and distributing to below-ground hyphal biomass. The extra-radical hyphae along with glomalin-related soil protein signifcantly infuence the soil carbon dynamics through their larger extent and turnover period (Parihar *et al.,* 2020). AMF could be considered as a replacement of inorganic fertilizers in the near future, as it can effectively reduce the quantitative use of chemical fertilizer inputs especially of phosphorus (Ortas, 2012).

The influence of carbon compounds on agriculture is not less since it affects soil pH, nutrient mobilization and microbial growth. Kerala soils are generally low in SOC and they are rated as low productive soils. The proper addition and management of organic matter through better agricultural practices assumes prime importance in rendering these soils more fertile and productive.

In this context the relative contribution of root biomass to SOC and NP pools of different agro ecological units (AEU) in comparison with litter inputs under different agricultural management practices in a legume - fodder cropping sequence were attempted here with the objective to study the links between soil carbon storage and root biomass in soils of different agro ecological units and to identify the key drivers of C stabilization and NP fluxes under different management practices.

2. REVIEW OF LITERATURE

Roots are vital organs that provide crop plants with water, nutrients, hormones and anchorage, affecting their economic yields. In addition, roots can also enhance soil organic matter by contributing to organic carbon (C), nitrogen (N), and microbial biomass pools of soil. Soil organic carbon (SOC) is one of the most extensively used soil quality indicators along with soil pH and available N, P and K content (Bunemann *et al.,* 2018). It has an impact on various soil chemical, physical, and biological properties, as well as many soil functions in agricultural soils, including nutrient cycling, soil aggregate formation, water retention, and habitat provision for biodiversity (Reeves, 1997).

In general, the amount of carbon contained in soil is the result of a balance between above ground shoot dry matter production and below ground root biomass production, along with root exudates and microbial decomposition. Below ground biomass often referred to as 'root biomass' plays a significant role in maintaining soil organic carbon levels in response to environmental changes (Hirte *et al.,* 2017).

Despite the significance of SOC, its depletion is one of the main threats for agricultural soils. Conventional agricultural practices like intensive land preparations using heavy machineries, deep tillage practices to control weeds and soil compaction, excessive use of fertilizers, removal of crop residues etc. were deleterious leading to environmental pollution, salinization, erosion, increased production costs, and deterioration in soil organic matter levels and soil quality. Soil organic carbon also plays a significant role in climate regulation, with the potential of increasing carbon sequestration, offsetting fossil-fuel emissions and compensating yield reduction created by extreme weather events (Lal, 2004). Agricultural interventions that are aimed at raising SOC stocks are therefore becoming a global priority.

Reduced tillage, use of cover crops with well developed root system, retention of crop residues particularly the root residues, appropriate use of chemical fertilizers in conjunction with organic manures, use of biofertilizers etc. are some of the conservation agriculture practices being promoted for the mitigation of soil erosion and greenhouse gases emissions, improvement in soil and water quality and crop productivity (Hobbs *et al.*, 2008). In this treatise, an attempt has been made to provide an overview on the contribution of root biomass in maintaining rhizosphere soil carbon status and their association with microbial activity and the influence of different agricultural practices on soil properties and crop productivity.

2.1 ROOTS AND RHIZOSPHERE

The rhizosphere, a thin area of soil surrounding roots that receives carbon (C) exudation from plants, represents a site of intense competition for available C and nutrients between surface-reactive particles, plant roots and soil microbial population (Merino e*t al.*, 2015).

The plant roots ability to synthesize, accumulate and exude a diverse range of compounds were well documented (Paul and Clark, 1996; Kumar *et al.*, 2006). According to Kuzyakov *et al*. (2001) more than 200 carbon compounds were released as root exudates, often ranging from mucilage, root border cells, extracellular enzymes, simple and complex sugars, phenolics, amino acids, vitamins, organic acids, nitrogenous macromolecules as purine and nucleosides to inorganic or gaseous molecules such as HCO_3, OH^- etc and were stored as rhizodeposition (Kuzyakov and Domanski, 2000).

One of the most significant metabolic functions of plant roots is the secretion of several compounds into rhizosphere termed as rhizodeposition which serves as the fuel for microbial activity (Darrah, 1993; Hortz *et al.*, 2017). Cereals releases 20-30 per cent of total assimilated carbon into the soil, half of which is found in the roots and one third of which is lost as CO_2 through root respiration and microbial consumption of root borne organic compounds (Gregory and Atwell, 1991). The rest of the underground translocated carbon is incorporated into soil microbes and organic matter. Pasture plants transfers 30-50 per cent of their assimilates below ground, and their translocation patterns are similar to cereals. According to many researchers, photosynthetically fixed carbon in cereals and grasses is swiftly transferred to the roots and can reach the root's external environment within an hour (Kuzyakov *et al.*, 2001; Kuzyakov and Domanski, 2000).

According to (Kuzyakov and Domanski, 2000), on an average the total amount of carbon translocated into the soil by cereals and pasture plants were reported to be same (1500 kg C/ha), if the same growth period was considered. But for one vegetative growth period, cereals and grasses allocated below ground C were noted as 1500 and 2200 kg C/ha respectively This accounted for nearly 5 to 21 per cent of all photosynthetically fixed carbon transferred to the rhizosphere through root exudates and ranged from 20 to 50per cent of plant biomass.

2.1.1 Root biomass and rhizospheric carbon

Most of the organic carbon found in the soil is primarily plant derived. The accumulation of soil organic matter due to the humification after plant death and root exudates and other root-borne organic substances released into the rhizosphere during plant growth as well as sloughing of root hairs and fine roots by root elongation are the main sources of root C addition to soil.

CO_2 fixation and its translocation into the roots is a simultaneous process occuring in crop plants. Metabolically active respiring roots are involved in exudation and CO_2 production activity whereas non metabolically active roots releases carbon in its soluble form, termed as lysis. The continuous release of carbon compounds from the roots into the soil can be categorized as basal exudation which is passive and not under control and exudates which are released for specific purpose are under tight control by plants (Kumar *et al.*, 2018).

The processes of root lysis, root exudation and root death delivers photosynthates to the root vicinity in the form of organic molecules. C transfer from the atmosphere to soil through the plant system strongly depends on a gradient which is maintained continuously as a result of constant removal of exudated carbon from the soil solution via biotic (e.g. soil microbial uptake) or abiotic (sorption) processes. In a study on maize crop, Kuzyakov and Domanski (2000) reported that 0.5-10 per cent of fixed carbon was transferred into the soil through the roots.

In field trials involving various crops and crop mixtures, the above ground carbon input retained in soil organic matter (SOM) was 8.3 per cent while the below ground carbon retained was as high as 46 per cent (Lajtha *et al.,* 2014; Austin *et al.,* 2017). The significance of root inputs for SOM formation is mainly due to their wide chemical composition and their immediate interactions with soil minerals, microorganisms, and aggregates upon death (Jackson *et al.,* 2017). However, the overall effects of roots and exudates on SOM formation is complicated (Lajtha *et al.,* 2014).

2.1.2 Root biomass and microbial activity

Plant growth can prosper or get deteriorated as a result of increased microbial population. Microbial colonies may have beneficial effects such as nutrient mobilisation, phytohormone synthesis, and vesicular arbuscular micorrhizal infection. Nutrient immobilisation, substrate competition, and plant disease are all potential deleterious effects. Root exudates can also attract pathogenic microbes and promotes the growth of plants, mutualistic fungi and rhizobacteria.

Generally the number of microorganisms in rhizospheric soil is very much higher than that of bulk soil. Rhizodeposition usually stimulates the growth and activity of gram negative bacteria and inhibits gram positive bacteria (Steer and Harris, 2000; Soderberg *et al.,* 2004; Johansen and Olsson, 2005). According to many reports, root architecture, root age, and plant age can influence the structure of microbial communities in rhizospheric soil (Gomes *et al.,* 2001; Marschner *et al.,* 2002) but the complex interaction between soil type, plant species, and root zone location is likely the most crucial factor (Marschner *et al.,* 2001). Root architecture, root age, disturbance, soil microflora stability, and other factors can also interfere with the effects of plant species on the composition of rhizospheric microbial population (Nannipieri *et al.*, 2003).

Nannipieri *et al.* (2003) stated that microbial activity can be evaluated in soil by measuring different attributes. Of these, the important indicators were soil respiration and enzyme activity. The rhizospheric respiration rates are very much higher than the bulk soil respiration rates as the contribution of root respiration and microbial decomposition of rhizodeposition are included in the former in addition to microbial respiration of SOC.

The SOC content is positively related to microbial respiration rates and enzymatic activities in soil (Chavarria *et al.*, 2016). In the rhizosphere, organic C generated through microbial activity and root exudates is likely the most mobile and accessible fraction of C (Merino *et al.*, 2015).

In agricultural soils plant roots and root residues do not represent a large C storage pool. But the root carbon deposits in the form of rhizodeposition and dead root mass in the soil results in the building of soil organic matter, which will reduce soil erosion, nutrient losses, environmental pollution and improve nutrient mobilization, water-retention capacity and microflora. As a result, this could play a critical role in ensuring the long-term viability of agriculture (Swinnen *et al.*, 1995; Hinsinger, 1998).

2.2 IMPACT OF AGRICULTURAL PRACTICES ON SOIL PROPERTIES AND CROP YIELDS

2.2.1 Tillage practices

Tillage plays an important role in maintaining physical as well chemical properties of soil and ultimately affecting the crop productivity. Tillage referred as the physical and mechanical manipulation of soil to prepare an ideal condition for crop growth, serves as an effective way to modify the properties of soil because of its effect on density, pore space, residue cover and surface roughness.

According to Yang and Wander (1999) the use of reduced and no-tillage practices increases the SOC concentration in surface soil compared to conventionally tilled soils and more stable aggregates in the upper surface of soil have been associated with no-till soils than tilled soils. It has been also found that NT not only increase aggregate stability but also improves SOM inside the aggregates.

Infiltration was greater under no tillage than in tilled soils because of the large proportion of macropores and increased microbial activity (McGarry *et al.*, 2000). Shukla *et al.* (2003) also reported higher infiltration rates under NT than CT because of the protection of the soil surface and effect of soil organic matter.

The conservation tillage practices increases the amount of crop residue left in the soil after harvest, thereby reducing soil erosion and increasing organic matter, aggregation, water infiltration, and water holding capacity compared with conventional tillage (Baughman *et al.*, 2001).

According to Romero *et al.* (2017) loss of soil carbon as carbon dioxide-carbon equivalent reached 1.9 pounds C/acre in the first hour and 125 pounds C/acre in the first three weeks following moldboard plowing compared to no-tillage with residue losses of 0.60 pounds C/acre in the first hour and 73 pounds C/acre in the first three weeks.

No-tillage systems, without soil tillage and inversion, maintaining crop residue cover, and ensuring proper crop sequences, have been reported to improve SOM level and ensure carbon accumulation and sequestration in diverse soils from contrasted climate regimes (Kassam *et al.*, 2012).

Investigations reported that NT systems affected not only the amount of SOM but also its characteristics (McCallister and Chein, 2000). Soil organic matter quality is affected by no tillage either in terms of particulate organic matter or in terms of its composition of humic acids, fulvic acids, and humin and these humic substances are involved in improving soil structural stability and plant growth (Madrid *et al.*, 2004).

Mbuthia *et al.* (2015) studied the impact of tillage (till and no till) and N fertilization rates (0, 34, 67 and 101 kg N ha^{-1}) on soil microbial activity, C, N and P content of soil and yields in a continuous cotton cropping system maintained for 31 years. The no-till treatments were characterized by a significantly greater abundance of Gram positive bacteria, actinomycetes and mycorrhizae fungi fatty acid methyl ester (FAME) biomarkers compared to till. Key enzymes associated with C, N & P cycling (b-glucosidase, b-glucosaminidase, and phosphodiesterase) had significantly higher rates under no-till relative to till, corresponding to significantly greater soil C, N and P content. A 13 per cent increase in yield was recorded by no till treatment relative to till treatment.

For C sequestration, C should be converted from active C to less reactive intermediate or passive C fractions and can be stored in the soil for decades (Wang *et al.*, 2017). A study by Kassam *et al.* (2012) in vertisols after 20 years of cultivation, demonstrated that no-till (NT) sequesters more C than conventional tillage (CT) and the N fertilizer application rate did not affect C sequestration in these soils, despite resulting in an increased biomass production.

Romero *et al*. (2017) studied the impact of tillage and N fertilization on labile and recalcitrant SOC fractions and characterized isotopic ^{13}C in soil profile (0–120 cm) from a long-term experiment on vertisols. The treatments were: conventional tillage (CT) vs. no-tillage (NT) and two N fertilizer application rates (0 and 100 kg N ha^{-1}). The SOC contents of the soil samples from five soil layers (0–15, 15–30, 30–60, 60–90 and 90–120 cm) were determined.

Throughout the experiment, the SOC content was greater in surface than in deeper layers. The treatment NT resulted in greater SOC content than CT, 10.7 Mg $ha^{-1}$and 8 Mg ha^{-1} respectively in the most superficial soil layer and SOC content was greater in the recalcitrant fraction than in labile fraction (62 per cent and 38per cent of total SOC respectively). The recalcitrant SOC fraction was greater under CT than under NT whereas the labile organic C fraction was greater in the NT treatments than in the CT treatments. The influence of N rate on SOC was very low and the stable C isotopic composition was greater at depth than at the surface for both total SOC and the recalcitrant fraction and the labile fraction had more value than the recalcitrant fraction. (Romero *et al.,* 2017).

Many studies have reported a reduction in soil aggregate stability, pore connectivity and porosity under conventional tillage than under no till treatment. The implementation of CT also reduced soil organic matter, microbial biomass and glomalin related protein which serves as binding agents during soil aggregation (Xiao et al., 2019 and Guo *et al.,* 2020).

The effect of tillage and crop residue management on aggregate stability, binding agents and the resulting aggregate microstructure in a sweet sorghum-based cropping system was studied by Malobane *et al.* (2021). The two tillage levels; no-till (NT) and conventional tillage (CT) and three crop residue retention levels; 0 per cent, 15 per cent and 30 per cent were tested. Aggregate stability, SOC and glomalin related soil protein content (GRSP) were found to be higher under NT than in CT. GRSP was also enhanced by 30 per cent residue retention compared to other residue management practices. This study showed that tillage is the main factor that influenced soil aggregation followed by residue management.

Jiao *et al.* (2020) investigated the effects of tillage systems on phosphorus content in rhizosphere and non rhizosphere soils under maize crop. The tillage methods adopted were continuous rotary tillage (CR), continuous no-tillage (CN) plowing-rotary tillage (PR), and plowing-no tillage (PN). The results indicated that under different tillage methods, available P content was more in the non-rhizospheric region than that of rhizospheric soil and a reduction of soil available P with the age of the crop till physiological maturity was also reported. The non-rhizosphere region had 132.9 per cent, 82.5 per cent, 259.8 per cent, and 148.4 per cent more available P than the rhizosphere region under the CR, PR, CN, and PN treatments, respectively.

Lopez *et al*. (2008) studied the influence of different tillage levels on SOC particulate organic matter C (POMC) and mineralizable C (Min C) at different depths of soil (0–5, 5–10, 10–20, 20–30 and 30–40-cm). Higher soil bulk density was observed under NT than under reduced tillage (RT), subsoil tillage (ST), or conventional tillage (CT). At the soil surface (0–5 cm depth), the highest total SOC concentration, POMC, and Min C were measured under NT, followed by RT, ST and CT, respectively. In the whole soil profile (0–40 cm), similarly, slightly greater SOC content was measured under NT than under CT.

The effects of tillage and soil amendments on C and N mineralization and P release were studied by Kingerry *et al.* (1996) by incubating field soil samples. Tillage systems investigated were strip and conventional tillage with various soil nutrient amendments (no amendment, mineral fertilizer, and broiler litter). Soil organic P concentration was 60 per cent greater in soils that had been conventionally tilled, as compared with strip-tilled and those maintained under strip-till/broiler litter mineralized greatest amount of C and N.

The results of N mineralization indicated that strip tillage had promoted a more readily mineralizable pool of N (6.1 %) than with conventional till (4.2 %), and broiler litter amendments had a larger labile N fraction (6.7 %) than mineral fertilizer (4.1 %) or no amendment (4.7 %). Tillage also affected P release and 20 per cent more inorganic P was released from strip-tilled soils than from conventionally tilled plots and greater P release was observed for amended soils (Kingerry *et al.*, 1996).

Kustermann *et al.* (2013) investigated the long term effects of tillage and fertilization on yields, soil properties, nitrogen and energy efficiency in a crop rotation of wheat– potatoes - wheat–maize. Three soil tillage systems were: CT (conventional tillage with moldboard plough, 25 cm plowing depth), RT_1 (reduced tillage with chisel plow, 18 cm working depth), and RT_2 (reduced tillage with chisel plow, 8 cm working depth) and three fertilization systems were: (high (N_3), medium (N_2) and low (N_1) mineral N input).

Conventional tillage (CT) produced yields of 8.03 (N_1), 8.82 (N_2) and 8.88 (N_3) GE (grain equivalents) ha^{-1} yr^{-1}; reduced tillage (RT_1) yields of 7.82 (N_1), 8.54 (N_2) and 9.10 (N_3) GE ha^{-1} yr^{-1} and RT_2 yields of 6.9 (N_1), 7.82 (N_2) and 8.6

(N_3) GE ha^{-1} yr^{-1}. A lower consumption of diesel fuel (reduced by 35 %) and fossil energy (by 10 %) was reported for CT.

The SOC reserves in the plowed treatments decreased by about 300 kg C ha^{-1} yr^{-1} and increased by 150–500 kg C ha^{-1} yr^{-1} in the chiseled treatments. The SON content were around 4000 kg ha^{-1} (CT), 4500 kg ha^{-1} (RT1) and 5000 kg N ha−1 (RT2) (Kustermann *et al.,* 2013).

The maintenance of good soil physical conditions is extremely important to ensure a satisfactory crop growth and high yields. Soil properties such as macrostructure, aggregate size distribution and stability, bulk density, resistance to root penetration, and water and air permeability decisively influence root growth and activity and hence overall crop growth and tillage acts as prime factor influencing the above soil properties.

Sidiras *et al.* (2001) investigated the effect of tillage systems and types of fertilization on root system development and soil physical properties using barley as the crop. Three levels of tillage, conventional tillage (CT), rotary-hoed (MT) and no tillage (NT) along with nutrient management; NP fertilizer, FYM, NP + FYM and control (no manure and fertilizer), were included as treatments. The root mass density in NT plots was 9 per cent greater than that in CT plots, and in MT plots it was 3 per cent greater. Among the nutrient management, soil fertilization with NP, FYM (30 t ha^{-1}) and NP + FYM farmyard manure improved the root density of barley by 5, 10 and 11 per cent, respectively, in comparison with control plots and the diameter of barley roots were greater in CT plots than NT plots where the thinnest roots were found. A significant positive correlation was obtained for between root density and the soil properties like bulk density, porosity, penetration resistance and aggregate stability.

A four year research was conducted by Sadiq *et al.* (2021) to explore the influence of tillage practices on wheat yield and on soil fertility parameters. The two tillage treatments adopted were, no tillage and conventional tillage. The conservative no tillage practice improved the soil nitrate nitrogen, ammonium nitrogen and carbon contents in the 0-30 cm soil layer by 12 per cent, 9 per cent and 15 per cent respectively and wheat yield by 26 per cent over conventional tillage.

Awale *et al.* (2013) evaluated the effects of tillage (conventional till [CT], strip till [ST] and no-till [NT] on C fractions - SOC, CPOM-C, $KMnO_4$-C, MBC, and C_{min} in a corn –sugarbeet- soybean rotation for two years. Compared with CT, ST and NT had significantly higher SOC concentration by 3.8 and 2.7 per cent, SOC stock by 7.2 per cent and 9.2 per cent, CPOM-C by 22 and 25 per cent, and $KMnO_4$-C by 4.8 and 4.1 per cent, respectively. CPOM-C was reported as the most sensitive fraction to tillage changes and tillage influences on SOC fractions followed the order: physical (CPOM-C) > biological (cumulative C_{min}) > chemical (KMnO4-C).

2.2.2 Organic fertilizers

Organic materials contributes directly to the building block of SOM, which performs diverse functions in improving the soil physical, chemical and biological properties. The maintenance and management of SOM in a cropped field are central to sustain soil fertility and organic manures serves as a suitable option for it (Woomer and Swift, 1994).

Organic manure has the tendency to improve soil properties by decreasing bulk density, increasing water holding capacity, aggregate stability, saturated hydraulic conductivity, water infiltration rate and biochemical activities, leading to a slow release of available nutrients through OM decomposition and resulting in better plant growth and yield. Organic manures and compost applications had resulted in higher SOC content compared to same amount of inorganic fertilizers applications (Turner *et al.*, 2007).

Thakur *et al.* (2010) reported that continuous application of FYM @ 15 t ha^{-1} along with 100 per cent NPK for a period of 36 years in soyabean – wheat cropping system resulted in an increase of SOC content by 3.9 g kg^{-1}, and N, P and S content by 126.8, 25.5 and 28.5 kg ha^{-1}, respectively over its initial values.

Hou *et al.* (2012) stated that combined application of FYM at different levels such as 7.5, 15, 22.5 t ha^{-1} in conjunction with chemical fertilizer in a continuous maize cropping system resulted in a lower soil bulk density and significantly increased the > 0.25 mm water-stable aggregate content compared to control and chemically fertilized treatment. The soil properties and crop yields were found to be positively correlated with FYM rates.

According to reports by Kuzucu (2019) application of FYM @ 75 kg per olive tree increased the soil organic matter content by 1.32 per cent and soil porosity by 13.9 per cent wrt control.

In a long term experimentation on integrated nutrient management of wheat - maize cropping system for 36 years, Brar *et al.* (2015) reported an increased cumulative infiltration, infiltration rate and aggregate MWD with integrated use of FYM along with 100 per cent NPK compared to control. The treatment 100 per cent NPK+FYM recorded highest SOC content and lowest value was for control.

Hou *et al.* (2012) stated that the combined application of organic manure and chemical fertilizers increased soil urease, alkaline phosphatase, and invertase activities by 17.1 per cent, 33.8 per cent, and 11.5 per cent, respectively compared with chemical fertilizer alone treatment.

Jacob (2018) reported that soil application of fortified thermochemical organic fertilizer @ 20 t ha^{-1} enhanced the soil population of bacteria, fungi and actinomycetes and a peak growth rate was observed at 60 days after the application of organic manure @ 7.19, 4.35 and 3.86 log cfu g^{-1} of soil, bacteria, fungi and actinomycetes, respectively.

Ramesha (2019) conducted a field experiment with amaranthus and stated that the treatment of thermochemical organic fertilizer @ 16.5 t ha^{-1} recorded higher bacteria population of 0.75 log cfu g^{-1} of soil. While the treatment which received microbial compost @ 18.5 t ha^{-1} recorded higher dehydrogenase activity (14.96 µg of TPF g^{-1} soil 24 hr^{-1}).

Maltas *et al.* (2018) studied the effects of organic amendments on carbon sequestration in a 37 year field experiment and observed an increase in SOC content with the application of fresh cattle manure @ 70 t ha^{-1}, while organic amendments such as mustard green manure, cereal straw residues, and fresh cattle manure and cattle slurry @ 35 t ha^{-1} did not result in an increase of SOC content.

SOC concentration and its storage to a depth of 60 cm were studied by Liu *et al.* (2013) and reported an increase in SOC concentration by 41.3 per cent, 32.9 per cent, 28.1 per cent and 17.9 per cent for treatment such as NP + FYM, NP + Straw residue, FYM alone and NP alone respectively than the control plots. Application of organic manure along with inorganic fertilizers increased soil labile carbon up to 60 cm depth and the concentration of particulate organic carbon, dissolved organic carbon and microbial biomass carbon was increased by 27 per cent, 14.4 per cent, and 24.7 per cent respectively compared to the control.

Islam *et al.* (2017) conducted field trials on tomato for testing yield and quality of fruits under different types of organic and inorganic fertilizers. The study revealed that integrated nutrient application of FYM @ 10 t ha^{-1} + vermi compost 12 t ha^{-1} and 1/3rd RDF produced higher yield of 21.7 per cent over control than the solo FYM application (7.1 % over control).

Continuous application of organic amendments (FYM @ 10 t ha^{-1} and straw incorporation) for 20 years enhanced the soil organic carbon by 49 per cent than the unfertilized control plot and 29 per cent than the fertilized plot. The effect of application of organic amendments on soil microbial biomass and nitrogen content was more pronounced when the soil was low in nitrogen and microbial load (Chen *et al.*, 2018).

The effect of poultry manure on the growth and yield of aerial yam and maize were evaluated by Udom *et al.* (2019) in a sole and intercrop farming pattern. The treatments were sole maize (SM), sole aerial yam (AY), aerial yam and maize intercrop (A+M), and four levels of poultry manure: 0 tons ha^{-1} (control), 5 tons ha^{-1} (PM_5), 10 tons ha^{-1} (PM_{10}), and 15 tons ha^{-1} (PM_{15}).

Results showed that bulk density, total porosity, saturation water content and saturated hydraulic conductivity of the soil were significantly improved by the application of poultry manure compared to the control. The mean value of bulk density were recorded as 1.4 g cm^{-3} and 1.43 g cm^{-3} respectively for PM_{10} and PM_{15} compared to initial value of 1.57 g cm^{-3}. The treatment PM_{15} gave the most rapid permeability class for the 3 cropping patterns and followed the same pattern for the values of total porosity, mean weight diameter (MWD) of water stable aggregates and saturation water content. The yield and growth of plants and chemical properties of soil were higher for PM_{10} and PM_{15} treatments for both sole and intercrop patterns (Udom *et al.,* 2019)

A field experiment was carried out for two years to compare the effect of different organic manures and NPK fertilizer on soil properties, growth, yield, and mineral contents of okra. The treatments were rabbit manure, cow dung, poultry manure, green manure, pig manure NPK 15-15-15 fertilizer applied at 120 kg N ha^{-1} and a control (no manure or inorganic fertilizer).

Organic manured soils recorded highest SOC content than that of control and chemically fertilized soils and among manures, poultry manure was found to be superior. Okra growth and yield parameters were significantly higher for second crop. The treatments, control, rabbit manure, cow dung, poultry manure, green manure, pig manure and NPK fertilizer increased the pod yield of okra by 9.7 per cent, 35.3 per cent, 57.9 per cent, 36.2 per cent, 39.2 per cent, 45.5 per cent and 3.2 per cent, respectively for second crop when compared with the first crop. Amongst the various organic manures, poultry manure produced significantly higher plant growth, yield, mineral composition of okra because of its high effect on soil chemical properties which could be related to its lowest C: N ratio, lignin and lignin: N ratio (Adekiya, 2020).

Jagdeesha *et al.* (2019) compared the impact of different organic manures like farmyard manure (FYM), sewage sludge, poultry manure compost (PMC), urban garbage compost, enriched urban garbage compost and vermicompost (VC) @ 50 kg N equivalent with inorganic fertilizers alone on soil properties and yield of crops in a finger millet – red gram intercropping system. Application of sewage sludge recorded highest soil microbial load of bacteria, fungi and actinomycetes, microbial biomass carbon and microbial biomass N, 23.54 x 10^7cfu g^{-1}, 25.65 x 10^4 cfu g^{-1} and 23.04 x 10^3 cfu g^{-1}, 2131.8 mg g^{-1} and 239.7 mg g^{-1} of soil, respectively followed by poultry manure compost and lowest value was for inorganic fertilizer.

The highest organic carbon content was noticed with the application of sewage sludge (0.68 %) followed by poultry manure. Significantly higher grain and straw yield of finger millet (2498 and 4075 kg ha^{-1} respectively), red gram grain and stalk yield (370 and 1407 kg ha^{-1}) was recorded with application of sewage sludge followed by poultry manure compost over all other treatments (Jagadeesha *et al.*, 2019).

Zhao *et al.* (2009) compared the effects of two organic manures, straw and farmyard manure on soil properties and crop yields in a crop rotation system maintained for 25 years. The treatments were unfertilized control (CK), inorganic N and P (NP), straw and NP (S + NP), and farmyard manure with NP (M + NP). Farmyard manure combined with chemical fertilizer management (M + NP) resulted in higher content of SOC, available-N, available-P, and higher activities of protease, urease, and alkaline phosphatase compared with those under straw manure with chemical fertilizer management (S + NP).

The soil of straw treatment had higher levels of soil respiration, soil water retention, microbial biomass, soil porosity, invertase, catalase and lower bulk density than farmyard manure treatment. The M + NP treatment produced the highest crop yields at all levels (Zhao *et al.*, 2009).

Safiullah *et al.* (2018) reported that application of 100 per cent RDN through Nadep compost significantly increased plant height, stem girth, cob length, cob girth, cob weight plant^{-1}, green cob (15801 kg ha^{-1}) and fodder (19628 kg ha^{-1}) yield. Similarly, significantly higher plant height, cob weight plant^{-1}, green cob (16145 kg ha^{-1}) and fodder (20068 kg ha^{-1}) yield, cob length and cob and stem girth were noted with application of Jeevamrut, Panchgavya and Sanjeevak @ 600 l/ha, respectively.

Ogbomo *et al.* (2018) evaluated the effect of different animal manures (rabbit manure, goat manure, poultry manure and cattle manure) on the growth and yield of maize. The results showed that the application of animal manures significantly increased the plant height, leaf area index, number of leaves, total dry matter, ear length and grain yield over control. The highest ear yield (11.61 t ha^{-1}) and grain yield (5.77 t ha^{-1}) was observed in plots treated with rabbit manure compared to the lowest ear and grain yields (7.05 and 3.66 t ha^{-1} respectively) from control. In their study rabbit manure treated plants were not significantly superior to other manures.

A study by Mahmood *et al.* (2018) investigated the effects of organic and inorganic manures on maize and their residual impacts on soil physico chemical characteristics. Results have showed that the growth and yield of maize were substantially improved by fertilizer application along with organic manures whereas soil total organic C and total N, P, K contents increased when inorganic fertilizers were applied alone or in combination with organic manures. However, soil pH and soil bulk density decreased due to the application of organic fertilizer and showed a negative correlation with grain yield. A significant and positive correlation was observed among maize grain yield and available N, P and K contents, respectively in the soil.

Wang *et al.* (2017) reported that applications of organic manure increased maize yield by 5-10 per cent and water – productivity by 3-8 per cent in a semi-arid region cropping system.

Gunjal *et al.* (2018) investigated the influence of integrated nutrient management on growth attributes and yield contributes of sweet corn (maize) in sweet corn-potato cropping sequence. They reported that the maximum and significantly higher green cob yield, green fodder yield, biological yield and harvest index of sweet corn was observed in treatment with 125 per cent RDN + 25 per cent N through VC.

Acharya and Kumar (2018) investigated effects of organic manure sources like vermicompost, poultry manure, sheep & goat manure and cattle FYM on growth and yield attributing characters of garlic in greenhouse condition with three application rates of organic manures *viz.* 10, 20 and 30 tonnes ha^{-1}. The results revealed that, organic manure application enhanced plant growth, improved garlic yield and its components *viz.* no. of cloves per bulb, bulb diameter and weight. Highest garlic yield (105.03 q ha^{-1}) was achieved in poultry manure @ 20 tonnes ha^{-1}.

Islam *et al.* (2018) conducted a study to observe the effects of different organic manures like poultry manure, cow dung and commercial fertilizer on the growth and yield of lettuce. The average maximum number of leaves, root length and yield per plot were observed by using cow dung @ 35 tonnes ha^{-1} while the lowest was in control. The poultry manure fertilized plants had relatively higher average leaves length, leaves breadth and base diameter; while the maximum dry matter content and yield per hectare were found by applying cow dung @ 25 tonnes ha^{-1}.

Kumar *et al.* (2018) studied the effect of organic and inorganic sources of nutrients on yield, quality and nutrients uptake by mustard (*Brassica juncea* L.) variety Pusa Mustard 30. The experimental results revealed that maximum growth parameters (plant height, branches $plant^{-1}$, dry matter accumulation and leaf area index), yield attributes(siliqua length, siliqua $plant^{-1}$, seeds $siliqua^{-1}$and test weight), yield (grain and stover), were recorded with application of 50 per cent

RDF + FYM 6 tonnes ha^{-1} + Vermicompost 2 tonnes ha^{-1} + bio-fertilizer higher than the rest of the treatments.

Jayakrishna (2017) observed that the custom blended thermochemical digest had significantly influenced the total dry matter production and plant height in chilly at 30 D, at 60 D and at 90 D. Fortification of thermochemical digest with NPK @ 25 g $plant^{-1}$resulted in highest yield.

2.2.3 Arbuscular mychorrhizal fungi (AMF) as a biofertilizer

Bio-fertilizers are mixtures of naturally occurring substances used to improve soil health, plant growth and development (Sadhana, 2014). Arbuscular mycorrhizal fungi (AMF), an upcoming potential bio fertilizer, forms vesicles, arbuscules, and hyphae in roots, and spores and hyphae in the rhizosphere. About 90 per cent of plant species including flowering plants, bryophytes, and ferns can establish interdependent connections with AMF (Ahanger *et al.*, 2014).

According to the reports by Sieverding (1991) volume of land explored by mychorrhizal plants was nearly 100 times more than that of non mycorrhizal plants. Formation of hyphal network by AMF with plant roots can significantly increase plant roots accessibility to a vast soil surface, leading to an improvement in plant growth (Bowles *et al.,* 2016).

Besides their effects on plant nutrition, AMF plays a significant role in modulating plants resistance to pathogens, tolerance to environmental stress conditions and stabilization by promoting soil aggregation (Miller and Jastrow, 2002). This is accomplished by mechanical binding of soil particles by AMF hyphae through glomalin, a hyphal exudation (Rillig, 2004).

As per researcher's opinion, AMF can improve plant nutrition and soil quality by increasing the availability as well as translocation of nutrients and also by influencing structure and texture of the soil respectively (Zou *et al.,* 2016; Thirkell *et al.,* 2017). Fungal hyphae can also hasten the decomposition process of SOM (Paterson *et al.,* 2016).

2.2.3.1 AMF and mineral nutrition

Many studies revealed that inoculation of AMF increased the availability of various macro and micro nutrients significantly, which leads to an increased photosynthate production and thus resulting in an increased biomass accumulation (Chen *et al.,* 2017; Mitra *et al.,* 2019). Besides that AMF has the capability to stimulate the uptake of inorganic nutrients in plants, particularly of phosphate ions (Nell *et al.,* 2010). AMF are more active in nutrient-deficient soils and assists plants for effective nutrient mining (Kayama and Yamanaka, 2014).

Experimental trials in tomato plants reported an increase in the leaf area, nitrogen, potassium, calcium, and phosphorus contents of plants inoculated with AMF indicating an enhanced plant growth by AMF (Balliu *et al.,* 2015).

A report by Bagheri *et al.* (2012) revealed that under drought stress, AMF inoculated Pistachio plants had high levels of P, K, Zn, and Mn. In addition, AMF inoculation had boosted P and N levels in Chrysanthemum plant tissues (Wang *et al.,* 2018) and increased seedling weight in rye grass by enhancing water content and intercellular CO_2, P and N contents (Jixiang *et al.,* 2017).

Zhang *et al.* (2018) reported an increased allocation of shoot biomass to panicles and grains through an increased N and P redistribution to panicles especially under low fertilizer levels.

According to Battini *et al.* (2017) AMF can produce extensive underground extra radical mycelia ranging from the roots up to the surrounding rhizosphere, after establishing symbiosis with plant roots thereby aiding in enhanced uptake of nutrients specifically N.

2.2.3.2 AMF and plant yield

A study was conducted by to examine the effect of application of rhizobium and AMF bio-fertilizers on growth and yield of soybean under different nutrient managements as follows: F_1-without fertilizer; F_2-rhizobium application; F_3-NPK only; F_4- rhizobium + AMF. Results indicated that application of both bio-fertilizers (rhizobium and AMF) significantly increased soybean yield components like grain yield, 100 grain weight, grain number and total biomass per clump compared with the other treatments (Wangiyana *et al.,* 2019)

In a pot culture experiment by Wangiyana *et al.* (2019), AMF inoculated soyabean plants showed an increased growth rate of 25 per cent and grain yield of 17 per cent when compared with uninoculated plants.

AMF can improve the nutritional quality of many crops by increasing the levels of production of carotenoids and certain volatile compounds (Hart et al., 2015). Bona *et al.* (2017) observed the beneficial effects of AMF in improving quality of tomatoes. In a study by Zeng *et al.* (2014) enhancement in citrus fruit quality was noted due to an increased concentration of sugars, organic acids, vitamin C, flavonoids, and minerals by AMF - *Glomus versiforme.*

Enhanced accumulation of anthocyanins, chlorophyll, carotenoids, total soluble phenolics, tocopherols, and various mineral nutrients in association with mycorrhizal symbiosis was reported by Baslam *et al.* (2011).

AMF have been used in large-scale field production of maize (Sabia *et al.*, 2015), yams and potatoes (Hijri, 2016), demonstrating that they have a significant potential for crop yield enhancement.

A field experiment was done to investigate the impact of native inoculum and inoculation with AMF (*Funneliformis mosseae*) on the growth and productivity of sugarcane in presence or absence of P fertilizer. The treatments were as follows: control with native inoculum, inoculation with AMF only, inoculation with AMF + 50 per cent P fertilizer and full dosage of fertilizer with native inoculum. The mycorrhizal colonization was significantly higher in both AMF inoculated treatments as compared to the uninoculated treatments, suggesting inoculum limitation in the natural fields. Among various treatments the highest plant biomass and productivity were observed in AMF + 50 per cent P treatment (Junatuhum and Boonlue, 2018).

2.2.3.3 Impact of agricultural practices on AMF

Of all the factors affecting the AMF community dynamics and associations with plants, agricultural practices may be considered as the most prime one. As per many studies, tillage practices, fallow periods, crop rotation sequences of host and non-host plants and other farming and crop management systems were some of the critical factors determining the development, activity and diversity of AMF fungi (Galvez *et al.,* 2001; Jansa *et al.,* 2003).

The proportions of fungal to bacterial biomass were usually higher in non tilled soils than in conventionally tilled soils (Spedding *et al.,* 2004). As per many records, tillage practices lead to a reduction in AMF spore and hyphal length densities, as well as a decrease in glomalin concentrations in both temperate and tropical soils (Wright *et al.,* 1999; Boddington and Dodd, 2000).

According to Mozafar *et al.* (2000) faster AMF colonization was observed in non tilled soils as compared to tilled soils, resulting in a greater proportion of the roots being colonized by AMF in the non-tilled soil early in the season. Early uptake of P and Zn by plants is frequently higher under no tillage than under conventional tillage due to faster AMF colonization in roots and this may later get reflected as increase in yield of plants.

A study by Jansa *et al.* (2003) on changes in the community structure and hyphal density of AMF in soybean crop, induced by moldboard plow (MP) or no till (NT), and fertilization with 0, 17.5, or 35 kg P ha^{-1} in soil after harvest indicated that phosphorus fertilization reduced AMF phylotype richness and Shannon diversity index. The results also indicated that AMF phylotype can vary depending on tillage levels, ie it declined with P fertilization under MP, but increased under NT.

Castillo *et al.* (2018) studied the influence of conventional tillage (CT) and no-tillage (NT) on AMF propagules in a wheat- oat cropping sequence. Mycorrhizal root colonization was reported to be higher under NT than under CT for both crops. The number of AMF spores were also higher for NT than for CT, ranging from 158 to 641 spores per 100 cm^3.

According to Martensson and Carlgren (1994) when moderate amounts of mineral P fertilizers (5-15 kg P ha^{-1}) were applied to P-deficient soils, the densities of AMF spores and hyphae in soils may increase slightly while in more rich soils, moderate P inputs have no effect on AMF. Mineral P fertilizer additions of 50 kg ha or more, usually results in lower densities of AMF spores and hyphae. (Kahiluoto *et al.,* 2001)

Several years of N fertilization in the form of NH_4 or NO_3 at levels ranging from 100 to 170 kg N ha^{-1} decreased spore densities in grassland soils, particularly those of the *Gigasporaceae*, but increased spore densities in a limestone-derived soil. (Johnson *et al.,* 2003). Organic fertilizers such as animal dung and green manure, in contrast to mineral P and N fertilization, tend to boost both spore and hyphal densities in soils (Gryndler *et al.,* 2001).

The unfavorable responses of root colonization to mineral P fertilizers are generally fast and persists for a long period of time. According to Duke *et al*. (1994) arbuscular colonization of *Agropyron dessertorum* was reduced three days after P fertilizer application and cereal root colonization was reported to be lower in fields previously over fertilized with P, even 10 years after stoppage of P fertilization (Dekkers and Van der Werff, 2001).

Applications of P and N through organic fertilizers had lesser inhibitory effect on the AMF colonization of roots than mineral fertilizers (Joner, 2000). As per the investigation done by Corkidi *et al.* (2002), nitrogen fertilization resulted in a reduction of AMF root colonization in case of grasses grown in soils containing sufficient P for plant growth (18.4 mg kg^{-1}), but not in grasses grown in soils with lower P availability (6.6 mg kg^{-1}). Therefore, the uncertainties related to varied responses of AMF to N fertilization could be attributed to the systems initial N content and N:P ratios of available elements in the soil (Treseder and Allen, 2002).

Crop rotation had a significant impact on the diversity and composition of AMF spore communities in the soil, with more AMF diversity found in rotated crops than in monocultures. Alvey *et al.* (2001) reported an increased colonization of AMF in sorghum roots by 10-15 per cent when rotated with cowpeas or groundnuts than monocultures. Similar responses of increased colonization of AMF were also reported in irrigated cotton when intercropped with peas or wheat than under monocultures (Hulugalle *et al.,* 1999).

2.2.3.4 AMF and carbon storage

Plant carbon allocation to AMF can be large, especially in nutrient-poor or boreal ecosystems and turnover of the external mycelium serves as a dominant pathway by which carbon enters the SOM pool (Clemmensen *et al.*, 2013). The extra radical hyphae (ERH) of AMF and roots get entangled with soil particles by glomalin deposited on cell wall of ERH, resulting in the formation of macro aggregate structures (Miller and Jastrow, 2002). According to Ryan (2002) extra radical hyphae and glomalin together contribute up to 15 per cent of soil organic C in a grasslands. Fungi dominated communities can accumulate more soil carbon than bacteria-dominated systems as fungi can produce more recalcitrant compounds (Six *et al.,* 2006).

3. MATERIALS AND METHODS

The study entitled "Exploration on the links between soil carbon storage and root biomass and elucidation of drivers of carbon stabilization" was conducted at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during November 2019 to September 2021 with the objective to study the links between soil carbon storage and root biomass in soils of different agro ecological units and to identify the key drivers of C stabilization and NP fluxes under different management practices.

The study was conducted in three parts: 1. Exploration on the links between soil organic C and NP pools with root biomass in soils of different AEUs. 2. Assessment of carbon storage under different land use system and identifying the drivers of C stabilization. 3. Field experiments to study the effect of tillage and nutrient management on the link between root and shoot biomass C, SOC and NP pools. The methodologies followed for the study are detailed in this chapter.

3.1 EXPLORATION ON THE LINKS BETWEEN SOIL ORGANIC C AND NP POOLS WITH ROOT BIOMASS IN SOILS OF DIFFERENT AEUs

The study area mainly consisted of regions from three agro ecological units (AEUs) of Southern Kerala, ie. Southern and Central Foot Hills (AEU 12), Southern High Hills (AEU 14) and Kumily High Hills (AEU 16). Based on the maps developed by Kerala State Land Use Board, areas under different AEUs were selected and surveyed and sampling details are furnished in Table 1. The geocoded soil samples were collected @ 15 samples from each AEU from two different depths of sampling, 0-20 cm and 20-60 cm using core sampling technique.

For soil sampling a customized power operated core sampler was designed. The core sampler consisted of a percussion hammer, metallic shaft and core segment (Plate 1 to Plate 3). For both depths of sampling separate metallic shafts and core segments of length 20 cm and 40 cm were made. The diameter of the core sampler was 5 cm. After sampling, the root biomass present in the core segments were separated by washing and sieving and weight of root biomass, were also recorded. The collected soil samples were analyzed for various physical, chemical and biological properties as per standard methods (Table 2) and separate soil samples were maintained for the estimation of soil properties and roots from each site. The correlation and regression analysis between root biomass and C, N and P pools of soil were also done.

3.2 ASSESSMENT OF CARBON STORAGE UNDER DIFFERENT LAND USE SYSTEM AND IDENTIFYING THE DRIVERS OF C STABILIZATION

The main land use system of each AEUs were selected, namely rubber plantations from Southern and Central Foot Hills (AEU 12) and Southern High Hills (AEU 14) and cardamom plantations from Kumily High Hills (AEU 16), crops grown there were uprooted, shoot and root biomass were separated out and fresh weight of both were recorded separately. The sampling area was 1 m^2 and five samples were collected from each land use system (Plate 4 to Plate 6).

As rubber plants were perennial, weed biomass from interspaces of rubber trees were uprooted to account for shoot and root biomass. The weed biomass collected from rubber plantations were mixtures of *Pueraria phaseoloides*, *Mimosa pudica* and *Paspalum conjugatum*. In case of cardamom plantations, cardamom plants were uprooted and shoot and root biomass were recorded. The soil samples were also collected from each sampling sites at two depths, 0-20 cm and 20-60 cm and analyzed for various parameters as per standard methods (Table 2). The collected plant samples were also analyzed for C, N, P and lignin content as per standard procedures (Table 3). The nutrient uptake in plant samples were calculated based on the nutrient concentration in the plant parts and their dry matter content. Nutrient uptake by shoot and root were calculated separately and added together to get the total uptake of nutrients and were expressed in kg ha^{-1}. Basic information regarding sampling sites ie. depth of water table, soil temperature, weather conditions, slope and previous land use were also collected. The total carbon storage of each land use system was estimated as suggested by Zhang *et al.* (2015).

Metallic Shaft

Core segment

Percussion Hammer

Plate 1. Parts of soil sampling machine

Plate 2 . Soil sampling machine when all parts are assembled

Plate 3. Soil sampling using soil sampler

Table 1. Details of soil sampling of different Agro ecological units (AEUs)

Sample No:	Latitude (^oN)	Longitude (^oE)	Place (District)	Crops
Southern and Central foot hills (AEU 12)				
1	9.66340880	76.78039935	Thidanadu (Kottayam)	Banana
2	9.70010263	76.80733737	Teekoy (Kottayam)	Coconut
3	9.79839992	76.76547641	Melukaavu (Kottayam)	Tapioca
4	9.79014395	76.85500712	Moolamattam (Idukki)	Coconut
5	8.56495408	77.05480843	Vellanad(Trivandrum)	Rubber
6	9.55936277	76.77158245	Kanjirapally (Kottayam)	Rubber
7	9.70239759	76.72152507	Bharananganam (Kottayam)	Rubber
8	9.68459791	76.77976698	Erattupetta (Kottayam)	Rubber
9	9.65723460	76.83801168	Poonjar (Kottayam)	Rubber
10	9.87666814	76.74516591	Thodupuzha (Idukki)	Rubber
11	9.84257328	76.73671243	Muttom (Idukki)	Rubber
12	9.85362709	76.68616033	Karinkunnam (Idukki)	Rubber
13	9.55187215	76.87520010	Kootikkal (Idukki)	Coffee
14	9.70251082	76.74054784	Melampaara (Kottayam)	Homestead
15	9.68865434	76.76304717	Kondoor (Kottayam)	Banana
Southern High Hills (AEU 14)				
1	10.05734526	76.63047879	Kothamangalam (Ernakulam)	Rubber
2	9.39764167	76.77715930	Ranni (Pathanamthitta)	Rubber
3	8.95153665	76.81537616	Panavelikuzhi (Pathanamthitta)	Pineapple
4	9.44035872	76.79248014	Makkapuzha (Pathanamthitta)	Coffee
5	9.51378269	76.57434223	Vakathanam (Pathanamthitta)	Coffee
6	9.28809428	76.71991089	Elanthoor (Pathanamthitta)	Rubber
7	9.32970410	76.69845008	Kozhanchery (Pathanamthitta)	Rubber
8	9.32763394	76.92425130	Chittar (Pathanamthitta)	Rubber
9	9.32017472	76.96829416	Seethathode (Pathanamthitta)	Banana+ vegetables

10	9.22540573	76.84315784	Konni (Pathanamthitta)	Rubber
11	9.22553281	76.84358700	Kumbazha (Pathanamthitta)	Rubber
12	9.63538570	76.97599633	Elappara (Idukki)	Cardamom
13	9.55608589	77.03634087	Parunthanpaara (Idukki)	Tea
14	8.57640092	77.08359589	Aryanad (Thiruvananthapuram)	Coconut + tapioca
15	8.72723453	77.04917792	Peringamala (Thiruvananthapuram)	Banana+ vegetables
Kumily High hills (AEU 16)				
1	9.74235908	77.09979631	Kattappana (Idukki)	Cardamom
2	9.75234878	77.15496537	Puliyanmala (Idukki)	Tea
3	9.74904989	77.09308687	Thovarayar (Idukki)	Cardamom
4	9.76144721	77.10729134	Valiyakandam (Idukki)	Tea
5	9.77335321	77.12815398	Kochuthovala (Idukki)	Coffee
6	9.77107890	77.09799798	Vellayamkudy (Idukki)	Cardamom
7	9.79528096	77.15600062	Pampadumpaara(Idukki)	Cardamom
8	9.83925246	77.15879158	Nedumkandam (Idukki)	Cardamom
9	10.0389384	77.18064873	Chinnakanal (Idukki)	Cardamom
10	10.12890874	77.1403594	Gundumala (Idukki)	Cardamom
11	10.03432151	77.16952021	Periakanal (Idukki)	Cardamom
12	13.66208279	80.13163229	Venadu (Idukki)	Cardamom
13	8.406902695	76.98673730	Muttukadu (Idukki)	Coffee
14	9.721555903	77.16202473	Vandanmedu (Idukki)	Tea
15	9.56792288	77.08666550	Vandiperiyaar (Idukki)	Tea

Plate 4. Rubber plantations of AEU 12

Plate 5. Rubber plantations of AEU 14

Plate 6. Cardamom plantations of AEU 16

Table 2. Standard analytical procedures followed for soil analysis

Parameter	Method	Reference
Physical		
Bulk density	Core method	Gupta and Dakshinamoorthy (1980)
Aggregate stability	Yoder's wet sieving method	Yoder (1936)
Chemical		
pH (1:2.5)	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	Jackson (1973)
EC (1:2.5)	Conductometry EC-TDS Analyzer (CM 183, Elico India)	Jackson (1973)
Total organic carbon	Weight loss on ignition CHNS Analyzer (Vario EI cube, Elementar, Germany)	Nelson and Sommers (1996)
DOC	Extraction with water followed by modified Walkley and Black titration method	Jones and Willet (2006)
Labile carbon	Potassium permanganate oxidation method	Blair *et al.* (1995)
Recalcitrant carbon	Modified Walkley and Black titration method	Chan *et al.* (2001)
NH_3-N	Extraction with 2 M KCl followed by macro Kjeldahl distillation and titrimetry	Hesse (1971)
NO_3-N	Extraction with 2 M KCl followed by macro Kjeldahl distillation and titrimetry	Hesse (1971)
Organic N	Total N – (NH_3-N + NO_3-N)	Hesse (1971)
Total N	Digestion with H_2SO_4 followed by micro Kjeldahl distillation and titrimetry	Jackson (1973)
Total P	Nitric-perchloric (9:4) acid digestion and spectrophotometry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Jackson (1973)
Labile P	0.5 M $NaHCO_3$ extraction and spectrophotometey (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Pierzynski (2000)
Non labile P	Total P- Labile P	Pierzynski (2000)
Biological		
Microbial biomass C	Fumigation – incubation technique	Jenkinson and Ladd (1976)
Dehydrogenase activity	Colorimetric determination of 2,3,5-triphenyl formazan (TPF)	Casida *et al.* (1964)

Table 3. Standard analytical procedures followed for plant analysis

Parameter	Method	Reference
C	Weight loss on ignition CHNS Analyzer (Vario EI cube, Elementar, Germany)	Nelson and Sommers (1996)
N	Micro kjeldahl digestion in H_2SO_4 followed by distillation	Jackson (1973)
P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdo yellow colour method (Double Beam UVVIS spectrophotometer 2201, Systronics)	Jackson (1973)
Lignin	Extraction with neutral and acid detergent solution followed by gravimetry	Georing and Soest (1970)
Crude fibre	Extraction with acid and alkali followed by oven drying and ignition at 550ºC	Sadasivam and Manickam (1992)
Crude protein	N content x 6.25	Simpson et al., (1965)

Table 4. Weather parameters during cropping period (January 2020-September2020)

Crop	Temperature (^{0}C) Max	Temperature (^{0}C) Min	RH (%)	Evaporation (mm)	Wind velocity (km hr^{-1})	Total rainfall (mm)
Grain cowpea	33.0	23.6	90.1	4.2	5.7	105.8
Fallow period	32.8	25.3	89.2	3.4	5.3	865.7
Fodder maize	31.5	25.2	92.5	2.9	3.6	487.2

*Mean values are represented in table for weather parameters except rainfall

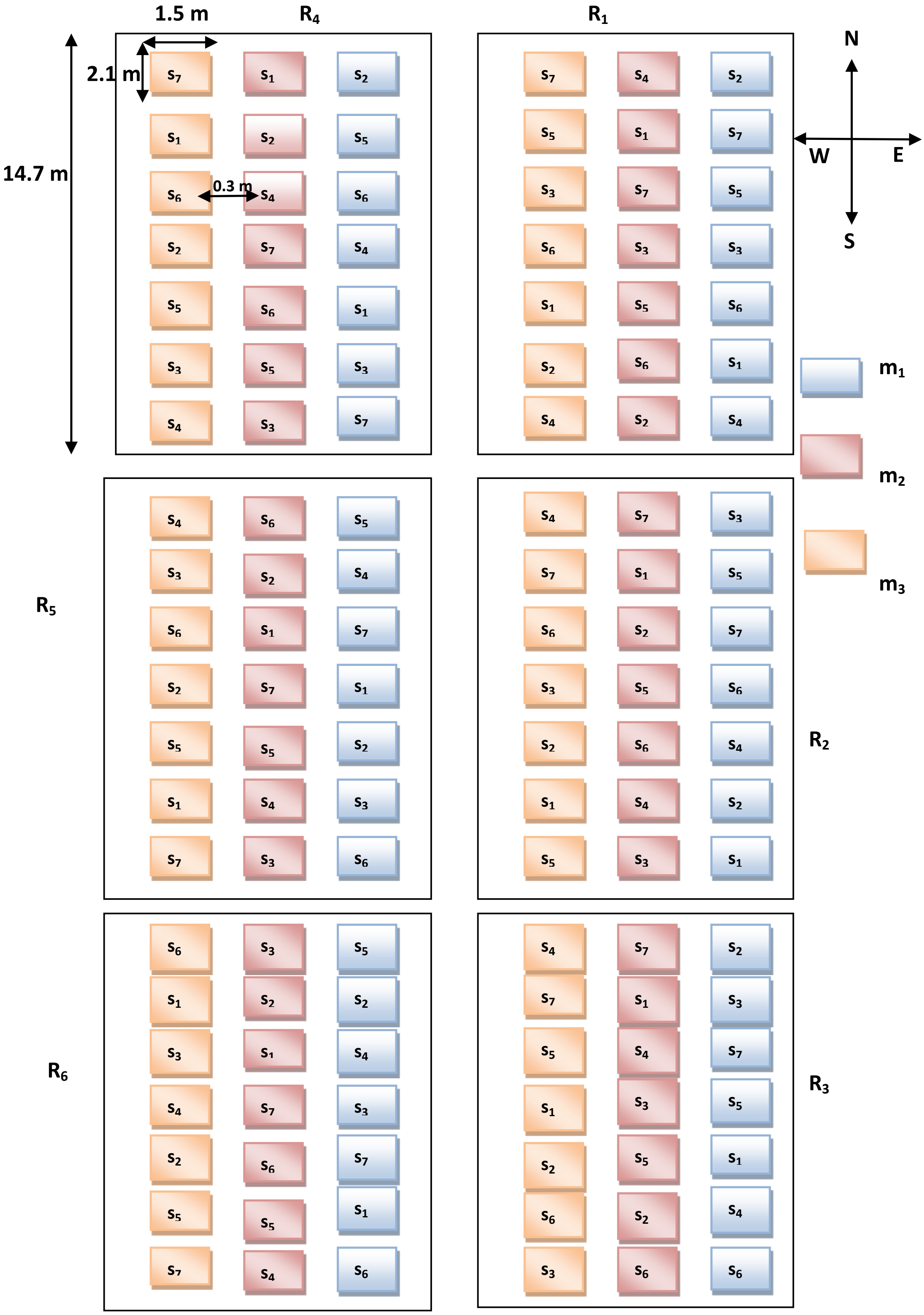


Fig 1. Layout of experimental field

Total C storage (kg m^{-2}) = [TOC (%) x soil thickness (cm) x BD (g cm^{-3})] /10. The correlation and regression analysis between C, N, and P pools and biomass were also done.

3.3 FIELD EXPERIMENTS TO STUDY THE EFFECT OF TILLAGE AND NUTRIENT MANAGEMENT ON THE LINK BETWEEN ROOT AND SHOOT BIOMASS C, AND SOC AND NP POOLS.

3.3.1 Location

Field experiments were carried out at the Instructional Farm, College of Agriculture, Vellayani from January 2020 to September 2020. The experimental site is situated at 8˚ 25′ 46″ North latitude and 76˚ 59′ 24″ East longitude, at an altitude of 29 m above MSL.

3.3.2 Weather parameters

The weather parameters during the cropping period were collected from the Department of Agricultural Meteorology, College of Agriculture, Vellayani and are presented in Table 4.

3.3.3 Soil

The soil of the experimental site was classified as loamy, kaolinitic isohyperthermic Typic Kandiustults of Vellayani series.

3.3.4 Layout

Field experiment was carried out with a legume-fodder cropping sequence, grain cowpea – fodder maize with a fallow period of three months in between the crops. The field experiment was laid out as shown in Fig.1 and Plate 7 to Plate 8.

3.3.5 Experimental details

Design: Split plot design

Replication: 6

Treatments

Main plot (m) - 3

m_1: Conventional tillage m_2: Deep tillage (30 cm depth) m_3: No till

Sub plot (s) - 7

s_1: POP Recommendation

s_2: Soil test based POP

s_3: Organic nutrient management (thermochemical fortified organic fertilizer (TOF-F)

s_4: POP + AMF

s_5: Soil test based POP + AMF

s_6: Organic nutrient management (TOF-F) + AMF

s_7: Absolute control

Crop variety

Grain cowpea - Kanakamony

Fodder maize - African Tall

Plot size

Main plot - 14.7 m x 1.5 m

Sub plot – 2.1 m x 1.5 m

3.3.6 GRAIN COWPEA

3.3.6.1 Land preparation

The experimental field was treated with glyphosate @ 0.8 kg active ingredient ha^{-1} prior to field preparation. The main plots (14.7 m x 1.5 m) and sub plots (2.1 m x 1.5 m) were laid out after thorough ploughing in conventional and deep tilled treatments and with a minimum disturbance in no tilled plots. A distance of 30 cm was maintained between sub plots and main plots (Fig 1). Lime was applied @ 350 kg ha^{-1} and after two weeks of lime application basal dose of FYM (20 t ha^{-1}) was also provided as per POP recommendation for grain cowpea (KAU, 2016).

3.3.6.2 Sowing

Seeds of grain cowpea, variety Kanakamony obtained from ORARS, Kayamkulam were treated with *Rhizobium* culture, shade dried and dibbled immediately by maintaining a spacing of 25 cm between rows and 15 cm between plants @ two seeds per hole.

Plate 7. Field experiment with grain cowpea in a grain cowpea – fodder maize cropping sequence

Plate 8. Field experiment with fodder maize in a grain cowpea – fodder maize cropping sequence

3.3.6.3 Fertilizer and manure application

POP recommendation (KAU, 2016) was followed for sub plot treatments s_1 and s_4, soil test based POP recommendation for s_2 and s_5 and thermo chemical fortified organic manure (TOF-F) for s_3 and s_6.

The fertilizer recommendations as per POP, N (20 kg ha^{-1}), P_2O_5 (30 kg ha^{-1}) and K_2O (10 kg ha^{-1}) were applied where half dose of N and whole P and K was applied as basal and remaining nitrogen was applied 15-20 days after sowing. The soil test based POP recommendations for s_2 and s_5 were 84 per cent of general recommendation for N and 25 per cent for P and K.

The fortified thermochemical organic fertilizer (TOF-F) popularized as Suchitha was purchased from the department of Soil Science & Agricultural Chemistry, College of Agriculture, Vellayani and characterized for its various properties as per standard methods (Table 5). The organic manure, TOF-F was applied in terms nitrogen equivalence ie. 1.33 t ha^{-1} for s_3 and s_6 where half of the dose as basal and remaining half after 15 days of sowing. The AMF was applied @ 5 g $plant^{-1}$ along with dibbled seed for treatments s_4, s_5 and s_6.

3.3.6.4 Irrigation

Plants were irrigated daily during initial days and when needed after establishment period.

3.3.6.5 Plant protection

The soil was drenched with 4 per cent Blitox thoroughly after the application of FYM to disinfect the soil. During the cropping period *Fusarium* wilt of cow pea was observed which was managed by drenching of affected plants with 2 per cent COC followed by 1 per cent Saaf spray. The attack of aphids and pod borers were managed by the application of Confidor @ 1.5 mL per 10 L and Fame @ 2 mL per 10 L respectively.

3.3.6.6 Weeding

Weeding was done in the field as and when needed to maintain a weed free situation for the proper growth of crop plants.

3.3.6.7 Harvesting

The pods were harvested at mature stage, dried in shade and labelled separately as per treatments. After the final harvest, observational plants were pulled out and dried to record the dry matter. The plant samples were oven dried at 70 ^{o}C and powdered for chemical analysis as per standard methods (Table 4).

Shoot, root and seed samples were dried and powdered separately.

3.3.6.8 Collection of soil samples

After final harvest of the crop, soil samples were collected from two depths, 0-20 cm and 20-60 cm and were analyzed for various parameters as per standard analytical procedures (Table 2).

3.3.6.9 Growth and yield attributes

The growth and yield characters were recorded from the tagged observational plants for each treatment avoiding the border plants.

3.3.6.9.1 Plant height

Height of observational plants were measured from base of the plants to the terminal leaf bud at final harvest stage and the mean was worked out and expressed in meters (m).

3.3.6.9.2 Number of primary branches per plant

The branches formed from the main stem of the crop were counted from observational plants and the mean was worked out.

3.3.6.9.3 Fresh weight and dry weight of shoot

After harvest, shoots from the observational plants were separated and weighed to account fresh shoot weight and then they were dried in shade and kept in oven at 70 ^{o}C for complete drying and then weighed to obtain dry weight of shoot.

3.3.6.9.4 Fresh weight and dry weight of root

After harvest, roots from observational plants were separated and weighed to account fresh root weight and then they were dried in shade and kept in oven at 70 ^{o}C for complete drying and then weighed to obtain the dry weight.

Table 5. Standard analytical procedures followed for organic manure analysis

Parameter	Method	Reference
Colour	Munsell chart	Munsell (1905)
Odour	Sensory perception	FAI (2018)
Bulk density	Tap volume	Saha *et al.* (2010)
pH (1:2.5)	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	Jackson (1973)
EC (1:2.5)	Conductometry EC-TDS Analyzer (CM 183, Elico India)	Jackson (1973)
Total organic carbon	Weight loss on ignition CHNS Analyzer (Vario EI cube, Elementar, Germany)	Nelson and Sommers (1996)
DOC	Extraction with water followed by modified Walkley and Black titration method	Jones and Willet (2006)
Labile carbon	Potassium permanganate oxidation method	Blair *et al.* (1995)
Recalcitrant carbon	Modified Walkley and Black titration method	Chan *et al.* (2001)
NH_3-N	Extraction with 2 M KCl followed by macro Kjeldahl distillation and titrimetry	Hesse (1971)
NO_3-N	Extraction with 2 M KCl followed by macro Kjeldahl distillation and titrimetry	Hesse (1971)
Organic N	Total N – (NH_3-N + NO_3-N)	Hesse (1971)
Total N	Digestion with H_2SO_4 followed by micro Kjeldahl distillation and titrimetry	Jackson (1973)
Total P	Nitric-perchloric (9:4) acid digestion and spectrophotometry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Jackson (1973)
Labile P	0.5 M $NaHCO_3$ extraction and spectrophotometey (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Pierzynski (2000)
Non labile P	Total P- Labile P	Pierzynski (2000)
Cellulose	Extraction with neutral and acid detergent solution followed by gravimetry	Updegraff (1969)
Hemicellulose	Extraction with neutral and acid detergent solution followed by gravimetry	Georing and Soest (1970)
Lignin	Extraction with neutral and acid detergent solution followed by gravimetry	Georing and Soest (1970)
Dehydrogenase activity	Colorimetric determination of 2,3,5-triphenyl formazan (TPF)	Casida *et al.* (1964)

3.3.6.9.5 Number of active nodules

The nodules with pink color inside were counted from the roots of observational plants and the mean of values were worked out for each treatments.

3.3.6.9.6 Days to 50 per cent flowering

Number of days taken by 50 per cent of the plants to flower was noted for each treatment and expressed as mean values.

3.3.6.9.7 Number of pods plant^{-1}

The number of pods from the observational plants were counted and expressed as mean values for each treatment.

3.3.6.9.8 Number of seeds pod^{-1}

The number of seeds from selected pods of observational plants were counted and expressed as mean values for each treatment (10 pods were taken and average is found out and expressed as mean).

3.3.6.9.9 Length and weight of pod

The length and weight of selected pods from observational plants were measured and expressed as mean values for each treatment (10 pods were taken and average is found out and expressed as mean).

3.3.6.9.10 100 seed weight

The weight of 100 seeds from the pods of observational plants were noted and expressed as mean values for each treatment.

3.3.6.9.11 Grain yield plant^{-1}

The seeds of all the pods of observational plants were weighed and expressed as mean values for each treatment.

3.3.6.9.12 Total dry matter production plant^{-1}

The observational plants, both shoot and root excluding the pods, were shade dried initially and then dried in hot air oven at 70°C until a constant weight was attained and expressed as mean values for each treatment.

3.3.7 Fallow period

After the harvest of grain cowpea, shoot biomass were removed and roots Were retained in three replications and in the other three replications total biomass of grain cowpea were added into the soil and left for decomposition. The field was kept as fallow for about three months for decomposition of added biomass to take place. After the fallow period, field was completely infested with weeds and was controlled by the application of Roundup @ 0.8 kg active ingredient ha^{-1}, followed by deep ploughing in m_1 and m_2 and simple raking in m_3 before sowing of second crop- fodder maize.

3.3.8 FODDER MAIZE

3.3.8.1 Sowing

Lime was applied @ 350 kg ha^{-1} and after two weeks of lime application basal dose of FYM (10 t ha^{-1}) was also provided as per POP recommendation for fodder maize for all treatments (KAU, 2016).

Seeds of fodder maize, variety African tall, obtained from Department of Forage crops, TNAU, Coimbatore were dibbled by maintaining a spacing of 25 cm between rows and 15 cm between plants @ two seeds per hole. The AMF was applied @ 5 g $plant^{-1}$ along with dibbled seed for treatments s_4, s_5 and s_6.

3.3.8.2 Fertilizer and manure application

POP recommendation (KAU, 2016) was followed for sub plot treatments s_1 and s_4, soil test based POP recommendation for s_2 and s_5 and thermo chemical fortified organic manure for s_3 and s_6.

The fertilizer recommendations as per POP, N (120 kg ha^{-1}), P_2O_5 (60 kg ha^{-1}) and K_2O (40 kg ha^{-1}) were applied as basal dressing. The soil test based POP recommendations for s_2 and s_5 were 71 per cent of general recommendation for N and 25 per cent for P and K.

The organic manure, TOF-F was applied as basal for s_3 and s_6 in terms nitrogen equivalence (8 t ha^{-1}).

3.3.8.3 Irrigation

Plants were irrigated daily during the initial stages and as and when needed after the establishment period.

3.3.8.4 Plant protection

The soil was drenched with 4 per cent copper oxy chloride thoroughly after the application of FYM to disinfect the soil. During the cropping period the attack of aphids and leaf eating caterpillars were managed by the application of Imidachloprid @ 1.5 mL per 10 L and Fame @ 2 mL per 10 L respectively.

3.3.8.5 Weeding

Weeding was done in the field as and when needed to maintain a weed free situation for the proper growth of crop plants.

3.3.8.6 Harvesting

The fodder maize plants were cut from the base at milky cob stage and observational plants were pulled out and shoot and root biomass were separated. The plant samples were oven dried at 70 ^{o}C and powdered for chemical analysis as per standard methods (Table 3). Shoot and root samples were dried and powdered separately.

3.3.8.7 Collection of soil samples

The soil samples were collected from two depths, 0-20 cm and 20-60 cm before and after the crop and were analyzed for various parameters as per standard analytical procedures (Table 2). **3.3.8.8 Growth and yield attributes**

The growth and yield characters were recorded from the tagged observational plants at the centre for each treatment avoiding the border plants.

3.3.8.8.1 Plant height

Height of observational plants were measured from base of the plant to the terminal leaf bud and the mean was worked out and expressed in meters (m).

3.3.8.8.2 Fresh weight and dry weight of shoot

After harvest, shoots from the observational plants were separated and weighed to account for fresh shoot weight and then they were dried in shade and kept in oven at 70 ^{o}C for complete drying and then weighed to obtain the dry weight.

3.3.8.8.3 Fresh weight and dry weight of root

After harvest, roots from the observational plants were separated and weighed to account fresh root weight and then they were dried in shade and kept in oven at 70 ^{o}C for complete drying and then weighed to obtain the dry weight.

3.3.8.8.4 Green fodder and dry fodder yield plant^{-1}

The green shoot biomass of observational plants were weighed and average mean values for each treatment were worked out as green fodder yield plant^{-1} and the shoot biomass were dried and kept in oven at 70 ^{o}C for complete drying and then weighed and average mean values for each treatment were worked out as dry fodder yield plant^{-1}.

3.3.9 Statistical analysis

The data generated from the field experiment were analyzed statistically by applying the analysis of variance technique for split plot design using KAU GRAPES software (Gopinath, 2021). The significance between treatments were tested by comparing CD values for main plots, sub plots and their interaction effects with the respective table values and the significance were tested at 5 per cent level.

4. RESULTS

The study entitled “Exploration on the links between soil carbon storage and root biomass and elucidation of drivers of carbon stabilization” was conducted at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during November 2019 to September 2021 with the objective to study the links between soil carbon storage and root biomass in soils of different agro ecological units and to identify the key drivers of C stabilization and NP fluxes under different management practices. The salient results are presented in this chapter.

4.1 PART 1: EXPLORATION ON THE LINKS BETWEEN SOIL ORGANIC C AND NP POOLS WITH ROOT BIOMASS IN SOILS OF DIFFERENT AEUS

The three Agro- ecological units (AEUs) of Southern Kerala namely Southern and Central foot hills (AEU 12), Southern high hills (AEU 14) and Kumily high hills (AEU 16) were surveyed and geocoded soil samples (15 nos each) were collected from depths of 0-20 cm and 20-60 cm using core sampling technique. The root biomass from soil samples were separated out using washing and sieving techniques and weighed and soil samples were analyzed for its various physical, chemical and biological properties to account for the contribution of root biomass to SOC and NP pools. The results of the study are outlined below.

4.1.1 Soil properties of Southern and Central Foot Hills (AEU 12)

The physical, chemical and biological characteristics of surveyed soil samples from AEU 12 are presented in Table 6a to 6i.

4.1.1.1 Physical and electrochemical parameters

The physical parameters of soil samples, BD and gravel percentage at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 6 a. At 0-20 cm depth, BD ranged from 1.30 Mg m^{-3} to 1.41 Mg m^{-3} with a mean value of 1.33 Mg m^{-3} and for gravel percentage an average value of 35.2 per cent was reported. At 20-60 cm depth an increased value was noted with mean value of 1.66 Mg m^{-3} and 43.60 per cent for BD and gravel percentage respectively.

As depicted in Table 6 b at 0-20 cm depth, pH of soil samples ranged from 5.09 to 5.89 with average pH of 5.59 and for EC mean value of 0.22 dS m^{-1} was noted with 0.29 dS m^{-1} (Sample no. 4) and 0.16 dS m^{-1} (Sample no. 15) as highest and lowest values respectively. For 20-60 cm sampling depth, average values were lower for both pH (5.28) and EC (0.17 dS m^{-1}).

4.1.1.2 Soil C fractions

The different C fractions of soil samples namely total organic carbon (TOC), dissolved organic carbon (DOC), labile carbon (LC) and recalcitrant carbon (RC) were determined as per standard methods at two depths of sampling and are outlined in Table 1c and Table 6 d. At 0-20cm depth of soil sampling, the mean values for different C fractions were as follows: TOC (3.41 %), DOC (37.43 mg kg^{-1}), LC (802.51 mg kg^{-1}) and RC (1.62 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various C fractions compared to surface soil and were reported as follows: TOC (3.11 %), DOC (33.39 mg kg^{-1}), LC (697.36 mg kg^{-1}), and RC (1.17 mg kg^{-1}).

4.1.1.3 Soil N fractions

The different N fractions of soil samples namely total nitrogen (TN), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N) and organic nitrogen (ON) at two depths of sampling are outlined in Table 6 e and Table 6 f. At 0-20 cm depth of soil sampling, the mean values for different N fractions were as follows: TN (7386 mg kg^{-1}), NH_4-N (351.09 mg kg^{-1}), NO_3-N (83.88 mg kg^{-1}) and ON (6951 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various N fractions compared to surface soil and were reported as follows: TN (6941 mg kg^{-1}), NH_4-N (280.72 mg kg^{-1}), NO_3-N (69.14 mg kg^{-1}) and ON (6590 mg kg^{-1}).

4.1.1.4 Soil P fractions

The different P fractions of soil samples namely total phosphorus (TP), labile phosphorus (LP), and non labile phosphorus (NLP) at two depths of sampling are outlined in Table 6 g and Table 6 h. At 0-20 cm depth of soil sampling, the mean values for different P fractions were as follows: TP (773.14 mg kg^{-1}), LP (101.70 mg kg^{-1}) and NLP (671.44 mg kg^{-1}). For second sampling

Part I.

Table 6: Physical, chemical and biological characteristics of soil samples collected from Southern and Central Foot Hills (AEU 12)

Table 6 a. Bulk density (Mg m^{-3}) and gravel percentage (%) of soil samples collected at two different depths from AEU 12

Sample No:	0-20 cm		20-60 cm	
	BD	Gravel %	BD	Gravel %
1	1.32	35	1.63	42
2	1.32	35	1.65	42
3	1.33	35	1.66	42
4	1.34	35	1.67	44
5	1.34	36	1.68	44
6	1.30	31	1.59	37
7	1.31	32	1.59	38
8	1.31	32	1.61	38
9	1.31	34	1.62	40
10	1.32	34	1.62	41
11	1.34	36	1.70	44
12	1.34	37	1.70	47
13	1.36	38	1.71	48
14	1.36	38	1.77	49
15	1.41	40	1.80	58
Mean ± SD Range	1.33± 0.03 1.30 – 1.41	35.20 ± 2.4 31- 40	1.66 ± 0.06 1.59-1.80	43.60± 5.36 38-58

Table 6 b. Electrochemical properties of soil samples, pH and EC (dS m^{-1}) collected at two different depths from AEU 12

Sample No:	0-20 cm		20-60 cm	
	pH	EC	pH	EC
1	5.09	0.25	4.79	0.19
2	5.37	0.27	5.07	0.21
3	5.60	0.22	5.29	0.22
4	5.46	0.29	5.15	0.24
5	5.56	0.25	5.25	0.20
6	5.69	0.26	5.38	0.21
7	5.68	0.24	5.37	0.19
8	5.25	0.26	4.96	0.21
9	5.52	0.17	5.23	0.11
10	5.77	0.19	5.46	0.13
11	5.62	0.19	5.32	0.13
12	5.77	0.21	5.47	0.15
13	5.89	0.17	5.60	0.11
14	5.89	0.18	5.59	0.12
15	5.67	0.16	5.38	0.10
Mean ± SD Range	5.59 ± 0.22 5.09 – 5.89	0.22 ± 0.04 0.16-0.29	5.28 ± 0.22 4.79-5.60	0.17 ± 0.04 0.10-0.24

Table 6 c. TOC (%) and DOC (mg kg^{-1}) content of soil samples collected at two different depths from AEU 12

Sample No:	0-20 cm		20-60 cm	
	TOC	DOC	TOC	DOC
1	3.49	38.52	3.24	34.37
2	3.46	38.14	3.19	34.30
3	3.45	37.70	3.18	33.71
4	3.40	37.22	3.14	32.63
5	3.40	36.14	3.12	31.96
6	3.64	41.51	3.51	39.81
7	3.57	40.52	3.43	37.95
8	3.54	39.82	3.34	37.84
9	3.51	39.59	3.28	36.07
10	3.49	39.46	3.27	34.47
11	3.30	36.03	2.96	31.62
12	3.30	35.97	2.89	31.09
13	3.27	34.43	2.77	29.77
14	3.20	33.30	2.70	28.34
15	3.14	33.15	2.70	26.93
Mean ± SD Range	3.41 ± 0.14 3.14-3.64	37.43 ± 2.6 33.15-41.51	3.11 ± 0.26 2.70-3.51	33.39 ± 3.6 26.93-39.81

Table 6 d. LC (mg kg^{-1}) and RC (%) content of soil samples collected at two different depths from AEU 12

Sample No:	0-20 cm		20-60 cm	
	LC	RC	LC	RC
1	891.96	1.81	739.63	1.30
2	878.92	1.76	727.41	1.24
3	846.83	1.69	677.14	1.24
4	823.56	1.57	661.75	1.20
5	815.11	1.46	635.69	1.19
6	1043.00	2.24	877.70	1.50
7	957.34	2.17	864.72	1.42
8	930.06	1.96	812.71	1.34
9	929.46	1.90	804.01	1.33
10	921.68	1.84	745.05	1.33
11	782.05	1.41	631.11	1.15
12	755.65	1.32	630.28	1.05
13	687.61	1.22	622.53	0.96
14	644.81	0.97	551.98	0.70
15	629.32	0.95	478.68	0.69
Mean ± SD Range	802.51 ± 213 629.32 -1043.00	1.62 ± 0.39 0.95-2.24	697.36 ± 115.78 478.68-877.70	1.17± 0.23 0.69-1.50

Table 6 e. Total N (mg kg^{-1}) and NH_4-N (mg kg^{-1}) content of soil samples collected at two different depths from AEU 12

Sample No:	0-20 cm		20-60 cm	
	TN	NH_4-N	TN	NH_4-N
1	7560	355.73	7108	288.47
2	7464	353.21	7051	276.59
3	7447	352.91	6990	276.29
4	7211	351.80	6767	270.89
5	7190	350.18	6738	270.19
6	8483	385.92	8014	320.77
7	8172	376.60	7725	312.19
8	8170	375.96	7716	298.62
9	7967	366.68	7470	296.97
10	7653	356.09	7170	295.92
11	7030	337.06	6591	267.28
12	6961	332.97	6534	267.12
13	6682	329.40	6259	264.64
14	6491	327.56	6074	253.62
15	6305	314.39	5908	247.98
Mean ± SD Range	7386± 640 6305-8483	351.09 ± 20 314.39-385.92	6941 ± 620 5908-8014	280.78 ± 21 247.98-320.77

Table 6 f. NO_3-N (mg kg^{-1}) and Organic N (mg kg^{-1}) content of soil samples collected at two different depths from AEU 12)

Sample No:	0-20 cm		20-60 cm	
	NO_3-N	ON	NO_3-N	ON
1	86.54	7118	70.73	6748.8
2	97.96	7013	70.65	6703.76
3	81.02	7013	67.66	6646.05
4	80.59	6779	65.55	6430.56
5	81.63	6758	65.22	6402.59
6	91.88	8005	85.56	7607.67
7	92.71	7703	81.38	7331.43
8	90.22	7704	80.13	7337.25
9	84.22	7516	71.88	7101.15
10	83.70	7213	71.60	6802.48
11	80.39	6613	62.96	6260.76
12	78.86	6549	62.77	6204.11
13	79.41	6273	60.70	5933.66
14	75.86	6088	60.23	5760.15
15	73.19	5917	60.15	5599.87
Mean ± SD Range	83.88 ± 6.80 73.19-97.96	6951 ± 621 5917-8005	69.14 ± 8.01 60.15-85.56	6590 ± 630 5599.87-7607.67

Table 6 g. TP (mg kg^{-1}) and LP (mg kg^{-1}) content of soil samples collected at two different depths from AEU 12

Sample No:	0-20 cm		20-60 cm	
	TP	LP	TP	LP
1	836.25	89.74	1047.09	131.41
2	815.84	89.2	989.14	129.31
3	807.91	82.13	977.81	121.13
4	807.91	76.45	941.67	111.23
5	704.85	74.94	892.52	102.29
6	971.67	219.55	1207.46	264.31
7	971.67	201.04	1179.51	223.51
8	945.12	158.38	1116.78	202.97
9	945.12	140.77	1083.46	162.39
10	836.25	90.84	1048.84	150.42
11	704.85	74.09	842.91	100.40
12	574.31	65.54	777.27	92.56
13	574.31	59.61	771.31	89.21
14	550.55	54.94	704.71	82.03
15	550.55	40.83	674.84	64.61
Mean ± SD Range	773.14 ± 155 550.55-971.67	101.70 ± 53 40.83-219.55	950.35 ± 168 674.84-1207.46	135.85 ± 57 64.61-264.31

Table 6 h. Non labile P (mg kg^{-1}) and MBC (mg kg^{-1}) content of soil samples collected at two different depths from AEU 12

Sample No:	0-20 cm		20-60 cm	
	NLP	MBC	NLP	MBC
1	746.51	28.12	915.68	18.33
2	726.64	28.69	859.83	19.38
3	725.78	28.55	856.68	19.52
4	731.46	28.45	830.44	19.67
5	629.91	33.94	790.23	22.12
6	752.12	31.60	943.15	22.41
7	770.63	22.99	956.00	14.07
8	786.74	27.64	913.81	18.76
9	804.35	20.36	921.07	20.05
10	745.41	23.05	898.42	22.73
11	630.76	26.08	742.51	25.73
12	508.77	26.58	684.71	26.23
13	514.70	25.43	682.10	25.02
14	495.61	27.74	622.68	27.30
15	509.72	19.69	610.23	19.25
Mean ± SD Range	671.44 ± 118 495.61-804.35	26.59 ± 6.6 19.69-33.94	815.17 ± 127 610.23-956.0	21.37 ± 3.5 14.07-27.30

Table 6 i. Dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1}) of soil samples collected at two different depths from AEU 12

Sample No:	0-20 cm	20-60 cm
1	31.49	20.53
2	37.88	25.58
3	35.68	24.40
4	35.28	24.39
5	35.36	30.08
6	41.08	29.13
7	30.81	18.86
8	37.59	25.51
9	27.48	27.06
10	28.82	28.41
11	33.65	33.19
12	36.69	36.20
13	35.35	34.78
14	35.79	35.22
15	25.21	24.64
Mean ± SD Range	33.87 ± 4.3 25.21-37.59	27.86 ± 5.3 24.64-36.20

Table 7. Root biomass weight and root density of soil samples collected at two different depths from AEU 12

Sample No:	0-20 cm			20-60 cm		
	Fresh weight (g V_1^{-1})	Dry weight (g V_1^{-1})	Root density (mg cm^{-3})	Fresh weight (g V_2^{-1})	Dry weight (g V_2^{-1})	Root density (mg cm^{-3})
1	1.15	0.52	1.32	0.30	0.13	0.17
2	1.14	0.51	1.30	0.29	0.14	0.18
3	1.13	0.51	1.30	0.28	0.13	0.17
4	1.11	0.5	1.27	0.24	0.11	0.14
5	1.09	0.49	1.25	0.22	0.1	0.13
6	1.29	0.58	1.48	0.46	0.21	0.27
7	1.27	0.57	1.45	0.46	0.21	0.27
8	1.26	0.57	1.45	0.44	0.2	0.25
9	1.2	0.54	1.37	0.36	0.14	0.18
10	1.16	0.52	1.32	0.32	0.16	0.20
11	1.08	0.49	1.25	0.2	0.09	0.11
12	1.05	0.47	1.20	0.2	0.09	0.11
13	1.03	0.46	1.17	0.14	0.06	0.08
14	0.95	0.43	1.09	0.07	0.03	0.04
15	0.87	0.39	0.99	0.06	0.03	0.04
Mean ± SD	1.12 ± 0.12	0.5 ± 0.06	1.28± 0.13	0.27 ± 0.13	0.12 ± 0.05	0.16± 0.07

V_1 = Volume of core 1 (0-20 cm) - 393 cm^3 V_2 = Volume of core 2 (20-60 cm) – 785 cm^3

depth ie. 20-60 cm, an increase was noted for various P fractions compared to surface soil and were reported as follows: TP (950.35 mg kg^{-1}), LP (135.85 mg kg^{-1}) and NLP (815.17 mg kg^{-1}).

4.1.1.5 Biological parameters

The biological parameters of soil samples, microbial biomass C and dehydrogenase activity at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 6 h and 6 i. At 0-20 cm depth, MBC ranged from 33.94 mg kg^{-1} to 19.69 mg kg^{-1} with a mean value of 26.59 mg kg^{-1} and for dehydrogenase activity an average value of 33.87 µg TPF g^{-1} 24 hr^{-1} was reported with 41.08 µg TPF g^{-1} 24 hr^{-1} and 25.21 µg TPF g^{-1} 24 hr^{-1} as highest and lowest values respectively. At 20-60 cm depth a decrease in value were noted with mean value of 21.37 mg kg^{-1} and 27.86 µg TPF g^{-1} 24 hr^{-1} for MBC and dehydrogenase activity respectively.

4.1.1.6 Root biomass

The fresh weight and dry weight of soil separated root biomass and root density are outlined in Table 7. At 0-20 cm depth, fresh weight of roots (g per volume of core) ranged from 1.29 g to 0.87 with average of 1.12 and for root dry weight (g per volume of core) mean value of 0.50 was noted with 0.58 and 0.39 as highest and lowest values respectively. For 20-60 cm sampling depth, average values were lower for both fresh weight (0.27g per volume of core) and dry weight (0.12 g per volume of core). The root density ranged from 0.99 mg cm^{-3} – 1.48 mg cm^{-3} at 0-20 cm and from 0.04 mg cm^{-3} – 0.27 mg cm^{-3} at 20-60 cm depth of sampling.

4.1.2 Soil properties of Southern High Hills (AEU 14)

The physical, chemical and biological characteristics of surveyed soil samples from AEU 14 are presented in Table 8 a - 8 i.

4.1.2.1 Physical and electrochemical parameters

The physical parameters of soil samples, BD and gravel percentage at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 8 a. At 0-20 cm depth, BD ranged from 1.20 Mg m^{-3} (Sample 6) to 1.33 Mg m^{-3} (Sample 15) with a mean value of 1.24 Mg m^{-3} and for gravel percentage an average value of 34.53 per cent was reported. At 20-60 cm depth an increased value was noted with mean value of 1.48 Mg m^{-3} and 42.27 per cent for BD and gravel percentage respectively.

As depicted in Table 3 b at 0-20 cm depth, pH of soil samples ranged from 5.87 to 4.80 with average pH of 5.49 and for EC mean value of 0.37 dS m^{-1} was noted with 0.44 dS m^{-1} (Sample no. 1) and 0.28 dS m^{-1} (Sample no. 12) as highest and lowest values respectively. For 20-60 cm sampling depth, average values were lower for both pH (5.08) and EC (0.15 dS m^{-1}).

4.1.2.2 Soil C fractions

The different C fractions of soil samples namely total organic carbon (TOC), dissolved organic carbon (DOC), labile carbon (LC) and recalcitrant carbon (RC) at two depths of sampling are outlined in Table 8 c and Table 8 d. At 0-20cm depth of soil sampling, the mean values for different C fractions were as follows: TOC (5.94 %), DOC (50.70 mg kg^{-1}), LC (871.80 mg kg^{-1}) and RC (1.64 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various C fractions compared to surface soil and were reported as follows: TOC (4.38 %), DOC (34.85 mg kg^{-1}), LC (568.84 mg kg^{-1}), and RC (1.14 mg kg^{-1}).

4.1.2.3 Soil N fractions

The different N fractions of soil samples namely total nitrogen (TN), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N) and organic nitrogen (ON) at two depths of sampling are outlined in Table 8 e and Table 8 f. At 0-20 cm depth of soil sampling, the mean values for different N fractions were as follows: TN (5985 mg kg^{-1}), NH_4-N (272.20 mg kg^{-1}), NO_3-N (79.96 mg kg^{-1}) and ON (5632 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various N fractions compared to surface soil and were reported as follows: TN (5692 mg kg^{-1}), NH_4-N (225.76 mg kg^{-1}), NO_3-N (66.49 mg kg^{-1}) and ON (5403 mg kg^{-1}).

4.1.2.4 Soil P fractions

The different P fractions of soil samples namely total phosphorus (TP), labile phosphorus (LP), and non labile phosphorus (NLP) at two depths of sampling are outlined in Table 8 g and Table 8 h. At 0-20cm depth of soil

Table 8: Physical, chemical and biological characteristics of soil samples collected from Southern High Hills (AEU 14)

Table 8 a. Bulk density (Mg m^{-3}) and gravel percentage (%) of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm		20-60 cm	
	BD	Gravel %	BD	Gravel %
1	1.22	34	1.44	40
2	1.23	34	1.51	41
3	1.23	34	1.58	41
4	1.24	35	1.51	42
5	1.24	35	1.44	42
6	1.2	31	1.42	38
7	1.2	31	1.47	40
8	1.21	32	1.44	40
9	1.21	32	1.46	40
10	1.22	33	1.46	40
11	1.24	39	1.43	42
12	1.24	40	1.42	45
13	1.28	40	1.5	47
14	1.31	44	1.59	48
15	1.33	44	1.56	48
Mean ± SD Range	1.24 ± 0.04	34.53 ± 2.5	1.48 ± 0.05	42.27± 3.2

Table 8 b. Electrochemical properties of soil samples, pH and EC (dS m^{-1}) collected at two different depths from AEU 14

Sample No:	0-20 cm		20-60 cm	
	pH	EC	pH	EC
1	5.80	0.44	5.28	0.21
2	5.72	0.42	5.21	0.18
3	5.20	0.29	4.95	0.12
4	5.20	0.39	4.87	0.14
5	5.78	0.44	5.12	0.16
6	4.92	0.32	4.73	0.11
7	5.67	0.31	5.09	0.10
8	5.84	0.35	5.25	0.16
9	5.52	0.31	5.15	0.14
10	5.62	0.49	5.17	0.15
11	5.87	0.32	5.27	0.21
12	5.38	0.28	5.16	0.14
13	5.75	0.37	5.35	0.12
14	5.30	0.42	4.93	0.14
15	4.80	0.36	4.69	0.17
Mean ± SD Range	5.49 ± 0.34 4.80-5.87	0.37 ± 0.06 0.28-0.49	5.08 ± 0.20 4.69-5.28	0.15 ± 0.03 0.10-0.21

Table 8 c. TOC (%) and DOC (mg kg^{-1}) content of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm		20-60 cm	
	TOC	DOC	TOC	DOC
1	6.14	53.21	4.52	35.08
2	6.13	52.97	4.32	36.02
3	6.04	51.35	4.31	34.74
4	6.01	50.15	4.29	34.85
5	5.81	50.07	4.27	33.92
6	7.23	57.6	4.86	36.2
7	6.96	55.24	4.69	36.15
8	6.84	55.39	4.66	36.09
9	6.27	54.27	4.6	37.52
10	6.21	53.28	4.58	35.43
11	5.66	48.81	4.24	33.85
12	5.32	46.47	4.19	33.31
13	5.24	46.08	4.18	34.01
14	5.16	43.53	4.15	33.56
15	4.98	42.15	3.89	32.06
Mean ± SD Range	5.94 ± 0.64	50.70 ± 4.5	4.38 ± 0.25	34.85 ± 1.4

Table 8 d. LC (mg kg^{-1}) and RC (%) content of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm		20-60 cm	
	LC	RC	LC	RC
1	890.65	1.74	592.02	1.23
2	889.24	1.67	580.95	1.22
3	887.94	1.65	569.20	1.19
4	870.25	1.56	552.17	1.14
5	869.12	1.54	537.77	1.10
6	903.28	1.98	650.25	1.28
7	902.25	1.95	648.91	1.27
8	901.93	1.86	635.84	1.26
9	900.10	1.81	620.12	1.25
10	899.54	1.75	610.77	1.24
11	855.89	1.49	520.89	1.09
12	850.84	1.46	519.04	1.08
13	830.17	1.44	512.22	0.98
14	825.41	1.37	502.22	0.94
15	800.34	1.32	480.27	0.89
Mean ± SD Range	871.80 ± 32.70 800.34-903.28	1.64 ± 0.21 1.32-1.98	568.84± 56.13 480.27-650.25	1.14± 0.13 0.89-1.28

Table 8 e. Total N (mg kg^{-1}) and NH_4-N (mg kg^{-1}) content of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm		20-60 cm	
	TN	NH_4-N	TN	NH_4-N
1	6053	289.27	5728	239.25
2	6014	278.7	5716	230.68
3	5971	278.69	5647	231.67
4	5964	263.27	5686	218.25
5	5892	257.69	5638	211.67
6	6874	317.23	6564	266.21
7	6412	301.97	6100	248.95
8	6407	297.54	6118	243.52
9	6212	294.37	5908	237.35
10	6087	291.00	5782	238.98
11	5846	257.34	5585	216.32
12	5741	251.58	5440	211.56
13	5512	241.36	5218	183.34
14	5410	232.87	5141	182.85
15	5377	230.14	5103	176.12
Mean ± SD Range	5985± 399 5377-6874	272.20 ± 27 230.14-317.23	5692 ± 389 5103-6564	225.76 ± 26 176.12-266.21

Table 8 f. NO_3-N (mg kg^{-1}) and Organic N (mg kg^{-1}) content of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm		20-60 cm	
	NO_3-N	ON	NO_3-N	ON
1	81.01	5682.72	66.78	5422
2	80.04	5655.26	65.83	5419
3	79.42	5612.89	65.53	5350
4	79.21	5621.52	66.00	5402
5	79.05	5555.26	66.51	5360
6	86.63	6470.14	69.38	6228
7	86.25	6023.78	70.24	5781
8	84.06	6025.4	69.02	5805
9	82.87	5834.76	68.01	5603
10	81.69	5714.31	67.13	5476
11	78.42	5510.24	65.88	5303
12	77.54	5411.88	65.51	5163
13	76.12	5194.52	64.89	4970
14	75.22	5101.91	64.86	4893
15	71.93	5074.93	61.81	4865
Mean ± SD Range	79.96 ± 4.01 71.93-86.63	5632 ± 370 5074.93-6470.14	66.49 ± 2.09 61.81-70.24	5403 ± 362 4865-5805

Table 8 g. Total P (mg kg^{-1}) and labile P (mg kg^{-1}) content of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm		20-60 cm	
	TP	LP	TP	LP
1	774.45	64.77	907.03	95.51
2	734.25	64.33	855.61	93.07
3	653.71	64.21	803.92	91.95
4	607.52	63.97	769.75	89.71
5	604.61	63.23	754.15	89.97
6	1005.77	70.12	1138.75	101.86
7	856.12	69.90	1010.35	103.64
8	845.23	67.18	990.35	101.92
9	823.45	66.14	960.70	103.88
10	814.02	66.11	955.30	98.85
11	593.14	62.24	723.39	83.98
12	561.25	61.77	684.83	82.51
13	501.23	61.62	646.46	100.36
14	444.48	61.36	592.17	92.10
15	403.52	60.32	542.49	95.06
Mean ± SD Range	681.52± 171 403.52-1005.77	64.48 ± 2.9 60.32-70.12	820 ± 170 542.49-1138.75	94.96 ± 6.78 92.10-103.88

Table 8 h. Non labile P (mg kg^{-1}) and MBC (mg kg^{-1}) content of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm		20-60 cm	
	NLP	MBC	NLP	MBC
1	709.68	26.11	811.52	17.08
2	669.92	26.43	762.54	16.92
3	589.50	25.76	711.97	16.35
4	543.55	26.75	680.04	18.43
5	541.38	27.35	664.18	18.57
6	935.65	26.98	1036.89	17.93
7	786.22	24.02	906.71	14.82
8	778.05	25.67	888.43	15.62
9	757.31	24.45	856.82	14.67
10	747.91	26.51	856.45	16.41
11	530.90	27.23	639.41	16.67
12	499.48	27.63	602.32	16.75
13	439.61	29.96	546.10	21.59
14	383.12	28.08	500.07	20.20
15	343.20	27.74	447.43	19.53
Mean ± SD Range	617.03 ± 169 343.20-935.65	26.71 ± 1.46 24.02-29.96	722.39 ± 167 447.43-1036.89	17.44 ± 2.1 14.67-21.59

Table 8 i. Dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1}) of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm	20-60 cm
1	34.98	22.89
2	35.94	23.00
3	34.78	22.07
4	33.17	22.85
5	37.20	25.26
6	35.08	23.31
7	33.39	20.60
8	33.12	20.15
9	31.29	18.78
10	33.14	20.51
11	35.12	21.50
12	38.13	23.12
13	33.55	24.18
14	37.07	26.67
15	34.68	24.41
Mean ± SD Range	34.71 ± 1.84 33.12-37.20	22.62 ± 2.09 18.78-26.67

Table 9. Root biomass weight and root density of soil samples collected at two different depths from AEU 14

Sample No:	0-20 cm			20-60 cm		
	Fresh weight (g V_1^{-1})	Dry weight (g V_1^{-1})	Root density (mg cm^{-3})	Fresh weight (g V_2^{-1})	Dry weight (g V_2^{-1})	Root density (mg cm^{-3})
1	1.47	0.88	2.24	0.52	0.31	0.39
2	1.44	0.86	2.19	0.48	0.29	0.37
3	1.38	0.83	2.11	0.41	0.25	0.32
4	1.25	0.75	1.91	0.35	0.21	0.27
5	1.24	0.74	1.88	0.34	0.20	0.25
6	1.83	1.1	2.80	0.88	0.53	0.68
7	1.82	1.09	2.77	0.82	0.49	0.62
8	1.78	1.07	2.72	0.68	0.41	0.52
9	1.68	1.01	2.57	0.54	0.32	0.41
10	1.54	0.92	2.34	0.53	0.32	0.41
11	1.13	0.68	1.73	0.32	0.19	0.24
12	0.99	0.59	1.50	0.31	0.19	0.24
13	0.98	0.59	1.50	0.24	0.14	0.18
14	0.78	0.47	1.20	0.24	0.14	0.18
15	0.65	0.39	0.99	0.21	0.13	0.17
Mean ± SD	1.33 ± 0.37	0.8 ± 0.22	2.03± 0.57	0.46 ± 0.21	0.27 ± 0.12	0.35± 0.16

V_1 = Volume of core 1 (0-20 cm) - 393 cm^3 V_2 = Volume of core 2 (20-60 cm) – 785 cm^3

sampling, the mean values for different P fractions were as follows: TP (681.52 mg kg^{-1}), LP (64.48 mg kg^{-1}) and NLP (617.03 mg kg^{-1}). For second sampling depth ie. 20-60 cm, an increase was noted for various P fractions compared to surface soil and were reported as follows: TP (820 mg kg^{-1}), LP (94.96 mg kg^{-1}) and NLP (722.39 mg kg^{-1}).

4.1.2.5 Biological parameters

The biological parameters of soil samples, microbial biomass C and dehydrogenase activity at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 8 h and 8 i. At 0-20 cm depth, MBC ranged from 29.96 mg kg^{-1} to 24.02 mg kg^{-1} with a mean value of 26.71 mg kg^{-1} and for dehydrogenase activity an average value of 34.71 µg TPF g^{-1} 24 hr^{-1} was reported with 37.07 µg TPF g^{-1} 24 hr^{-1} and 31.29 µg TPF g^{-1} 24 hr^{-1} as highest and lowest values respectively. At 20-60 cm depth a decrease in value was noted with mean value of 17.44 mg kg^{-1} and 22.62 µg TPF g^{-1} 24 hr^{-1} for MBC and dehydrogenase activity respectively.

4.1.2.6 Root biomass

The fresh weight and dry weight of soil separated root biomass and root density are outlined in Table 9. At 0-20 cm depth, fresh weight of roots (g per volume of core) ranged from 0.65 to 1.83 with average of 1.33 and for root dry weight (g per volume of core) mean value of 0.8 was noted with 1.10 and 0.39 as highest and lowest values respectively. For 20-60 cm sampling depth, average values were lower for both fresh weight (0.46 g per volume of core) and dry weight (0.27 g per volume of core). The root density ranged from 0.99 mg cm^{-3} – 2.8 mg cm^{-3} at 0-20 cm and from 0.17 mg cm^{-3} – 0.68 mg cm^{-3} at 20-60 cm depth of sampling.

4.1.3 Soil properties of Kumily High Hills (AEU 16)

The physical, chemical and biological characteristics of surveyed soil samples from AEU 16 are presented in Table 10 a to Table 10 i.

4.1.3.1 Physical and electrochemical parameters

The physical parameters of soil samples, BD and gravel percentage at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 10 a. At

0-20 cm depth, BD ranged from 0.87 Mg m^{-3} to 1.26 Mg m^{-3} with a mean value of 1.22 Mg m^{-3} and for gravel percentage an average value of 30.53 per cent was reported. At 20-60 cm depth an increased value was noted with mean value of 1.38 Mg m^{-3} and 36.93 per cent for BD and gravel percentage respectively.

As depicted in Table 10 b at 0-20 cm depth, pH of soil samples ranged from 4.95 to 5.87 with average pH of 5.58 and for EC mean value of 0.47 dS m^{-1} was noted with 0.74 dS m^{-1} (Sample no. 4) and 0.15 dS m^{-1} (Sample no. 5) as highest and lowest values respectively. For 20-60 cm sampling depth, average values were lower for both pH (5.01) and EC (0.22 dS m^{-1}).

4.1.3.2 Soil C fractions

The different C fractions of soil samples namely total organic carbon (TOC), dissolved organic carbon (DOC), labile carbon (LC) and recalcitrant carbon (RC) at two depths of sampling are outlined in Table 10 c and Table 10 d. At 0-20cm depth of soil sampling, the mean values for different C fractions were as follows: TOC (5.68 %), DOC (54.63 mg kg^{-1}), LC (877.50 mg kg^{-1}) and RC (1.62 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various C fractions compared to surface soil and were reported as follows: TOC (3.66 %), DOC (30.21 mg kg^{-1}), LC (635.77 mg kg^{-1}) and RC (1.13 mg kg^{-1}).

4.1.3.3 Soil N fractions

The different N fractions of soil samples namely total nitrogen (TN), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N) and organic nitrogen (ON) at two depths of sampling are outlined in Table 10 e and Table 10 f. At 0-20 cm depth of soil sampling, the mean values for different N fractions were as follows: TN (6367 mg kg^{-1}), NH_4-N (320.67 mg kg^{-1}), NO_3-N (78.09 mg kg^{-1}) and ON (5969 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various N fractions compared to surface soil and were reported as follows: TN (6078 mg kg^{-1}), NH_4-N (275.41 mg kg^{-1}), NO_3-N (62.15 mg kg^{-1}) and ON (5740 mg kg^{-1}).

4.1.3.4 Soil P fractions

The different P fractions of soil samples namely total phosphorus (TP), labile phosphorus (LP), and non labile phosphorus (NLP) were at two depths of

Table 10: Physical, chemical and biological characteristics of soil samples collected from Kumily High Hills (AEU 16)

Table 10 a. Bulk density (Mg m^{-3}) and gravel percentage (%) of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm		20-60 cm	
	BD	Gravel %	BD	Gravel %
1	1.05	28	1.28	34
2	1.14	30	1.39	35
3	1.17	30	1.40	38
4	1.18	31	1.40	38
5	1.21	32	1.41	38
6	0.87	26	1.08	32
7	0.94	27	1.20	32
8	0.97	28	1.20	33
9	0.98	28	1.20	34
10	0.99	28	1.23	34
11	1.22	32	1.44	38
12	1.22	33	1.44	40
13	1.23	34	1.48	40
14	1.24	34	1.51	42
15	1.26	36	1.51	44
Mean ± SD Range	1.22 ± 0.12 0.87-1.26	30.53 ± 2.9 26-36	1.38 ± 0.13 1.08-1.51	36.93 ± 3.6 32-44

Table 10 b. Electrochemical properties of soil samples, pH and EC (dS m^{-1}) collected at two different depths from AEU 16

Sample No:	0-20 cm		20-60 cm	
	pH	EC	pH	EC
1	5.74	0.72	4.98	0.16
2	5.69	0.34	4.85	0.19
3	5.76	0.73	4.91	0.17
4	5.87	0.74	5.36	0.28
5	5.47	0.32	4.94	0.15
6	5.62	0.48	4.91	0.13
7	5.61	0.47	5.07	0.23
8	5.71	0.59	5.11	0.25
9	5.54	0.34	5.05	0.20
10	5.78	0.71	5.01	0.21
11	5.42	0.29	4.84	0.18
12	5.44	0.27	5.17	0.31
13	4.95	0.15	4.71	0.12
14	5.39	0.24	4.77	0.19
15	5.82	0.73	5.38	0.49
Mean ± SD Range	5.58 ± 0.23 4.95-5.87	0.47 ± 0.21 0.15-0.74	5.01 ± 0.19 4.71-5.36	0.22 ± 0.09 0.12-0.49

Table 10 c. TOC (%) and DOC (mg kg^{-1}) content of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm		20-60 cm	
	TOC	DOC	TOC	DOC
1	5.92	46.44	3.65	31.23
2	5.64	44.57	3.58	30.58
3	5.57	44.81	3.55	30.29
4	5.51	43.78	3.49	29.06
5	5.47	43.24	3.28	29.28
6	7.02	47.40	4.98	31.20
7	6.39	45.88	4.72	31.44
8	6.34	45.91	4.53	31.41
9	6.28	46.62	4.31	31.15
10	6.07	46.38	3.67	30.97
11	5.33	44.01	3.27	29.15
12	5.31	42.88	3.21	29.57
13	5.23	42.91	3.21	29.79
14	5.17	42.38	3.18	28.97
15	4.57	41.62	3.08	29.57
Mean ± SD Range	5.68 ± 0.59 4.57-7.02	54.63 ± 1.84 42.38-47.40	3.66 ± 0.59 3.08-4.98	30.21 ± 0.91 28.97-31.44

Table 10 d. LC (mg kg^{-1}) and RC (%) content of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm		20-60 cm	
	LC	RC	LC	RC
1	900.45	1.81	682.04	1.17
2	885.23	1.76	663.48	1.16
3	880.76	1.68	652.02	1.14
4	872.05	1.67	617.94	1.12
5	860.39	1.56	613.11	1.11
6	922.50	1.98	720.00	1.29
7	920.18	1.95	710.23	1.23
8	910.91	1.94	708.94	1.21
9	910.79	1.92	703.17	1.20
10	900.62	1.92	694.62	1.18
11	860.07	1.39	602.34	1.06
12	852.45	1.34	590.14	1.04
13	850.35	1.21	580.74	1.04
14	830.06	1.17	544.75	1.01
15	825.75	1.14	500.39	1.01
Mean ± SD Range	877.50 ± 30.68 825.75-922.50	1.62 ± 0.30 1.14-1.98	635.77 ± 64.75 500.39-720.00	1.13± 0.085 1.01-1.29

Table 10 e. Total N (mg kg^{-1}) and NH_4-N (mg kg^{-1}) content of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm		20-60 cm	
	TN	NH_4-N	TN	NH_4-N
1	6519	341.74	6218	294.21
2	6395	325.44	6093	281.91
3	6315	324.43	6020	281.9
4	6298	307.01	5977	266.48
5	6245	302.43	5970	260.9
6	7187	366.97	6880	320.44
7	6957	353.71	6687	305.18
8	6727	352.56	6418	303.63
9	6705	350.28	6413	300.75
10	6699	350.11	6405	297.58
11	6149	298.10	5898	260.55
12	6110	297.08	5852	254.79
13	6045	290.32	5747	244.57
14	5809	282.88	5518	236.08
15	5682	281.61	5416	233.35
Mean ± SD Range	6367 ± 406 5682-7187	320.67 ± 28 281.61-366.97	6078 ± 397 5416-6880	275.41 ± 27 233.35-320.44

Table 10 f. NO_3-N (mg kg^{-1}) and Organic N (mg kg^{-1}) content of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm		20-60 cm	
	NO_3-N	ON	NO_3-N	ON
1	81.95	6095	63.94	5860
2	79.03	5991	62.35	5749
3	76.73	5914	60.37	5678
4	77.20	5914	61.52	5649
5	77.71	5865	62.70	5646
6	82.58	6737	62.86	6497
7	83.44	6520	64.96	6317
8	82.22	6292	64.71	6050
9	81.20	6274	63.86	6048
10	80.33	6269	63.30	6044
11	77.08	5774	62.07	5575
12	74.71	5738	60.21	5537
13	74.09	5681	60.39	5442
14	74.06	5452	61.23	5221
15	71.01	5329	58.42	5124
Mean ± SD Range	78.09 ± 3.61 71.01-83.44	5969 ± 386 5329-6737	62.15 ± 1.81 58.42-64.96	5740 ± 383 5124-6497

Table 10 g. Total P (mg kg^{-1}) and labile P (mg kg^{-1}) content of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm		20-60 cm	
	TP	LP	TP	LP
1	855.3	79.54	983.88	109.14
2	755.61	78.59	864.27	108.44
3	703.92	78.18	841.43	107.93
4	669.75	77.36	819.28	105.54
5	654.15	75.57	790.99	103.16
6	1038.75	82.57	1159.03	116.49
7	911.09	81.46	1051.88	113.03
8	910.35	80.92	1040.56	112.11
9	890.35	80.32	1022.77	111.89
10	860.70	79.92	985.25	109.89
11	623.39	74.25	740.94	101.75
12	584.83	72.97	695.71	101.40
13	546.46	72.86	678.99	101.14
14	492.17	72.83	627.16	93.82
15	442.49	71.87	568.76	91.43
Mean ± SD Range	722.35 ± 171 442.49-1038.75	77.12 ± 3.81 71.87-82.57	851 ± 170 568.76-1159.03	105.77 ± 7.01 91.43-116.49

Table 10 h. Non labile P (mg kg^{-1}) and MBC (mg kg^{-1}) content of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm		20-60 cm	
	NLP	MBC	NLP	MBC
1	775.76	26.03	874.74	19.51
2	677.02	25.92	755.83	19.38
3	625.74	25.47	733.5	18.29
4	592.39	26.76	713.74	20.64
5	578.58	27.69	687.83	20.74
6	956.18	26.99	1042.54	19.87
7	829.63	24.02	938.85	17.08
8	829.43	26.51	928.45	16.94
9	810.03	25.22	910.88	15.28
10	780.78	26.24	875.36	18.38
11	549.14	27.21	639.19	19.62
12	511.86	28.43	594.31	18.75
13	473.60	30.63	577.85	23.90
14	419.34	28.65	533.34	22.11
15	370.62	27.66	477.33	21.77
Mean ± SD Range	644.89 ± 168 370.62-956.18	26.89 ± 1.61 24.02-30.63	744.72 ± 166 477.33-1042.54	19.5 ± 2.2 16.94-23.90

Table 10 i. Dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1}) of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm	20-60 cm
1	34.88	26.14
2	35.24	26.35
3	34.39	24.70
4	33.18	25.60
5	37.66	28.20
6	35.08	25.83
7	33.38	23.74
8	34.20	21.86
9	32.28	19.56
10	32.80	22.97
11	35.10	25.31
12	39.23	25.87
13	34.30	26.77
14	37.82	29.19
15	34.58	27.22
Mean ± SD Range	34.94 ± 1.93 32.28-39.23	25 ± 2.46 19.56-29.19

Table 11. Root biomass weight and root density of soil samples collected at two different depths from AEU 16

Sample No:	0-20 cm			20-60 cm		
	Fresh weight (g V_1^{-1})	Dry weight (g V_1^{-1})	Root density (mg cm^{-3})	Fresh weight (g V_2^{-1})	Dry weight (g V_2^{-1})	Root density (mg cm^{-3})
1	1.38	0.69	1.76	0.41	0.21	0.27
2	1.36	0.68	1.73	0.41	0.21	0.27
3	1.34	0.67	1.70	0.38	0.19	0.24
4	1.32	0.66	1.68	0.34	0.17	0.22
5	1.28	0.64	1.63	0.32	0.16	0.20
6	1.52	0.76	1.93	0.61	0.31	0.39
7	1.5	0.75	1.91	0.58	0.29	0.37
8	1.47	0.74	1.88	0.57	0.29	0.37
9	1.45	0.73	1.86	0.52	0.26	0.33
10	1.41	0.71	1.81	0.48	0.24	0.31
11	1.27	0.64	1.63	0.3	0.15	0.19
12	1.25	0.63	1.60	0.27	0.14	0.18
13	1.24	0.62	1.58	0.27	0.14	0.18
14	1.23	0.62	1.58	0.25	0.13	0.17
15	1.21	0.61	1.55	0.25	0.13	0.17
Mean ± SD	1.35 ± 0.10	0.67 ± 0.05	1.72± 0.13	0.41 ± 0.13	0.22 ± 0.06	0.26± 0.08

V_1 = Volume of core 1 (0-20 cm) - 393 cm^3 V_2 = Volume of core 2 (20-60 cm) – 785 cm^3

sampling a are outlined in Table 10 g and Table 10 h. At 0-20cm depth of soil sampling, the mean values for different P fractions were as follows: TP (722.35 mg kg^{-1}), LP (77.12 mg kg^{-1}) and NLP (644.89 mg kg^{-1}). For second sampling depth ie. 20-60 cm, an increase was noted for various P fractions compared to surface soil and were reported as follows: TP (851 mg kg^{-1}), LP (105.77 mg kg^{-1}) and NLP (744.72 mg kg^{-1}).

4.1.3.5 Biological parameters

The biological parameters of soil samples, microbial biomass C and dehydrogenase activity at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 10 h and 10 i. At 0-20 cm depth, MBC ranged from 30.63 mg kg^{-1} to 24.02 mg kg^{-1} with a mean value of 26.89 mg kg^{-1} and for dehydrogenase activity an average value of 34.94 µg TPF g^{-1} 24 hr^{-1} was reported with 37.82 µg TPF g^{-1} 24 hr^{-1} and 32.28 µg TPF g^{-1} 24 hr^{-1} as highest and lowest values respectively. At 20-60 cm depth a decrease in value was noted with mean value of 19.5 mg kg^{-1} and 25 µg TPF g^{-1} 24 hr^{-1} for MBC and dehydrogenase activity respectively.

4.1.3.6 Root biomass

The fresh weight and dry weight of soil separated fine root biomass and root density are outlined in Table 11. At 0-20 cm depth, fresh weight of roots (g per volume of core) ranged from 1.21 to 1.52 with average of 1.35 and for root dry weight (g per volume of core) mean value of 0.67 was noted with 0.76 and 0.61 as highest and lowest values respectively. For 20-60 cm sampling depth, average values were lower for both fresh weight (0.41 g per volume of core) and dry weight (0.22 g per volume of core). The root density ranged from 1.55 mg cm^{-3} – 1.93 mg cm^{-3} at 0-20 cm and from 0.17 mg cm^{-3} – 0.39 mg cm^{-3} at 20-60 cm depth of sampling.

4.2 PART II. ASSESSMENT OF CARBON STORAGE UNDER DIFFERENT LAND USE SYSTEM AND IDENTIFYING THE DRIVERS OF C STABILIZATION

Based on the survey conducted, most prominent land use system of each AEU ie. rubber plantations for AEU 12 and AEU 14 and cardamom plantations for AEU 16 were selected to study the relation between plant biomass carbon and soil C and NP pools. As rubber plants are hard to uproot, weed biomass to an area of 1 m^2 between rubber trees were uprooted to account for the shoot and root biomass. For cardamom plantations, cardamom plants were uprooted and their shoot and root biomass were recorded. Soil samples were also collected from each system at two depths of sampling (0-20 cm and 20-60 cm). Five samples, both plant and soil samples were collected from each system and analyzed for its various parameters as per standard methods to establish a relation between plant biomass C and soil C, N and P pools.

4.2.1 Soil properties in rubber plantations of Southern and Central Foot Hills (AEU 12)

The physical, chemical and biological characteristics of soil samples collected from rubber plantations of AEU 12 are presented in Table 12 a to Table 12 e.

4.2.1.1 Physical and electrochemical parameters

The physical and electro chemical parameters of soil samples, collected from rubber plantations of AEU 12 at two different depths of sampling are depicted in Table 12 a. At 0-20 cm, the average values for various parameters were as follows: pH (5.61), EC (0.39 dS m^{-1}), BD (1.23 Mg m^{-3}) and gravel (37.11 %). For second sampling depth ie. 20-60 cm, a decrease was noted for electro chemical parameters while an increase was recorded for physical properties and were reported as follows: pH (5.09), EC (0.18 dS m^{-1}), BD (1.50 Mg m^{-3}) and gravel (41.04 %).

Part II

Table 12: Physical, chemical and biological characteristics of soil samples collected from rubber plantations of Southern and Central Foot Hills (AEU 12)

Table 12 a: Physical and electro chemical properties of soil samples collected from rubber plantations of AEU 12

Sample No	0-20 cm				20-60 cm			
	pH	EC dS m^{-1}	BD Mg m^{-3}	Gravel %	pH	EC dS m^{-1}	BD Mg m^{-3}	Gravel %
1	5.80	0.44	1.22	35.04	5.18	0.21	1.42	40.07
2	5.70	0.42	1.23	35.89	5.21	0.18	1.43	40.27
3	5.34	0.29	1.23	36.78	4.75	0.14	1.52	41.09
4	5.52	0.47	1.23	37.11	5.07	0.16	1.57	41.56
5	5.67	0.35	1.24	37.87	5.24	0.21	1.58	42.21
Mean	5.61	0.39	1.23	37.11	5.09	0.18	1.50	41.04

Table 12 b: C fractions of soil samples collected from rubber plantations of AEU 12

Sample No	0-20 cm				20-60 cm			
	TOC %	DOC mg kg^{-1}	LC mg kg^{-1}	RC %	TOC %	DOC mg kg^{-1}	LC mg kg^{-1}	RC %
1	6.08	51.97	886.94	1.66	4.31	34.95	579.95	1.15
2	6.05	50.35	885.21	1.61	4.3	34.02	570.22	1.14
3	6.04	50.15	870.22	1.52	4.29	33.85	554.17	1.12
4	5.81	49.82	862.18	1.46	4.25	33.74	534.77	1.1
5	5.66	48.81	849.87	1.44	4.22	32.92	519.9	1.08
Mean	5.93	50.22	870.88	1.54	4.27	33.90	551.80	1.12

Table 12 c: N fractions of soil samples collected from rubber plantations of AEU 12

Sample No	0-20 cm				20-60 cm			
	TN mg kg^{-1}	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}	ON mg kg^{-1}	TN mg kg^{-1}	NH_4-N mg kg^{-1}	NO3-N mg kg^{-1}	ON mg kg^{-1}
1	6463	282.27	80.02	6101	5714	231.47	65.88	5417
2	6012	278.65	79.05	5654	5676	230.52	65.81	5380
3	5969	278.5	78.72	5612	5648	218.22	65.23	5365
4	5882	257.34	78.51	5546	5635	216.32	64.51	5354
5	5846	256.57	78.42	5511	5585	210.44	63.2	5311
Mean	6034	270.67	78.94	5685	5652	221.39	64.93	5365

Table 12 d: P fractions of soil samples collected from rubber plantations of AEU 12

Sample No	0-20 cm			20-60 cm		
	TP mg kg^{-1}	LP mg kg^{-1}	NLP mg kg^{-1}	TP mg kg^{-1}	LP mg kg^{-1}	NLP mg kg^{-1}
1	732.29	64.35	667.94	854.69	92.54	762.15
2	652.74	64.21	588.53	804.09	91.09	713
3	617.32	64.11	553.21	765.95	89.5	676.45
4	614.2	62.99	551.21	752.35	86.79	665.56
5	593.14	62.24	530.9	723.39	83.98	639.41
Mean	641.94	63.58	578.36	780.09	88.78	691.31

Table 12 e: Microbial biomass C and dehydrogenase activity of soil samples collected from rubber plantations of AEU 12

Sample No:	0-20 cm		20-60 cm	
	MBC mg kg^{-1}	DHA µg TPF g^{-1} 24 hr^{-1}	MBC mg kg^{-1}	DHA µg TPF g^{-1} 24 hr^{-1}
1	27.23	35.12	16.67	21.50
2	26.51	33.14	16.41	20.51
3	26.43	35.94	16.92	23.00
4	26.11	34.98	17.08	22.89
5	25.76	34.78	16.35	22.07
Mean	26.41	34.79	16.69	21.99

Table 13: Characteristics of plant biomass collected from rubber plantations of AEU 12

Sample No	Root			Shoot			
	Dry wt g m^{-2}	Lignin %	C %	Dry wt g m^{-2}	Lignin %	C %	RS ratio
1	145	15.2	47.76	644	10.54	46.59	0.23
2	139	14.4	47.5	446	10.41	46.34	0.31
3	127	12.5	47.44	385	10.25	46.25	0.33
4	126	11.2	47.05	385	10.01	45.83	0.33
5	124	10.9	46.23	345	8.94	44.38	0.36
Mean	132	12.84	47.20	441	9.98	45.88	0.311

Table 14: Plant biomass carbon density and nutrient uptake of rubber plantations of AEU 12

Sample No	Biomass C density ($g\ cm^{-3}$)	N uptake ($kg\ ha^{-1}$)	P uptake ($kg\ ha^{-1}$)
1	0.556	88.7	9.9
2	0.561	63.5	6.9
3	0.619	54.5	5.2
4	0.715	53.6	5.1
5	0.695	47.7	4.5
Mean	0.629	61.6	6.3

Table 15: Physical, chemical and biological characteristics of soil samples collected from rubber plantations of Southern High Hills (AEU 14)

Table 15 a: Physical and electro chemical properties of soil samples collected from rubber plantations of AEU 14

Sample No	0-20 cm				20-60 cm			
	pH	EC $dS\ m^{-1}$	BD $Mg\ m^{-3}$	Gravel %	pH	EC $dS\ m^{-1}$	BD $Mg\ m^{-3}$	Gravel %
1	5.75	0.37	1,2	31	5.35	0.12	1.42	38
2	5.30	0.42	1.2	32	4.93	0.14	1.44	40
3	4.80	0.36	1.21	32	4.69	0.17	1.46	40
4	5.20	0.39	1.21	34	4.87	0.14	1.46	40
5	5.78	0.44	1.22	34	5.12	0.16	1.47	40
Mean	5.37	0.40	1.21	32.60	4.99	0.15	1.45	39.60

Table 15 b: C fractions of soil samples collected from rubber plantations of AEU 14

Sample No	0-20 cm				20-60 cm			
	TOC %	DOC $mg\ kg^{-1}$	LC $mg\ kg^{-1}$	RC %	TOC %	DOC $mg\ kg^{-1}$	LC $mg\ kg^{-1}$	RC %
1	7.23	57.6	902.25	1.98	4.86	36.2	650.25	1.26
2	6.96	55.24	901.93	1.95	4.69	36.15	648.91	1.28
3	6.92	55.39	903.28	1.81	4.66	36.09	635.84	1.24
4	6.27	54.27	900.1	1.86	4.6	37.52	620.12	1.27
5	6.21	53.28	899.54	1.74	4.58	35.43	610.77	1.23
Mean	6.72	55.16	901.42	1.87	4.68	36.28	633.18	1.26

Table 15 c: N fractions of soil samples collected from rubber plantations of AEU 14

Sample No	0-20 cm				20-60 cm			
	TN mg kg^{-1}	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}	ON mg kg^{-1}	TN mg kg^{-1}	NH_4-N mg kg^{-1}	NO3-N mg kg^{-1}	ON mg kg^{-1}
1	6874	317.23	86.63	6470	6564	266.21	69.38	6228
2	6412	301.97	86.25	6024	6100	248.95	70.24	5781
3	6407	297.54	84.06	6025	6118	243.52	69.02	5806
4	6212	294.37	82.87	5835	5908	237.35	68.00	5603
5	6087	291	81.69	5714	5782	238.98	67.13	5476
Mean	6398	300.42	84.30	6014	6094	247.00	68.75	5779

Table 15 d: P fractions of soil samples collected from rubber plantations of AEU 14

Sample No	0-20 cm			20-60 cm		
	TP mg kg^{-1}	LP mg kg^{-1}	NLP mg kg^{-1}	TP mg kg^{-1}	LP mg kg^{-1}	NLP mg kg^{-1}
1	1005.77	70.12	935.65	1138.75	101.86	1036.89
2	856.12	69.9	786.22	1010.35	103.64	906.71
3	845.23	67.18	778.05	990.35	101.92	888.43
4	823.45	66.14	757.31	960.7	103.88	856.82
5	814.02	66.11	747.91	955.3	98.85	856.45
Mean	868.92	67.89	801.03	1011.09	102.03	909.06

Table 15 e: Microbial biomass C and dehydrogenase activity of soil samples collected from rubber plantations of AEU 14

Sample No:	0-20 cm		20-60 cm	
	MBC mg kg^{-1}	DHA µg TPF g^{-1} 24 hr^{-1}	MBC mg kg^{-1}	DHA µg TPF g^{-1} 24 hr^{-1}
1	29.96	33.55	21.59	24.18
2	28.08	37.07	20.20	26.67
3	27.74	34.68	19.53	24.41
4	26.75	33.17	18.43	22.85
5	27.35	37.20	18.57	25.26
Mean	27.98	35.13	19.66	24.67

4.2.1.2 Soil C fractions

The different C fractions of soil samples namely total organic carbon (TOC), dissolved organic carbon (DOC), labile carbon (LC) and recalcitrant carbon (RC) at two depths of sampling are outlined in Table 12 b. At 0-20 cm depth of soil sampling, the mean values for different C fractions were as follows: TOC (5.93 %), DOC (50.22 mg kg^{-1}), LC (870.88 mg kg^{-1}) and RC (1.54 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various C fractions compared to surface soil and were reported as follows: TOC (4.27 %), DOC (33.90 mg kg^{-1}), LC (551.80 mg kg^{-1}) and RC (1.12 mg kg^{-1}).

4.2.1.3 Soil N fractions

The different N fractions of soil samples namely total nitrogen (TN), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NH_4-N) and organic nitrogen (ON) at two depths of sampling are outlined in Table 12 c. At 0-20 cm depth of soil sampling, the mean values for different N fractions were as follows: TN (6034 mg kg^{-1}), NH_4-N (270.67 mg kg^{-1}), NO_3 –N (78.94 mg kg^{-1}) and ON (5685 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various N fractions compared to surface soil and were reported as follows: TN (5652 mg kg^{-1}), NH_4-N (221.39 mg kg^{-1}), NO_3 –N (64.93 mg kg^{-1}) and ON (5365 mg kg^{-1}).

4.2.1.4 Soil P fractions

The different P fractions of soil samples namely total phosphorus (TP), labile phosphorus (LP), and non labile phosphorus (NLP) at two depths of sampling are outlined in Table 12 d. At 0-20 cm depth of soil sampling, the mean values for different P fractions were as follows: TP (641.94 mg kg^{-1}), LP (63.58 mg kg^{-1}) and NLP (578.36 mg kg^{-1}). For second sampling depth ie. 20-60 cm, an increase was noted for various P fractions compared to surface soil and were reported as follows: TP (780.09 mg kg^{-1}), LP (88.78 mg kg^{-1}) and NLP (691.31 mg kg^{-1}).

4.2.1.5 Biological parameters

The biological parameters of soil samples, microbial biomass C and dehydrogenase activity at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 12 e. At 0-20 cm depth, MBC and dehydrogenase activity were reported as follows: MBC (26.41 mg kg^{-1}) and DHA (34.79 µg TPF g^{-1} 24 hr^{-1}). At 20-60 cm depth, a decrease in value was noted with mean value of 16.69 mg kg^{-1} and 21.99 µg TPF g^{-1} 24 hr^{-1} for MBC and dehydrogenase activity respectively.

4.2.1.6 Plant biomass

The dry weight, C and lignin content of root and shoot biomass are outlined in Table 13 and the mean values were as follows: Root - dry weight (132 g m^{-2}), lignin (12.84 %) and C (47.20 %); Shoot - dry weight (441 g m^{-2}), lignin (9.98 %), C (45.88 %), and RS ratio (0.31).

4.2.1.7 Plant biomass C density and nutrient uptake

The biomass C density, N and P uptake are presented in Table 14 and the mean values were as follows: biomass C density (0.629 g cm^{-3}), N uptake (61.6 kg ha^{-1}) and P uptake (6.3 kg ha^{-1}).

4.2.2 Soil properties in rubber plantations of Southern High Hills (AEU 14)

The physical, chemical and biological characteristics of soil samples collected from rubber plantations of AEU 14 are presented in Table 15 a. – Table 15 e.

4.2.2.1 Physical and electrochemical parameters

The physical and electro chemical parameters of soil samples, collected from rubber plantations of AEU 14 at two different depths of sampling are depicted in Table 15 a. At 0-20 cm, the average values for various parameters were as follows: pH (5.37), EC (0.40 dS m^{-1}), BD (1.21 Mg m^{-3}) and gravel (32.60 %). For second sampling depth ie. 20-60 cm, a decrease was noted for electrochemical parameters while an increase was recorded for physical properties and were reported as follows: pH (4.99), EC (0.15 dS m^{-1}), BD (1.45 Mg m^{-3}) and gravel (39.60 %).

4.2.2.2 Soil C fractions

The different *C* fractions of soil samples namely total organic carbon (TOC), dissolved organic carbon (DOC), labile carbon (LC) and recalcitrant carbon (RC) at two depths of sampling are outlined in Table 15 b. At 0-20 cm

Table 16: Characteristics of plant biomass collected from rubber plantations of AEU 14

Sample No	Root			Shoot			
	Dry wt g m^{-2}	Lignin %	C %	Dry wt g m^{-2}	Lignin %	C %	RS ratio
1	157	19.1	48.25	545	15.2	46.24	0.289
2	153	16.2	47.01	464	14.1	45.2	0.33
3	148	15.3	46.82	424	12.8	44.87	0.348
4	142	14.2	46.58	424	12.8	44.64	0.335
5	138	14.1	45.64	417	10.8	43.74	0.331
Mean	148	15.78	46.86	455	13.14	44.94	0.327

Table 17: Plant biomass C density and nutrient uptake of rubber plantations of AEU 14

Sample No	Biomass C density (g cm^{-3})	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})
1	0.661	129.8	14.0
2	0.647	114.6	9.3
3	0.618	96.2	8.4
4	0.670	96.2	7.8
5	0.636	90.9	7.5
Mean	0.646	105.5	9.4

Table 18: Physical, chemical and biological characteristics of soil samples collected from cardamom plantations of Kumily High Hills (AEU 16)

Table 18 a: Physical and electro chemical properties of soil samples collected from cardamom plantations of AEU 16

Sample No	0-20 cm				20-60 cm			
	pH	EC dS m^{-1}	BD Mg m^{-3}	Gravel %	pH	EC dS m^{-1}	BD Mg m^{-3}	Gravel %
1	4.95	0.15	0.87	26	4.71	0.12	1.08	32
2	5.39	0.24	0.94	28	4.77	0.19	1.20	32
3	5.42	0.73	0.98	28	5.38	0.49	1.20	34
4	5.47	0.74	0.99	28	5.36	0.28	1.23	34
5	5.47	0.32	1.05	28	4.94	0.15	1.28	34
Mean	5.34	0.44	0.97	28	5.03	0.25	1.20	33

Table 18 b: C fractions of soil samples collected from cardamom plantations of AEU 16

Sample No	0-20 cm				20-60 cm			
	TOC %	DOC mg kg^{-1}	LC mg kg^{-1}	RC %	TOC %	DOC mg kg^{-1}	LC mg kg^{-1}	RC %
1	7.02	47.4	922.5	1.98	4.98	31.44	720	1.23
2	6.39	46.62	920.18	1.95	4.72	31.41	710.23	1.21
3	6.28	46.38	910.79	1.94	4.53	31.2	708.94	1.17
4	6.07	45.91	900.62	1.92	3.67	31.15	694.62	1.16
5	5.92	45.88	900.45	1.81	3.65	30.97	682.04	1.14
Mean	6.34	46.44	910.91	1.92	4.31	31.23	703.17	1.18

Table 18 c: N fractions of soil samples collected from cardamom plantations of AEU 16

Sample No	0-20 cm				20-60 cm			
	TN mg kg^{-1}	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}	ON mg kg^{-1}	TN mg kg^{-1}	NH_4-N mg kg^{-1}	NO3-N mg kg^{-1}	ON mg kg^{-1}
1	7187	366.97	82.58	6737	6880	320.44	64.96	6495
2	6727	353.71	83.44	6290	6418	305.18	64.71	6048
3	6699	350.28	82.22	6267	6413	300.75	63.86	6048
4	6519	350.11	81.2	6088	6218	297.58	63.3	5857
5	6395	341.74	80.33	5973	6093	294.21	62.86	5736
Mean	6705	352.56	81.95	6270	6405	303.63	63.94	6037

Table 18 d: P fractions of soil samples collected from cardamom plantations of AEU 16

Sample No	0-20 cm			20-60 cm		
	TP mg kg^{-1}	LP mg kg^{-1}	NLP mg kg^{-1}	TP mg kg^{-1}	LP mg kg^{-1}	NLP mg kg^{-1}
1	1038.75	80.32	958.43	1159.03	109.89	1049.14
2	910.35	81.46	828.89	1051.88	113.03	938.85
3	890.35	79.54	810.81	1022.77	112.11	910.66
4	860.7	80.92	779.78	985.25	116.49	868.76
5	855.3	77.36	777.94	983.88	107.93	875.95
Mean	911.09	79.92	831.17	1040.56	111.89	928.67

depth of soil sampling, the mean values for different C fractions were as follows: TOC (6.72 %), DOC (55.16 mg kg^{-1}), LC (901.42 mg kg^{-1}) and RC (1.87 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various C fractions compared to surface soil and were reported as follows: TOC (4.68 %), DOC (36.28 mg kg^{-1}), LC (633.18 mg kg^{-1}) and RC (1.26 mg kg^{-1}).

4.2.2.3 Soil N fractions

The different N fractions of soil samples namely total nitrogen (TN), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NH_4-N) and organic nitrogen (ON) at two depths of sampling are outlined in Table 15 c. At 0-20 cm depth of soil sampling, the mean values for different N fractions were as follows: TN (6398 mg kg^{-1}), NH_4-N (300.42 mg kg^{-1}), NO_3 –N (84.30 mg kg^{-1}) and ON (6014 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various N fractions compared to surface soil and were reported as follows: TN (6094 mg kg^{-1}), NH_4-N (247.00 mg kg^{-1}), NO_3 –N (68.75 mg kg^{-1}) and ON (5779 mg kg^{-1}).

4.2.2.4 Soil P fractions

The different P fractions of soil samples namely total phosphorus (TP), labile phosphorus (LP), and non labile phosphorus (NLP) at two depths of sampling are outlined in Table 15 d. At 0-20 cm depth of soil sampling, the mean values for different P fractions were as follows: TP (868.92 mg kg^{-1}), LP (67.89 mg kg^{-1}) and NLP (801.03 mg kg^{-1}). For second sampling depth ie. 20-60 cm, an increase was noted for various P fractions compared to surface soil and were reported as follows: TP (1011.09 mg kg^{-1}), LP (102.03 mg kg^{-1}) and NLP (909.06 mg kg^{-1}).

4.2.2.5 Biological parameters

The biological parameters of soil samples, microbial biomass C and dehydrogenase activity at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 15 e. At 0-20 cm depth, MBC and dehydrogenase activity were reported as follows: MBC (27.98 mg kg^{-1}) and DHA (35.13 µg TPF g^{-1} 24 hr^{-1}). At 20-60 cm depth a decrease in value was noted with mean value of

19.66 mg kg^{-1} and 24.67 µg TPF g^{-1} 24 hr^{-1} for MBC and dehydrogenase activity respectively.

4.2.2.6 Plant biomass

The dry weight, C and lignin content of root and shoot biomass are outlined in Table 16 and the mean values were as follows: Root - dry weight (148 g m^{-2}), lignin (15.78 %), and C (46.86 %); Shoot - dry weight (455 g m^{-2}), lignin (13.14 %), C (44.94 %), and RS ratio (0.33).

4.2.2.7 Plant biomass C density and nutrient uptake

The biomass C density, N and P uptake are presented in Table 17 and the mean values were as follows: biomass C density (0.646 g cm^{-3}), N uptake (105.5 kg ha^{-1}) and P uptake (9.4 kg ha^{-1}).

4.2.3 Soil properties in cardamom plantations of Kumily High Hills (AEU 16)

The physical, chemical and biological characteristics of soil samples collected from cardamom plantations of AEU 16 are presented in Table 18a to 18 e.

4.2.3.1 Physical and electrochemical parameters

The physical and electro chemical parameters of soil samples, collected from cardamom plantations of AEU 16 at two different depths of sampling are depicted in Table 18 a. At 0-20 cm, the average values for various parameters were as follows: pH (5.34), EC (0.44 dS m^{-1}), BD (0.97 Mg m^{-3}) and gravel (28 %). For second sampling depth ie. 20-60 cm, a decrease was noted for electrochemical parameters while an increase was recorded for physical properties and were reported as follows: pH (5.03), EC (0.25 dS m^{-1}), BD (1.20 Mg m^{-3}) and gravel (33 %).

4.2.3.2 Soil C fractions

The different C fractions of soil samples namely total organic carbon (TOC), dissolved organic carbon (DOC), labile carbon (LC) and recalcitrant carbon (RC) at two depths of sampling are outlined in Table 18 b. At 0-20 cm depth of soil sampling, the mean values for different C fractions were as follows: TOC (6.34 %), DOC (46.44 mg kg^{-1}), LC (910.91 mg kg^{-1}) and RC (1.92 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for

Table 18 e: Microbial biomass C and dehydrogenase activity of soil samples collected from cardamom plantations of AEU 16

Sample No:	0-20 cm		20-60 cm	
	MBC mg kg^{-1}	DHA µg TPF g^{-1} 24 hr^{-1}	MBC mg kg^{-1}	DHA µg TPF g^{-1} 24 hr^{-1}
1	30.63	34.30	23.90	26.77
2	28.65	37.82	22.11	29.19
3	27.66	34.58	21.77	27.22
4	26.76	33.18	20.64	25.60
5	27.69	37.66	20.74	28.20
Mean	28.28	35.51	21.83	27.40

Table 19: Characteristics of plant biomass collected from cardamom plantations of AEU 16

Sample No	Root			Shoot			
	Dry wt g m^{-2}	Lignin %	C %	Dry wt g m^{-2}	Lignin %	C %	RS ratio
1	1790	12.21	49.04	2250	10.22	46.78	0.8
2	1302	11.18	46.53	1939	10.08	45.11	0.67
3	1254	10.8	46.23	1722	9.92	44.87	0.73
4	1188	10.24	45.98	1293	9.24	44.79	0.92
5	1032	10.58	45.9	1350	8.96	44.38	0.76
Mean	1313	11.00	46.53	1711	9.68	45.19	0.71

Table 20: Plant biomass C density and nutrient uptake of cardamom plantations of AEU 16

Sample No	Biomass C density (g cm^{-3})	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})
1	0.889	441.3	49.4
2	0.865	352.5	35.0
3	0.866	315.8	30.2
4	0.832	243.3	23.6
5	0.828	234.5	21.8
Mean	0.856	317.5	32.0

Table 21 : General information on selected land use systems of different AEUs under study

Parameters	AEU 12	AEU 14	AEU 16
Depth of water table (mbgl)	10.7 - 18.2	10.25 - 12.4	7.9 - 8.5
Soil temperature (^{O}C)	28.6 - 31.2	28.2 - 30.7	27.5 - 29.4
Slope (%)	3 - 5	5 - 10	10 - 15
Weather	Hot sunny day	Hot sunny day	Rainy day
Previous Land Use	Rubber plantation	Rubber plantation	Cardamom plantation

various C fractions compared to surface soil and were reported as follows: TOC (4.31 %), DOC (31.23 mg kg^{-1}), LC (703.17 mg kg^{-1}) and RC (1.18 mg kg^{-1}).

4.2.3.3 Soil N fractions

The different N fractions of soil samples namely total nitrogen (TN), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NH_4-N) and organic nitrogen (ON) at two depths of sampling are outlined in Table 18 c. At 0-20 cm depth of soil sampling, the mean values for different N fractions were as follows: TN (6705 mg kg^{-1}), NH_4-N (352.56 mg kg^{-1}), NO_3 –N (81.95 mg kg^{-1}) and ON (6270 mg kg^{-1}). For second sampling depth ie. 20-60 cm, a decrease was noted for various N fractions compared to surface soil and were reported as follows: TN (6405 mg kg^{-1}), NH_4-N (303.63 mg kg^{-1}), NO_3 –N (63.94 mg kg^{-1}) and ON (6037 mg kg^{-1}).

4.2.3.4 Soil P fractions

The different P fractions of soil samples namely total phosphorus (TP), labile phosphorus (LP), and non labile phosphorus (NLP) at two depths of sampling are outlined in Table 18 d. At 0-20 cm depth of soil sampling, the mean values for different P fractions were as follows: TP (911.09 mg kg^{-1}), LP (79.92 mg kg^{-1}) and NLP (831.17 mg kg^{-1}). For second sampling depth ie. 20-60 cm, an increase was noted for various P fractions compared to surface soil and were reported as follows: TP (1040.56 mg kg^{-1}), LP (111.89 mg kg^{-1}) and NLP (928.67 mg kg^{-1}).

4.2.3.5 Biological parameters

The biological parameters of soil samples, microbial biomass C and dehydrogenase activity at two different depths of sampling, 0-20 cm and 20-60 cm are depicted in Table 18 e. At 0-20 cm depth, MBC and dehydrogenase activity were reported as follows: MBC (28.28 mg kg^{-1}) and DHA (35.51 µg TPF g^{-1} 24 hr^{-1}). At 20-60 cm depth a decrease in value was noted with mean value of 21.83 mg kg^{-1} and 27.40 µg TPF g^{-1} 24 hr^{-1} for MBC and dehydrogenase activity respectively.

4.2.3.6 Plant biomass

The dry weight, C and lignin content of root and shoot biomass are outlined in Table 19 and the mean values were as follows: Root - dry weight (1313 g m^{-2}), lignin (11.00 %), and C (46.53 %); Shoot - dry weight (1711 g m^{-2}), lignin (9.68 %), C (45.19 %), and RS ratio (0.71).

4.2.2.7 Plant biomass C density and nutrient uptake

The biomass C density, N and P uptake are presented in Table 20 and the mean values were as follows: biomass C density (0.856 g cm^{-3}), N uptake (317.5 kg ha^{-1}) and P uptake (32.0 kg ha^{-1}).

4.2.4 General information on AEUs

The information on hydrology, weather, previous land use and slope of the area were also collected to find out their influence on biomass production and soil C pools and are outlined in Table 16. The basic information on AEU 12 were detailed as follows: depth of water level (10.7 -18.2 mbgl), soil temperature (28.6 - 31.2 ^{o}C), slope (3 - 5 %), weather (hot sunny day) and previous land use (rubber plantation). The basic information on AEU 14 were detailed as follows: depth of water level (10.25 -12.4 mbgl), soil temperature (28.2 - 30.7 ^{o}C), slope (5 - 10 %), weather (hot sunny day) and previous land use (rubber plantation). The basic information on AEU 16 were detailed as follows: depth of water level (7.9 – 8.5 mbgl), soil temperature (27.5 – 29.4 ^{o}C), slope (10 -15 %), weather (rainy day) and previous land use (cardamom plantation).

4.3 PART III. FIELD EXPERIMENTS TO STUDY THE EFFECT OF TILLAGE AND NUTRIENT MANAGEMENT ON THE LINK BETWEEN ROOT AND SHOOT BIOMASS C, AND SOC AND NP POOLS

Field experiments on grain cowpea- fodder maize cropping sequence was carried out during January 2020 to September 2020 by raising grain cowpea followed by fodder maize with an interval of three months. In the field trial the effect of tillage and nutrient management on various soil properties and growth and yield of grain cowpea and fodder maize was studied using thermochemical fortified organic fertilizer as the organic source for nutrition. The results of the experiments are detailed below.

4.3.1.1 Initial soil properties of experimental field

The soil sample was analyzed for its various physical, chemical and biological properties at two different sampling depths before the commencement of field experiment and the results are outlined in Table 22. The soil was moderately acidic and high in organic carbon content. At 0-20 cm depth of soil, the results were as follows; BD (1.37 Mg m^{-3}), WSA (58.32 %), pH (5.09), EC (0.16 dS m^{-1}), TOC (2.7 %), LC (460.92 mg kg^{-1}), DOC (40.25 mg kg^{-1}), RC (0.67 mg kg^{-1}), TN (5492 mg kg^{-1}), NH_4-N (225.90 mg kg^{-1}), NO_3 –N (71.25 mg kg^{-1}), ON (5195 mg kg^{-1}), TP (382.14 mg kg^{-1}), LP (16.59 mg kg^{-1}), NLP (365.85 mg kg^{-1}), dehydrogenase activity (20.22 µg TPF g^{-1} 24 hr^{-1}) and MBC (14.04 mg kg^{-1}).

At 20-60 cm depth of soil, the results were as follows; BD (1.54 Mg m^{-3}), WSA (65.28 %), pH (4.76), EC (0.14 dS m^{-1}), TOC (2.2 %), LC (386.29 mg kg^{-1}), DOC (32.35 mg kg^{-1}), RC (0.43 mg kg^{-1}), TN (5172 mg kg^{-1}), NH_4-N (186.49 mg kg^{-1}), NO_3 –N (62.15 mg kg^{-1}), ON (4923 mg kg^{-1}), TP (418.77 mg kg^{-1}), LP (20.21 mg kg^{-1}), NLP (398.68 mg kg^{-1}), dehydrogenase activity (15.87 µg TPF g^{-1} 24 hr^{-1}) and MBC (10.18 mg kg^{-1}).

A decrease was noted for pH, EC, and various fractions of carbon and nitrogen in the subsoil compared to surface soil while an increase was observed for bulk density, water stable aggregate percentage and fractions of P in subsoil. Dehydrogenase activity was also lower in subsoil.

4.3.1.2 Preparation and characterization of thermochemical fortified organic fertilizer – TOF-F

The themochemical fortified organic fertilizer was prepared as per the patented technology (Patent No. 321857) developed by Sudaharmaidevi *et al.* (2017) and analyzed for its various physical, chemical and biological properties. As depicted in Table 23, TOF-F had dark brown to black color and was odorless with a free flowing texture. The pH of the organic manure was near to neutral range (6.98) and had a safe EC of 0.657 dS m^{-1}. The carbon, nitrogen and phosphorus fractions of TOF-F were recorded as - TOC (40.5 %), labile C (1820 mg kg^{-1}), DOC (traces), NH_4-N (0.05 %), NO_3-N (0.22 %), organic N (1.94 %), total N (2.21 %), labile P (0.32 %), non labile P (0.53 %), and total P (0.85 %). The cellulose, hemicellulose and lignin content of 20.22 %, 11.28 % and 15.72 % respectively were recorded by TOF-F. A C:N ratio of 18.32, CP ratio of 52 and dehydrogenase activity of 339.25 µg TPF g^{-1} 24 hr^{-1} was noted for fortified TOF.

4.3.2 Growth, yield and quality parameters

4.3.2.1 Grain cowpea

The influence of tillage and nutrient management practices on growth, yield and quality parameters of grain cowpea are outlined in Table 24 to Table 32.

4.3.2.1.1 Plant height

The plant height of grain cowpea differed significantly for tillage and nutrient management practices (Table 24). Among various nutrient management, treatment s_5 (1.83 m) recorded highest value for plant height followed by s_4 (1.76 m) and lowest value was for s_7 (1.33 m). At different tillage levels m_3 (1.89 m) was found to be superior for plant height followed by m_1 (1.68 m). The interaction effect between tillage and nutrient management was found to be significant and the highest interaction was observed for m_3s_5 (2.21 m) followed by m_3s_4 (2.15 m) which was on par with m_3s_6 (2.13 m).

4.3.2.1.2 Number of primary branches

The number of primary branches was more for the nutrient management, s_6 trailed by s_4 which was on par with s_5 (Table 24). Among the tillage levels no till had more primary branches and the interaction effect also remained statistically significant. The treatment combination m_3s_6 remained superior and was on par with m_3s_5 and statistically different to all other combinations.

Part III

Table 22. Initial soil properties of experimental field at different depths of sampling

Parameter	0-20 cm	20-60 cm
BD (Mg m^{-3})	1.37	1.54
Water stable aggregates (%)	58.32	65.28
pH	5.09	4.76
EC (dS m^{-1})	0.16	0.14
TOC (%)	2.7	2.2
Labile C (mg kg^{-1})	460.92	386.29
DOC (mg kg^{-1})	40.25	32.35
RC (%)	0.67	0.43
Total N (mg kg^{-1})	5492	5172
NH_4-N (mg kg^{-1})	225.90	186.49
NO_3 -N (mg kg^{-1})	71.25	62.15
Organic N (mg kg^{-1})	5195	4923
Total P (mg kg^{-1})	382.14	418.77
Labile P (mg kg^{-1})	16.59	20.21
Non labile P (mg kg^{-1})	365.85	398.68
Dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1})	20.22	15.87
Microbial Biomass C (mg kg^{-1})	14.04	10.18

Table 23. Physical, chemical and biological characteristics of fortified thermochemical organic fertilizer (TOF-F)

Parameter	Value
Color	Dark brown to Black
Odor	Odorless
Bulk density (Mg m^{-3})	0.95
pH	6.98
EC (dS m^{-1})	0.657
TOC (%)	40.5
Labile C (mg kg^{-1})	1820
DOC (mg kg^{-1})	1420
RC (%)	30.25
NH_4-N (%)	0.05
NO_3 -N (%)	0.22
Organic N (%)	1.94
Total N (%)	2.21
Cellulose (%)	20.22
Hemicellulose (%)	11.28
Lignin (%)	15.72
CN ratio	18.32
Labile P (%)	0.32
Non labile P (%)	0.53
Total P (%)	0.85
CP ratio	52
Dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1})	339.25

Table 24. Effect of tillage and nutrient management on growth characteristics of grain cowpea

Plant height (m)					No of primary branches			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.85	1.26	1.81	1.64^{d}	4.00	3.67	3.67	3.78^{d}
s_2	1.58	1.16	1.72	1.49^{f}	3.67	4.67	3.67	4.00^{cd}
s_3	1.77	1.23	1.63	1.54^{e}	3.67	4.00	4.67	4.11^{c}
s_4	1.73	1.41	2.15	1.76^{b}	4.67	4.67	4.67	4.67^{b}
s_5	1.79	1.48	2.21	1.83^{a}	3.67	4.67	5.33	4.56^{b}
s_6	1.64	1.39	2.13	1.72^{c}	4.67	4.67	5.67	5.00^{a}
s_7	1.39	1.04	1.58	1.33^{g}	4.00	3.00	3.00	3.33^{e}
Mean	1.68^{b}	1.28^{c}	1.89^{a}		4.05^{c}	4.19^{b}	4.38^{a}	
SEm±	m 0.02		s 0.01	m x s 0.02	m 0.03	s 0.10		m x s 0.17
CD (0.05)	m 0.06		s 0.03	m x s 0.05	m 0.11	s 0.27		m x s 0.47

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 25. Effect of tillage and nutrient management on shoot biomass production by grain cowpea

Fresh weight (g plant^{-1})					Dry weight (g plant^{-1})			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	122.55	111.60	157.67	130.61^{c}	37.99	34.60	48.88	40.49^{c}
s_2	117.18	107.38	146.01	123.52^{e}	36.33	33.29	45.26	38.29^{e}
s_3	115.42	114.00	150.70	126.71^{d}	35.78	35.34	46.72	39.28^{d}
s_4	158.67	145.08	168.05	157.27^{b}	49.19	44.97	52.10	48.75^{b}
s_5	173.90	164.35	175.43	171.23^{a}	53.91	50.95	54.38	53.08^{a}
s_6	158.92	140.85	174.21	158.00^{b}	49.27	43.66	54.01	48.98^{b}
s_7	113.34	111.31	122.32	115.66^{f}	35.14	34.51	37.92	35.85^{f}
Mean	137.14^{b}	127.80^{c}	156.34^{a}		42.51^{b}	39.62^{c}	48.47^{a}	
SEm±	m 0.96		s 1.00	m x s 1.74	m 0.91	s 0.82		m x s 1.41
CD (0.05)	m 3.78		s 2.87	m x s 4.98	m 3.51	s 2.24		m x s 3.87

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 26. Effect of tillage and nutrient management on root characteristics of grain cowpea

No of active nodules					Root volume (cm^3)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	32.33	31.33	38.33	34.00^d	5.67	4.33	6.33	5.44^e
s_2	29.00	29.00	32.33	30.1^e	4.67	4.33	5.33	4.78^f
s_3	24.00	22.67	26.33	24.33^f	6.33	5.67	6.67	6.22^d
s_4	43.00	28.00	46.33	39.11^c	7.67	7.33	8.33	7.78^c
s_5	45.33	32.33	66.67	48.11^b	10.00	9.33	10.33	9.89^b
s_6	45.67	32.67	74.00	50.78^a	12.00	11.00	13.67	12.22^a
s_7	15.00	13.00	16.67	14.89g	4.67	3.67	4.67	4.33^g
Mean	33.48^b	27.00^a	42.95^a		7.29^b	6.52^c	7.91^a	
SEm±	m 0.44		s 0.43	m x s 0.74	m 0.07	s 0.13	m x s 0.23	
CD (0.05)	m 1.72		s 1.22	m x s 2.12	m 0.26	s 0.37	m x s 0.65	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 27. Effect of tillage and nutrient management on root biomass production by grain cowpea

Fresh weight (g $plant^{-1}$)					Dry weight (g $plant^{-1}$)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	20.90	17.10	21.08	19.69^d	14.42	11.80	14.55	13.59^d
s_2	13.02	11.83	17.67	14.17^e	8.98	8.16	12.19	9.78^e
s_3	12.93	12.35	14.61	13.30^f	8.92	8.52	10.08	9.17^f
s_4	22.40	21.39	23.75	22.51^b	15.46	14.76	16.39	15.53^b
s_5	20.68	18.47	25.85	21.67^c	14.27	12.74	17.84	14.95^c
s_6	24.66	24.09	26.87	25.21^a	17.02	16.62	18.54	17.39^a
s_7	11.24	9.43	13.90	11.52^g	7.76	6.51	9.59	7.95^g
Mean	17.98^b	16.38^c	20.53^a		12.40^b	11.30^c	14.17^a	
SEm±	m 0.96		s 1.00	m x s 1.74	m 0.94	s 0.82	m x s 1.29	
CD (0.05)	m 3.78		s 2.87	m x s 4.98	m 2.61	s 2.01	m x s 3.57	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.2.1.3 Fresh weight and dry weight of shoot

The highest fresh weight of shoot was recorded by s_5 (171.23 g) trailed by s_6 (158.00 g) which was on par with s_4 (157.27 g) for sub plot and m_3 (156.34 g) followed by m_1 (137.14 g) for main plot treatments respectively. The interaction effects were statistically significant and m_3s_5 (175.43 g) had highest interaction which was on par with m_3s_6 (174.21 g). Similarly for dry weight of shoot, highest value was recorded by s_5 (53.08 g) trailed by s_6 (48.98 g) which was on par with s_4 (48.75 g) for sub plot treatments and m_3 (48.47 g) followed by m_1 (42.51 g) for main plot treatments respectively. The interaction effects were statistically significant and m_3s_5 (54.38 g) had highest interaction which was on par with m_3s_6 (54.01 g) (Table 25).

4.3.2.1.4 Number of active nodules

The subplot treatment s_6 had more number of active nodules followed by s_5 and the lowest number was recorded by s_7. No till was found to be superior and significantly different from other tillage levels. A significant difference was noted for interaction effects and m_3s_6 combination had the highest effect (Table 26).

4.3.2.1.5 Root volume

The sub plot treatments, main plot treatment and their interaction effects were significantly different for root volume. Among sub plot treatment s_6 (12.22 cm^{-3}) recorded highest root volume followed by s_5 (9.89 cm^{-3}) and for main plot treatments, m_3 (7.91 cm^{-3}) had higher root volumes followed by m_1 (7.29 cm^{-3}). The interaction effect of m_3s_6 (13.36 cm^{-3}) remained superior and statistically different to all other treatment combinations (Table 26).

4.3.2.1.6 Fresh weight and dry weight of root

For fresh weight of root, s_6 (25.21 g) had highest value followed by s_4 (22.51 g) and the lowest value was for s_7 (11.52 g) and no till (20.53 g) was found to be superior and significantly different to other tillage levels. The interaction effect of m_3s_6 (26.87 g) remained superior and statistically different to all other treatment combinations. Similarly for dry weight of root, s_6 (17.39 g) had highest value followed by s_4 (15.53 g) and the lowest value was for s_7 (7.95 g) and no till (14.17 g) was found to be superior and significantly different to other tillage levels. The interaction effect of m_3s_6 (18.54 g) remained superior and statistically different to all other treatment combinations (Table 27).

4.3.2.1.7 Days to 50 per cent flowering

Among the different nutrient management, s_7 had more number of days to 50 per cent flowering followed by s_2 and s_3 and lowest value was for treatment s_4. At different tillage levels, conventional tillage (m_1) recorded more number of days to 50 per cent flowering which was on par with no till (m_3) treatment. The interaction effects were found to be significant and m_2s_7 and m_3s_4 recorded highest and lowest interaction effects respectively (Table 28).

4.3.2.1.8 Number of pods plant^{-1}

Higher number of pods plant^{-1} was observed for s_5 followed by s_4 and s_6 and the lowest number was for s_7. Among the tillage effects, m_3 was found to be superior and was on par with m_1. The treatment combinations m_3s_5 and m_1s_5 had higher values for interaction effects and were significantly different to all others (Table 28).

4.3.2.1.9 Length of pod

The length of pod varied among the treatments significantly, s_3 (16.97 cm) recorded highest value followed by s_5 (16.78 cm) which was on par with s_4 (16.63 cm). The tillage m_2 (16.68 cm) remained superior and significantly different to others and among interaction effects m_2s_3 (18.24 cm) had highest value which was on par with m_2s_4 and m_2s_6 (Plate 9).

4.3.2.1.10 Dry weight of pod

Significant difference was noted among treatments, for sub plot treatments s_4 (2.39 g) recorded highest value trailed by s_1 (2.31 g) and for main plot treatment m_3 (2.34 g) had highest value followed by m_1 (2.01 g). The interaction effects

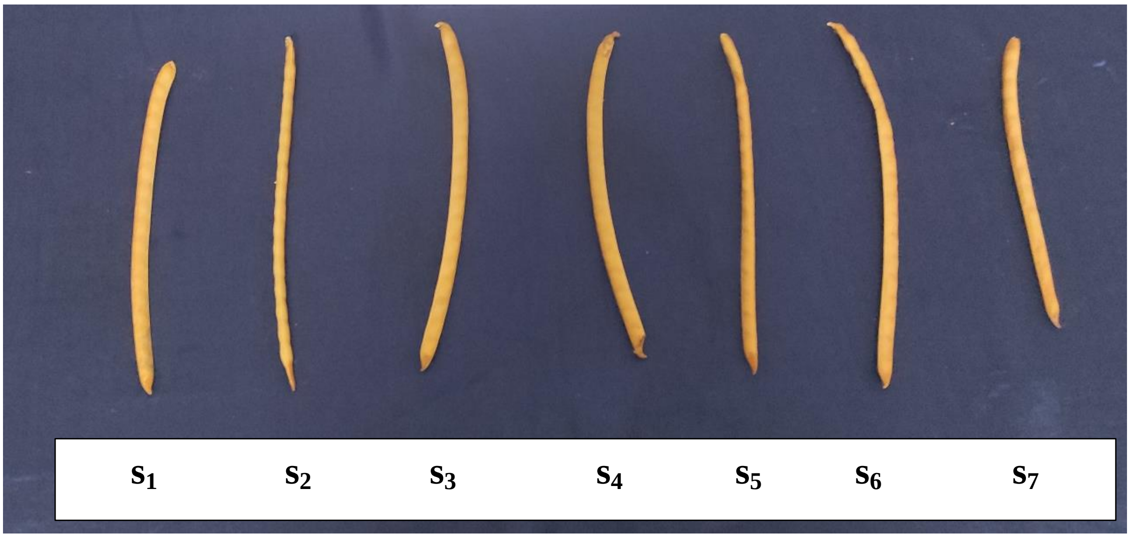


Plate 9. Effect of nutrient management on pod characteristics of grain cowpea under no till condition

Table 28. Effect of tillage and nutrient management on days to 50% flowering and no of cowpea pods plant^{-1}

	Days to 50% flowering				No of pods plant^{-1}			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	30.33	27.00	29.33	28.89^{c}	40.67	41.33	35.67	39.22^{d}
s_2	30.67	28.00	30.67	29.78^{b}	37.00	33.67	45.67	38.78^{d}
s_3	29.67	30.33	29.33	29.78^{b}	32.33	30.33	34.67	32.44^{e}
s_4	28.00	28.00	27.33	27.78^{d}	48.67	53.00	49.33	50.33^{b}
s_5	29.00	28.67	28.67	28.78^{c}	56.33	53.67	56.33	55.44^{a}
s_6	27.33	28.00	28.00	27.7^{d}	50.33	43.67	49.00	47.67^{c}
s_7	32.67	33.00	32.67	32.78^{a}	29.67	28.33	26.00	28.00^{f}
Mean	29.67^{a}	29.00^{b}	29.43^{ab}		42.14^{a}	40.57^{b}	42.38^{a}	
SEm±	m 0.12		s 0.19	m x s 0.33	m 0.15	s 0.37	m x s 0.63	
CD (0.05)	m 0.47		s 0.55	m x s 0.96	m 0.59	s 1.05	m x s 1.81	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 29. Effect of tillage and nutrient management on length and dry weight of pods

	Length (cm)				Dry weight (g)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	16.05	16.38	16.32	16.25^{d}	2.17	2.14	2.63	2.31^{b}
s_2	16.93	15.74	16.92	16.53^{bc}	2.11	2.04	2.60	2.25^{c}
s_3	15.51	18.24	17.17	16.97^{a}	2.04	1.99	2.02	2.02^{e}
s_4	15.96	17.95	15.99	16.63^{bc}	2.21	2.13	2.84	2.39^{a}
s_5	17.02	16.53	16.80	16.78^{ab}	2.28	2.07	2.29	2.21^{c}
s_6	16.44	17.79	15.29	16.51^{cd}	2.01	2.01	2.21	2.08^{d}
s_7	15.46	14.15	14.83	14.81^{e}	1.28	1.57	1.80	1.55^{f}
Mean	16.20^{b}	16.68^{a}	16.19^{b}		2.01^{b}	1.99^{b}	2.34^{a}	
SEm±	m 0.06		s 0.10	m x s 0.16	m 0.10	s 0.14	m x s 0.25	
CD (0.05)	m 0.24		s 0.27	m x s 0.47	m 0.37	s 0.41	m x s 0.71	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 30. Effect of tillage and nutrient management on no of seeds pod^{-1} and 100 seed weight of grain cowpea

	No of seeds pod^{-1}				100 seed weight (g)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	14.00	13.33	15.33	14.22^b	11.30	9.90	11.37	10.86^c
s_2	14.00	13.67	15.00	14.22^b	11.72	9.19	11.91	10.94^{bc}
s_3	15.67	15.33	14.33	15.11^a	10.90	9.60	11.96	10.82^c
s_4	13.00	13.00	15.33	13.78^c	11.29	9.30	13.34	11.31^a
s_5	14.33	15.67	15.67	15.22^a	11.47	10.06	11.64	11.06^b
s_6	15.33	14.00	16.67	15.33^a	11.33	9.45	12.05	10.94^{bc}
s_7	13.00	11.33	15.00	13.11^d	9.08	8.30	9.27	8.88^d
Mean	14.19^b	13.76^c	15.33^a		11.01^b	9.40^c	11.65^a	
SEm±	m 0.10		s 0.14	m x s 0.25	m 0.07	s 0.07	m x s 0.12	
CD (0.05)	m 0.37		s 0.41	m x s 0.71	m 0.26	s 0.20	m x s 0.34	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 31. Effect of tillage and nutrient management on grain yield plant^{-1} and total dry matter production plant^{-1}

	Grain yield plant^{-1}(g)				Total dry matter production plant^{-1} (g)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	72.92	68.31	75.36	72.20^d	131.29	127.06	147.44	135.26^d
s_2	70.31	51.01	93.33	71.55^d	117.13	104.45	167.85	129.81^e
s_3	64.83	49.13	72.74	62.23^e	104.45	98.26	119.62	107.44^e
s_4	82.22	74.22	122.41	92.95^c	161.88	162.83	197.64	174.12^c
s_5	103.21	99.23	120.64	107.70^a	186.81	165.94	189.38	180.71^a
s_6	105.89	66.64	114.93	95.82^b	156.23	137.26	168.62	154.01^b
s_7	40.71	29.88	41.51	37.37^f	75.35	80.70	87.67	81.24^f
Mean	77.16^b	62.63^c	91.56^a		133.31^b	125.21^c	154.03^a	
SEm±	m 0.76		s 0.84	m x s 1.46	m 0.33	s 0.35	m x s 0.60	
CD (0.05)	m 2.97		s 2.42	m x s 4.20	m 1.28	s 1.00	m x s 1.73	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

were significant and m_3s_4 (2.84 g) was found to be superior and statistically different to all other combinations (Table 29).

4.3.2.1.11 Number of seeds pod^{-1}

As depicted in Table 30. more number of seeds pod^{-1} was recorded by nutrient management s_6 which was on par with s_5 and s_3 and the lowest value was for s_7. Among the tillage levels m_3 had more number of seeds pod^{-1} followed by m_1. The interaction effects were found to be significant and the highest value was for m_3-s_6 combination trailed by m_3s_5.

4.3.2.1.12 100 Seed weight

The 100 seed weight remained significant among various treatments, for nutrient management s_4 (11.31 g) recorded highest value followed by s_5 (11.06 g) and between tillage levels m_3 (11.65 g) was found to be superior. The interaction effects were also significant and m_3s_4 (11.01 g) recorded highest value (Table 31).

4.3.2.1.13 Grain yield plant^{-1}

The effect of nutrient management, tillage levels and their interactions were found to be significant. For nutrient management s_5 (107.70 g) recorded highest value followed by s_6 (95.82 g) and among tillage levels m_3 (91.56 g) was found to be superior. A higher interaction effect was observed for m_3s_4 (122.41 g) combination which was on par with m_3s_5 (120.64 g) and significantly different to all other combinations (Table 31).

4.3.2.1.14 Total dry matter production plant^{-1}

As depicted in Table 31. more total dry matter production plant^{-1} was recorded by nutrient management s_5 (180.71 g) followed by s_6 (154.01 g) and the lowest value was for s_7. Among the tillage levels m_3 (154.03 g) had more dry matter plant^{-1} followed by m_1. The interaction effects were found to be significant and the highest value was for m_3s_5 which was on par with m_3s_6.

4.3.2.1.15 Crude protein

The effect of nutrient management, tillage and their interactions were found to be significant for crude protein content in grain cowpea. As depicted in Table 32, highest value was recorded by s_5 (13.63 %) followed by s_4 (13.20 %), m_3 (12.86 %) trailed by m_1 (12.47 %) and m_3s_5 (14.05 %) followed by m_1s_5 (13.63 %) among nutrient management, tillage levels and their interaction effects respectively.

4.3.2.2 Fodder maize

4.3.2.2.1 Fodder maize grown in total cowpea residue incorporated soil

The influence of tillage and nutrient management practices on growth, yield and quality parameters of fodder maize grown in total cowpea residue incorporated soil are outlined in Table 33 to Table 36.

4.3.2.2.1.1 Plant height

The plant height differed significantly for tillage and nutrient management practices (Table 33). Among various nutrient management, s_4 (2.74 m) recorded highest value which was on par with s_5 (2.71 m) and lowest value was for s_7 (2.34 m). At different tillage levels m_3 (2.68 m) was found to be superior followed by m_1 (2.61 m). The interaction effects between tillage and nutrient management were found to be significant and highest interaction was observed for m_3s_5 (2.88 m) which was on par with m_3s_4 (2.83 m).

4.3.2.2.1.2 Fresh weight of shoot

The highest fresh weight of shoot was recorded by s_5 (200 g) trailed by s_6 (195.84 g) which was on par with s_4 (195.45 g) for sub plot treatments and m_3 (189.69 g) followed by m_1 (185.45 g) for main plot treatments respectively. The interaction effects were statistically significant and m_3s_6 (211.28 g) combination had highest interaction which was on par with m_3s_5 (207.75 g) (Table 33).

Table 32. Effect of tillage and nutrient management on crude protein content (%)

Crude protein (%)				
Treatments	m_1	m_2	m_3	Mean
s_1	12.73	12.10	12.81	12.55[c]
s_2	12.02	11.65	12.58	12.09[d]
s_3	11.79	11.77	12.23	11.93[e]
s_4	13.17	12.89	13.54	13.20[b]
s_5	13.63	13.21	14.05	13.63[a]
s_6	12.44	12.34	13.21	12.66[c]
s_7	11.50	11.37	11.59	11.49[f]
Mean	12.47[b]	12.19[c]	12.86[a]	
SEm±	m 0.037		s 0.053	m x s 0.092
CD (0.05)	m 0.146		s 0.152	m x s 0.263

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 33. Effect of tillage and nutrient management on growth characteristics of succeeding fodder maize grown in total cowpea residue incorporated soil

Plant height (m)					Fresh weight of shoot (g)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	2.70	2.55	2.72	2.66[bc]	183.35	171.90	180.58	178.61[c]
s_2	2.66	2.42	2.69	2.59[d]	176.61	171.44	178.56	175.54[d]
s_3	2.50	2.44	2.56	2.50[e]	177.00	181.12	178.10	178.74[c]
s_4	2.77	2.64	2.83	2.74[a]	196.75	189.72	195.45	193.97[b]
s_5	2.67	2.59	2.88	2.71[ab]	199.28	192.98	207.75	200.00[a]
s_6	2.62	2.58	2.72	2.64[cd]	189.97	186.26	211.28	195.84[b]
s_7	2.34	2.31	2.36	2.34[f]	175.16	175.36	176.07	175.53[d]
Mean	2.61[b]	2.50[c]	2.68[a]		185.45[b]	181.25[c]	189.69[a]	
SEm±	m 0.02		s 0.02	m x s 0.04	m 0.70		s 1.07	m x s 1.85
CD (0.05)	m 0.07		s 0.06	m x s 0.11	m 2.74		s 3.07	m x s 5.31

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 34. Effect of tillage and nutrient management on root characteristics of succeeding fodder maize grown in total cowpea residue incorporated soil

	Root volume (cm^{-3})				Fresh weight of root (g)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	41.80	35.10	44.00	40.30^{d}	52.25	34.20	61.42	49.29^{d}
s_2	32.55	34.58	35.34	34.16^{e}	34.41	31.12	45.57	37.03^{f}
s_3	30.47	35.15	31.97	32.53^{f}	48.94	34.20	57.54	46.89^{e}
s_4	44.80	40.92	46.58	44.10^{b}	55.07	36.74	63.93	51.91^{c}
s_5	49.82	50.78	53.55	51.39^{a}	60.16	54.48	79.41	64.68^{b}
s_6	40.19	38.92	44.48	41.20^{c}	69.41	62.09	83.40	71.63^{a}
s_7	29.97	28.30	32.43	30.24^{g}	32.78	31.13	37.99	33.97^{g}
Mean	38.51^{b}	37.68^{c}	41.19^{a}		50.43^{b}	40.56^{c}	61.32^{a}	
SEm±	m 0.19		s 0.30	m x s 0.52	m 0.55	s 0.48		m x s 0.84
CD (0.05)	m 0.75		s 0.87	m x s 1.50	m 2.17	s 1.39		m x s 2.40

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 35. Effect of tillage and nutrient management on fodder yield (t ha^{-1}) of succeeding maize crop grown in total cowpea residue incorporated soil

	Fresh weight				Dry weight			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	40.34	37.82	39.73	39.30^{c}	8.07	7.56	7.95	7.86^{c}
s_2	38.85	37.72	39.28	38.62^{d}	7.77	7.54	7.86	7.72^{d}
s_3	38.94	39.84	39.18	39.32^{c}	7.79	7.97	7.84	7.86^{c}
s_4	43.28	41.74	43.00	42.67^{b}	8.66	8.35	8.60	8.54^{b}
s_5	43.84	42.45	45.71	44.00^{a}	8.77	8.49	9.14	8.80^{a}
s_6	41.79	40.98	46.48	43.08^{b}	8.36	8.19	9.30	8.62^{b}
s_7	38.53	38.58	38.73	38.62^{d}	7.71	7.72	7.75	7.72^{d}
Mean	40.80^{b}	39.88^{c}	41.73^{a}		8.16^{b}	7.98^{c}	8.35^{a}	
SEm±	m 0.15		s 0.24	m x s 0.41	m 0.03		s 0.05	m x s 0.08
CD (0.05)	m 0.60		s 0.67	m x s 1.17	m 0.12		s 0.13	m x s 0.23

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.2.2.1.3 Root volume

The sub plot treatment, main plot treatment and their interaction effects were significantly different for root volume. For sub plot treatment, s_5 (51.39 cm^{-3}) recorded highest root volume followed by s_4 (44.10 cm^{-3}) and the main plot treatment, m_3 (41.19 cm^{-3}) had higher root volume followed by m_1 (38.51 cm^{-3}). The interaction effect of m_3s_5 (53.55 cm^{-3}) remained superior and statistically different to all other treatment combinations (Table 34).

4.3.2.2.1.4 Fresh weight of root

For fresh weight of root, s_6 (71.63 g) had highest value followed by s_5 (64.68 g) and the lowest value was for s_7 (33.97 g) and no till (61.32 g) was found to be superior and significantly different to other tillage levels. The interaction effect of m_3s_6 (83.40 g) remained superior and statistically different to all other treatment combinations (Table 34).

4.3.2.2.1.5 Fodder yield

The effects of nutrient management, tillage and their interactions were found to be significant for green and dry fodder yield. Among nutrient management s_5 recorded highest value of fodder yield followed by s_6 and for tillage levels m_3 was found to be superior. A higher interaction effect was observed for m_3s_5 combination which was on par with m_3s_6 and significantly different to all other combinations (Table 35).

4.3.2.2.1.6 Crude fibre

The crude fibre content remained significant among various treatments, for nutrient management s_5 (32.00 %) recorded highest value followed by s_6 (31.34 %) which was on par with s_4 and between tillage levels m_3 (30.35 %) was found to be superior. The interaction effects were also significant and m_3s_6 (33.81%) recorded highest value which was on par with m_3s_5 (33.24 %) (Table 30).

4.3.2.2.1.7 Crude protein

Significant difference was noted among treatments, for crude protein content in fodder maize. As depicted in Table 36. highest value was recorded by s_5 (9.64 %) followed by s_4 (9.19 %), m_3 (8.86 %) followed by m_1 (8.47 %) and m_3s_5 (10.04 %) followed by m_1s_5 (9.63 %) among sub plot treatment, main plot treatment and their interaction effects respectively.

4.3.2.2.2 Fodder maize grown in cowpea root biomass residue incorporated soil

The influence of tillage and nutrient management practices on growth, yield and quality parameters of fodder maize grown in cowpea root biomass residue incorporated soil are outlined in Table 37 toTable 40.

4.3.2.2.2.1 Plant height

The plant height differed significantly for tillage and nutrient management practices (Table 37). Among various nutrient management, s_4 (2.35 m) recorded highest value which was on par with s_5 (2.24 m) and lowest value was for s_7 (2.06 m). At different tillage levels m_3 (2.24 m) was found to be superior followed by m_1 (2.15 m). The interaction effects were found to be significant and the highest value was observed for m_3s_4 (2.45 m) which was on par with m_3s_4 (2.33 m)

4.3.2.2.2.2 Fresh weight of shoot

The highest fresh weight of shoot was recorded by s_5 (196.04 g) trailed by s_6 (191.69 g) which was on par with s_4 (191.12 g) for sub plot treatments and m_3 (186.26 g) followed by m_1 (183.13 g) for main plot treatments respectively. The interaction effects were statistically significant and m_3s_6 (203.87 g) combination had highest interaction which was on par with m_3s_5 (202.21 g). For fresh weight of root, s_6 (55.36 g) had highest value followed by s_5 (50.75 g) and the lowest value was for s_7 (28.06 g) and no till (53.54 g) was found to be superior and significantly different to other tillage levels. The interaction effect of m_3s_6

Table 36. Effect of tillage and nutrient management on quality attributes of succeeding fodder maize grown in total cowpea residue incorporated soil

	Crude fibre (%)				Crude protein (%)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	29.33	27.50	28.89	28.58^{c}	8.73	8.10	8.83	8.55^{c}
s_2	28.26	27.43	28.57	28.09^{d}	8.02	7.68	8.60	8.10^{d}
s_3	28.32	28.98	28.50	28.60^{c}	7.79	7.78	8.22	7.93^{e}
s_4	31.48	30.36	31.27	31.04^{b}	9.16	8.89	9.53	9.19^{b}
s_5	31.88	30.88	33.24	32.00^{a}	9.63	9.23	10.04	9.64^{a}
s_6	30.40	29.80	33.81	31.34^{b}	8.45	8.34	9.21	8.67^{c}
s_7	28.03	28.06	28.17	28.08^{d}	7.49	7.37	7.59	7.48^{f}
Mean	29.67^{b}	29.00^{c}	30.35^{a}		8.47^{b}	8.20^{c}	8.86^{a}	
SEm±	m 0.11		s 0.17	m x s 0.30	m 0.037	s 0.052		m x s 0.091
CD (0.05)	m 0.44		s 0.49	m x s 0.85	m 0.147	s 0.150		m x s 0.260

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 37. Effect of tillage and nutrient management on growth characteristics of succeeding fodder maize grown in cowpea root residue incorporated soil

	Plant height (m)				Fresh weight of shoot (g)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	2.14	2.05	2.23	2.14^{c}	181.35	170.01	178.75	176.70^{c}
s_2	2.10	2.01	2.15	2.08^{d}	174.75	169.56	176.70	173.67^{de}
s_3	1.99	1.71	2.14	1.95^{e}	174.97	178.17	176.27	176.47^{cd}
s_4	2.35	2.23	2.45	2.35^{a}	193.91	186.75	192.71	191.12^{b}
s_5	2.23	2.16	2.33	2.24^{b}	195.99	189.93	202.21	196.04^{a}
s_6	2.17	2.11	2.27	2.19^{bc}	186.81	184.41	203.87	191.69^{b}
s_7	2.07	1.98	2.13	2.06^{d}	174.13	172.63	173.29	173.35^{e}
Mean	2.15^{b}	2.04^{c}	2.24^{a}		183.13^{b}	178.78^{c}	186.26^{a}	
SEm±	m 0.01		s 0.02	m x s 0.03	m 0.67	s 1.05		m x s 1.82
CD (0.05)	m 0.05		s 0.06	m x s 0.09	m 2.63	s 3.01		m x s 5.21

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 38. Effect of tillage and nutrient management on root characteristics of succeeding fodder maize grown in cowpea root residue incorporated soil

	Root volume (cm^{-3})				Fresh weight of root (g)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	38.00	30.60	41.25	36.62^d	33.25	27.00	50.42	36.89^e
s_2	32.55	30.03	33.48	32.0^e	26.97	29.12	40.92	32.34^f
s_3	29.55	29.45	31.05	30.02^f	32.32	30.40	54.80	39.17^d
s_4	40.13	38.13	44.75	41.01^b	42.00	34.41	62.11	46.17^c
s_5	45.12	41.55	47.09	44.59^a	46.06	39.70	66.48	50.75^b
s_6	38.36	37.07	43.55	39.66^c	50.23	44.48	71.35	55.36^a
s_7	29.04	28.30	30.58	29.31^f	28.10	27.36	28.73	28.06^g
Mean	36.11^b	33.59^c	38.82^a		36.99^b	33.21^c	53.54^a	
SEm±	m 0.20		s 0.26	m x s 0.46	m 0.59	s 0.38	m x s 0.67	
CD (0.05)	m 0.77		s 0.76	m x s 1.31	m 2.30	s 1.10	m x s 1.91	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 39. Effect of tillage and nutrient management on fodder yield (t ha^{-1}) of succeeding maize crop grown in cowpea root residue incorporated soil

	Fresh weight				Dry weight			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	39.90	37.40	39.33	38.88^c	7.98	7.48	7.87	7.78^c
s_2	38.44	37.30	38.88	38.21^{de}	7.69	7.46	7.77	7.64^{de}
s_3	38.49	39.20	38.78	38.82^{cd}	7.70	7.84	7.75	7.76^{cd}
s_4	42.66	41.08	42.40	42.05^b	8.53	8.22	8.48	8.41^b
s_5	43.12	41.78	44.48	43.00^a	8.62	8.36	8.90	8.63^a
s_6	41.10	40.57	44.85	42.17^b	8.22	8.11	8.97	8.43^b
s_7	38.31	37.98	38.12	38.14^e	7.66	7.60	7.62	7.63^e
Mean	40.29^b	39.33^c	40.98^a		8.06^b	7.87^c	8.20^a	
SEm±	m 0.15		s 0.23	m x s 0.40	m 0.03	s 0.05	m x s 0.08	
CD (0.05)	m 0.58		s 0.66	m x s 1.15	m 0.12	s 0.13	m x s 0.23	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

(71.35 g) remained superior and statistically different to all other treatment combinations (Table 37).

4.3.2.2.2.3 Root volume

The sub plot treatments, main plot treatments and their interaction effects were significantly different for root volume. Among sub plot treatments, s_5 recorded highest root volume (44.59 g cm^{-3}) followed by s_4 (41.01 g cm^{-3}) and for main plot teatments, m_3 (38.82 g cm^{-3}) had higher root volumes followed by m_1 (36.11 g cm^{-3}). The interaction effect of m_3s_5 combination (47.09 g cm^{-3}) remained superior and statistically different to all other treatment combinations (Table 38).

4.3.2.2.2.4 Fresh weight of root

The highest fresh weight of shoot was recorded by s_5 (196.04 g) trailed by s_6 (191.69 g) which was on par with s_4 (191.12 g) for sub plot treatments and m_3 (186.26 g) followed by m_1 (183.13 g) for main plot treatments respectively. The interaction effects were statistically significant and m_3s_6 (203.87 g) combination had highest interaction which was on par with m_3s_5 (202.21 g). For fresh weight of root, s_6 (55.36 g) had highest value followed by s_5 (50.75 g) and the lowest value was for s_7 (28.06 g) and no till (53.54 g) was found to be superior and significantly different to other tillage levels. The interaction effect of m_3s_6 (71.35 g) remained superior and statistically different to all other treatment combinations (Table 38).

4.3.2.2.2.5 Fodder yield

The effects of nutrient management, tillage and their interactions were found to be significant for green and dry fodder yield. Among nutrient management s_5 recorded highest value of fodder yield followed by s_6 and for tillage levels m_3 was found to be superior. A higher interaction effect was observed for m_3s_6 combination which was on par with m_3s_5 and significantly different to all other combinations (Table 39).

4.3.2.2.2.6 Crude fibre

The crude fibre content remained significant among various treatments, for nutrient management s_5 (31.37 %) recorded highest value followed by s_6 (30.67 %) and between tillage levels m_3 (29.80 %) was found to be superior. The interaction effects were also significant and m_3s_6 (32.62 %) recorded highest value which was on par with m_3s_5 (32.35 %) (Table 40).

4.3.2.2.2.7 Crude protein

Significant difference was noted among treatments, for sub plot treatments, s_5 (9.25 %) recorded highest value trailed by s_4 (8.93 %) and for main plot treatments m_1 (8.44 %) had highest value which was on par with m_3 (8.34 %). The interaction effects were significant and m_1s_5 (9.63 %) combination was found to be superior and on par with m_3s_5 (Table 40).

4.3.3 Nutrient concentration of shoot and root biomass

4.3.3.1 Grain cowpea

The effect of tillage and nutrient management practices on nutrient concentration of shoot and root biomass of grain cowpea are outlined in Table 41 to Table 43.

4.3.3.1.1 C content

As outlined in Table 41. the tillage effects were found to be non significant for shoot and root C. Among different nutrient management the highest shoot C was recorded by s_4 (52.36 %) followed by s_6 and lowest value was for s_7. The interaction effects were found to be significant and m_1s_4 combination (52.81 %) had highest interaction which was on par with m_2s_4. For root C among different nutrient management, s_5 (50.05 %) had highest value which was on par with s_6 and the interaction effect of m_1s_5 (50.69 %) remained superior and on par with m_3s_6 and m_2s_6 .

Table 40. Effect of tillage and nutrient management on quality attributes of succeeding fodder maize grown in cowpea root residue incorporated soil

	Crude fibre (%)				Crude protein (%)			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	29.01	27.20	28.60	28.27[c]	8.79	7.77	8.48	8.34[c]
s_2	27.96	27.13	28.27	27.79[de]	8.20	7.28	8.20	7.89[d]
s_3	28.00	28.51	28.20	28.24[cd]	7.90	7.36	7.82	7.70[e]
s_4	31.03	29.88	30.83	30.58[b]	9.28	8.43	9.08	8.93[b]
s_5	31.36	30.39	32.35	31.37[a]	9.63	8.66	9.47	9.25[a]
s_6	29.89	29.50	32.62	30.67[b]	8.11	7.36	8.22	7.90[d]
s_7	27.86	27.62	27.73	27.73[e]	7.20	6.96	7.12	7.09[f]
Mean	29.30[b]	28.6[c]	29.80[a]		8.44[a]	7.69[b]	8.34[a]	
SEm±	m 0.11		s 0.17	m x s 0.29	m 0.03	s 0.05	m x s 0.09	
CD (0.05)	m 0.42		s 0.48	m x s 0.83	m 0.11	s 0.15	m x s 0.25	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 41. Effect of tillage and nutrient management on carbon content (%) of grain cowpea

	Shoot				Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	46.24	43.74	44.64	44.87	48.25	45.64	46.58	46.82
s_2	45.20	44.16	45.22	44.86	47.01	45.93	47.03	46.66
s_3	44.35	45.55	43.89	44.60	47.37	48.66	46.87	47.63
s_4	52.81	52.54	51.72	52.36	48.80	48.55	47.78	48.38
s_5	45.29	44.40	46.18	45.29	50.69	49.72	49.73	50.05
s_6	45.66	46.24	46.33	46.08	49.54	50.17	50.19	49.96
s_7	44.50	44.75	44.05	44.44	47.35	47.61	46.86	47.27
Mean	46.29	45.91	46.01		48.43	48.04	47.86	
SEm±	m 0.15		s 0.26	m x s 0.46	m 0.15	s 0.27	m x s 0.47	
CD (0.05)	m NS		s 0.76	m x s 1.31	m NS	s 0.77	m x s 1.34	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 42. Effect of tillage and nutrient management on nitrogen content (%) of grain cowpea

Shoot					Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	2.04	1.94	2.05	2.01^{c}	1.31	1.27	1.23	1.27^{b}
s_2	1.92	1.86	2.01	1.93^{d}	1.17	1.18	1.13	1.1^{c}
s_3	1.89	1.88	1.96	1.91^{e}	1.09	1.16	1.04	1.09^{d}
s_4	2.11	2.06	2.17	2.11^{b}	1.44	1.48	1.37	1.43^{a}
s_5	2.18	2.11	2.25	2.18^{a}	1.29	1.31	1.22	1.27^{b}
s_6	1.99	1.97	2.11	2.03^{c}	1.25	1.31	1.21	1.2^{b}
s_7	1.84	1.82	1.85	1.84^{f}	1.00	1.04	0.96	1.00^{e}
Mean	2.00^{b}	1.95^{c}	2.06^{a}		1.22^{b}	1.25^{c}	1.17^{a}	
SEm±	m 0.006		s 0.008	m x s 0.015	m 0.004	s 0.008		m x s 0.015
CD (0.05)	m 0.023		s 0.024	m x s 0.042	m 0.016	s 0.024		m x s 0.042

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 43. Effect of tillage and nutrient management on phosphorus content (%) of grain cowpea

Shoot					Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.173	0.163	0.167	0.168^{e}	0.097	0.09	0.100	0.096^{e}
s_2	0.173	0.170	0.177	0.173^{d}	0.117	0.11	0.120	0.116^{d}
s_3	0.180	0.183	0.173	0.179^{c}	0.153	0.153	0.153	0.153^{b}
s_4	0.180	0.180	0.183	0.181^{c}	0.133	0.13	0.133	0.132^{c}
s_5	0.187	0.183	0.223	0.198^{b}	0.177	0.167	0.173	0.172^{a}
s_6	0.220	0.220	0.227	0.222^{a}	0.173	0.173	0.183	0.177^{a}
s_7	0.157	0.153	0.157	0.156^{f}	0.093	0.09	0.093	0.092^{e}
Mean	0.181^{b}	0.179^{b}	0.187^{a}		0.135^{a}	0.130^{b}	0.137^{a}	
SEm±	m 0.0012		s 0.0017	m x s 0.003	m 0.001	s 0.0016		m x s 0.0028
CD (0.05)	m 0.0026		s 0.0049	m x s 0.0085	m 0.0041	s 0.0047		m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.3.1.2 N content

The effects of nutrient management, tillage and their interactions were found to be significant for shoot and root N content. As depicted in Table 42, for shoot N content, highest value was noted for s_5 (2.18 %) followed by s_4 (2.11 %), m_3 (2.06 %) trailed by m_1 (2.00 %) and m_3s_5 (2.25 %) followed by m_3s_4 (2.17 %) among nutrient management, tillage levels and their interaction effects respectively. Among nutrient management s_4 (1.43 %) recorded highest value of root N followed by s_5 (1.27 %) which was on par with s_6 and for tillage levels m_2 (1.25 %) was found to be superior. A higher interaction effect was observed for m_2s_4 (1.48 %) combination which was significantly different to all other combinations.

4.3.3.1.3 P content

The shoot and root P content varied among the treatments as depicted in Table 43. For shoot P content, s_6 (0.222 %) recorded highest value followed by s_5 (0.198 %). The tillage m_3 (0.187 %) remained superior and significantly different to others and among interaction effects m_3s_6 (0.227 %) combination had highest value and significantly different to all other combinations. For root P content, s_6 (0.177 %) recorded highest value which was on par with s_5 (0.172 %) and among tillage levels highest P content was noted in case of m_3 (0.137 %) which was on par with m_1 (0.135 %). The interaction effects remained non significant for root P content.

4.3.3.2 Fodder maize

4.3.3.2.1 Fodder maize grown in total cowpea residue incorporated soil

The influence of different tillage and nutrient management on nutrient concentration of fodder maize grown in total cowpea residue incorporated soil are outlined in Table 44 – Table 46.

4.3.3.2.1.1 C content

As outlined in Table 44, the tillage effects and the interaction effects were found to be non significant for shoot and root C. Among different nutrient management the highest shoot C was recorded by s_5 (58.22 %) followed by s_6 and lowest value was for s_2 (45.74 %). For root C among different nutrient management, s_5 (60.30 %) was superior and statistically significant to others followed by s_6 (58.91 %).

4.3.3.2.1.2 N content

The effect of nutrient management, tillage and their interaction effects were found to be significant for shoot and root N content. Among nutrient management s_5 (1.54 %) recorded highest value of shoot N followed by s_4 (1.47 %) and for tillage levels m_3 (1.42 %) was found to be superior and significantly different. A higher interaction effect was observed for m_3s_5 (1.61 %) combination which was significantly different to all other combinations. For root N among different nutrient management, s_5 (1.37 %) recorded highest value followed by s_4 (1.33 %) and tillage level m_3 (1.27 %) remained superior and statistically significant followed by m_2. The interaction effect of m_3s_5 (1.38 %) was found to be superior and significant to other combinations (Table 45).

4.3.3.2.1.3 P content

The shoot and root P content varied among the treatments as depicted in Table 46. For shoot P content, s_5 (0.368 %) recorded highest value followed by s_6 (0.349 %). The tillage m_3 (0.258 %) remained superior and significantly different to others and the interaction effects remained non significant. For root P content, s_5 (0.237 %) recorded highest value and statistically different to others followed by s_6 (0.222 %). The tillage and interaction effects remained non significant for root P content.

Table 44. Effect of tillage and nutrient management on carbon content (%) of succeeding fodder maize grown in total cowpea residue incorporated soil

	Shoot				Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	49.92	47.22	48.19	48.45	53.66	50.76	51.79	52.07
s_2	46.08	45.02	46.12	45.74	50.54	49.38	50.57	50.16
s_3	45.68	46.92	45.22	45.94	50.08	51.44	49.58	50.37
s_4	54.87	54.59	53.67	54.38	58.50	58.22	57.27	58.00
s_5	58.93	57.81	57.92	58.22	61.04	59.89	59.98	60.30
s_6	55.89	56.63	56.68	56.40	58.36	59.14	59.24	58.91
s_7	46.34	46.59	45.83	46.25	47.50	47.76	47.05	47.44
Mean	51.10	50.68	50.52		54.24	53.80	53.64	
SEm±	m 0.16		s 0.32	m x s 0.56	m 0.17		s 0.34	m x s 0.59
CD (0.05)	m NS		s 0.93	m x s NS	m NS		s 0.97	m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 45. Effect of tillage and nutrient management on nitrogen content (%) of succeeding fodder maize grown in total cowpea residue incorporated soil

	Shoot				Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.397	1.297	1.410	1.37^c	1.247	1.233	1.327	1.27^d
s_2	1.283	1.223	1.373	1.29^d	1.220	1.133	1.233	1.19^e
s_3	1.247	1.243	1.317	1.27^e	1.157	1.127	1.157	1.15^f
s_4	1.467	1.423	1.527	1.47^b	1.363	1.293	1.337	1.33^b
s_5	1.540	1.473	1.607	1.54^a	1.413	1.320	1.383	1.37^a
s_6	1.350	1.333	1.473	1.39^c	1.327	1.263	1.333	1.31^c
s_7	1.200	1.180	1.213	1.20^f	1.093	1.043	1.100	1.08^g
Mean	1.36^b	1.31^c	1.42^a		1.260^b	1.202^c	1.267^a	
SEm±	m 0.006		s 0.008	m x s 0.015	m 0.005		s 0.008	m x s 0.014
CD (0.05)	m 0.023		s 0.024	m x s 0.042	m 0.020		s 0.022	m x s 0.039

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 46. Effect of tillage and nutrient management on phosphorus content (%) of succeeding fodder maize grown in total cowpea residue incorporated soil

Shoot					Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.247	0.233	0.240	0.240[d]	0.170	0.160	0.163	0.164
s_2	0.207	0.200	0.207	0.204[e]	0.120	0.120	0.127	0.122
s_3	0.183	0.183	0.183	0.183[f]	0.120	0.120	0.120	0.120
s_4	0.317	0.310	0.310	0.312[c]	0.183	0.183	0.183	0.183
s_5	0.373	0.363	0.367	0.368[a]	0.240	0.233	0.237	0.237
s_6	0.347	0.350	0.350	0.349[b]	0.220	0.220	0.227	0.222
s_7	0.150	0.150	0.150	0.150[g]	0.093	0.090	0.090	0.091
Mean	0.260[c]	0.256[b]	0.258[a]		0.164	0.161	0.164	
SEm±	m 0.001		s 0.003	m x s 0.005	m 0.001	s 0.002	m x s 0.003	
CD (0.05)	m 0.003		s 0.008	m x s NS	m NS	s 0.005	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 47. Effect of tillage and nutrient management on carbon content (%) of succeeding fodder maize grown in cowpea root residue incorporated soil

Shoot					Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	48.46	45.84	46.78	47.03	52.15	49.34	50.35	50.61
s_2	44.67	43.63	44.70	44.34	49.04	47.91	49.08	48.68
s_3	44.31	45.51	43.87	44.56	48.50	49.82	48.00	48.77
s_4	53.37	53.10	52.20	52.89	56.83	56.55	55.58	56.32
s_5	57.25	56.17	56.28	56.57	59.29	58.16	58.27	58.57
s_6	54.21	54.92	54.98	54.70	56.77	57.53	57.58	57.29
s_7	44.87	45.11	44.38	44.79	45.98	46.23	45.48	45.90
Mean	49.59	49.18	49.03		52.65	52.22	52.05	
SEm±	m 0.15		s 0.31	m x s 0.55	m 0.16	s 0.33	m x s 0.57	
CD (0.05)	m NS		s 0.90	m x s NS	m NS	s 0.95	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.3.2.2 Fodder maize grown in cowpea root biomass residue incorporated soil

The influence of different tillage and nutrient management on nutrient concentration of fodder maize grown in cowpea root biomass residue incorporated soil are outlined in Table 47- Table 49.

4.3.3.2.2.1 C content

As outlined in Table 47. for shoot and root C the tillage effects and the interaction effects were found to be non significant. Among different nutrient management the highest shoot C was recorded by s_5 (56.57 %) followed by s_6 and lowest value was for s_2 (44.34 %). For root C among different nutrient management, s_5 (58.57 %) was superior and statistically different to others followed by s_6 (57.29 %).

4.3.3.2.2.2 N content

The effect of nutrient management, tillage and their interactions were found to be significant for shoot and root N content. Among nutrient management s_5 (1.48 %) recorded highest value of shoot N followed by s_4 (1.43 %) and for tillage levels m_3 (1.33 %) was found to be superior and on par with m_1 (1.35 %). A higher interaction effect was observed for m_3s_5 (1.52 %) combination which was significantly different to all other combinations. For root N among different nutrient management, s_5 (1.30 %) recorded highest value followed by s_4 (1.27 %) and tillage level m_3 (1.24 %) remained superior and statistically significant followed by m_2. The interaction effect of m_3s_5 (1.37 %) was found to be superior and significant to other combinations (Table 48).

4.3.3.2.2.3 P content

The shoot and root P content varied among the treatments as depicted in Table 49. For shoot P content, s_5 (0.26 %) recorded highest value followed by s_4 (0.22 %). The tillage level m_3 and m_1 (0.178 %) were found to be superior and the interaction effects remained non significant. For root P content, s_5 (0.23 %)

recorded highest value and statistically different to others followed by s_6 (0.20 %). The tillage and interaction effects remained non significant for root P content.

4.3.4 Soil properties

The soil samples were drawn from two depths, 0-20 cm and 20-60 cm before and after each crop for estimation of C and NP pools and other important soil physical, chemical and biological parameters

4.3.4.1 Bulk density (BD)

The impact of tillage and nutrient management on bulk density at different depths of soil in a grain cowpea - fodder maize sequence are outlined in Table 50.

4.3.4.1.1 BD of soil at the harvest of grain cowpea

At 0-20 cm depth, lowest BD was recorded by s_6 (1.32 Mg m^{-3}) trailed by s_3 (1.33 Mg m^{-3}) for nutrient management and for tillage levels m_2 (1.335 Mg m^{-3}) was found to be superior followed by m_1 (1.352 Mg m^{-3}). The interaction effects were significant and m_2s_6 (1.30 Mg m^{-3}) combination was found to be superior. For second depth of sampling (20-60 cm), higher values of BD were noted than surface soil, sub plot s_6 (1.43 Mg m^{-3}) was superior and among tillage lowest BD was noted for m_2 (1.502 Mg m^{-3}) followed by m_1 (1.503 Mg m^{-3}) while the interaction effects remained non significant (Table 50 a).

4.3.4.1.2 BD of soil at the sowing of fodder maize (total residue incorporation)

As outlined in Table 50 b, nutrient management, tillage and their interaction effects were statistically significant for soil BD at both depths of sampling. At 0- 20 cm depth, lowest BD was noted for s_6 (1.30 Mg m^{-3}) followed by s_5 (1.31 Mg m^{-3}), m_2 (1.30 Mg m^{-3}) trailed by m_1 (1.32 Mg m^{-3}) and m_2s_6 (1.27 Mg m^{-3}) remained superior among subplot treatments, main plot treatments and their interactions respectively. At second depth of soil sampling, higher values were noted for BD than surface soil, and lowest BD was noted for s_6 (1.43 Mg m^{-3}) followed by s_5 (1.45 Mg m^{-3}), m_2 (1.52 Mg m^{-3}) trailed by m_1 (1.50

Table 48. Effect of tillage and nutrient management on nitrogen content (%) of succeeding fodder maize grown in cowpea root residue incorporated soil

	Shoot				Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.40	1.24	1.35	1.33^{c}	1.17	1.17	1.28	1.20^{d}
s_2	1.31	1.16	1.31	1.26^{d}	1.13	1.07	1.22	1.14^{e}
s_3	1.26	1.18	1.25	1.23^{e}	1.07	1.07	1.14	1.10^{f}
s_4	1.49	1.35	1.45	1.43^{b}	1.26	1.22	1.32	1.27^{b}
s_5	1.54	1.39	1.52	1.48^{a}	1.30	1.24	1.37	1.30^{a}
s_6	1.30	1.18	1.32	1.26^{d}	1.21	1.19	1.32	1.24^{c}
s_7	1.15	1.11	1.14	1.13^{f}	1.00	0.98	1.02	1.00^{g}
Mean	1.35^{a}	1.23^{b}	1.33^{a}		1.16^{b}	1.13^{c}	1.24^{a}	
SEm±	m 0.005		s 0.008	m x s 0.014	m 0.006	s 0.008		m x s 0.013
CD (0.05)	m 0.020		s 0.022	m x s 0.039	m 0.023	s 0.022		m x s 0.037

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 49. Effect of tillage and nutrient management on phosphorus content (%) of succeeding fodder maize grown in cowpea root residue incorporated soil

	Shoot				Root			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.18	0.16	0.17	0.17^{d}	0.16	0.15	0.16	0.16
s_2	0.14	0.14	0.14	0.14^{e}	0.12	0.11	0.12	0.12
s_3	0.13	0.13	0.13	0.13^{f}	0.11	0.12	0.11	0.11
s_4	0.23	0.22	0.23	0.22^{b}	0.18	0.17	0.17	0.17
s_5	0.26	0.26	0.26	0.26^{a}	0.23	0.22	0.23	0.23
s_6	0.19	0.20	0.20	0.20^{c}	0.20	0.20	0.20	0.20
s_7	0.11	0.11	0.11	0.11^{g}	0.09	0.09	0.09	0.09
Mean	0.178^{a}	0.174^{b}	0.178^{a}		0.155	0.152	0.154	
SEm±	m 0.0004		s 0.0017	m x s 0.0029	m 0.0011	s 0.0019		m x s 0.0033
CD (0.05)	m 0.002		s 0.005	m x s NS	m NS	s 0.0054		m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 50. Effect of tillage and nutrient management on bulk density of soil (Mg m^{-3}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 50 a. Bulk density of soil (Mg m^{-3}) at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.34	1.35	1.37	1.36[b]	1.55	1.55	1.55	1.55[a]
s_2	1.33	1.34	1.35	1.34[c]	1.54	1.54	1.54	1.54[b]
s_3	1.33	1.33	1.34	1.33[f]	1.52	1.52	1.52	1.52[c]
s_4	1.32	1.33	1.35	1.34[d]	1.49	1.49	1.49	1.49[d]
s_5	1.30	1.32	1.34	1.34[e]	1.45	1.45	1.45	1.45[e]
s_6	1.36	1.30	1.33	1.32[g]	1.43	1.43	1.43	1.43[f]
s_7	1.37	1.36	1.38	1.37[a]	1.54	1.54	1.54	1.54[b]
Mean	1.352[b]	1.335[c]	1.353[a]		1.503[b]	1.502[c]	1.505[a]	
SEm±	m 0.0015		s 0.0018	m x s 0.0029	m 0.0018	s 0.0029	m x s 0.0037	
CD (0.05)	m 0.004		s 0.005	m x s 0.008	m 0.005	s 0.008	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 50 b. Bulk density of soil (Mg m^{-3}) at the time of sowing of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.33	1.32	1.37	1.34[b]	1.54	1.53	1.58	1.55[a]
s_2	1.32	1.31	1.34	1.32[c]	1.53	1.51	1.55	1.53[c]
s_3	1.31	1.30	1.33	1.31[f]	1.52	1.5	1.54	1.52[d]
s_4	1.31	1.30	1.35	1.32[d]	1.48	1.47	1.52	1.49[e]
s_5	1.31	1.29	1.33	1.31[e]	1.45	1.43	1.47	1.45[f]
s_6	1.30	1.27	1.32	1.30[g]	1.43	1.41	1.45	1.43[g]
s_7	1.34	1.33	1.38	1.35[a]	1.53	1.52	1.57	1.54[b]
Mean	1.32[b]	1.30[c]	1.34[a]		1.50[b]	1.48[c]	1.52[a]	
SEm±	m 0.001		s 0.002	m x s 0.003	m 0.001	s 0.003	m x s 0.003	
CD (0.05)	m 0.003		s 0.006	m x s 0.007	m 0.004	s 0.007	m x s 0.009	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Mg m^{-3}) and m$_2$s$_6$ (1.27 Mg m^{-3}) remained superior among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.1.3 BD of soil at the harvest of fodder maize (total residue incorporation)

The effect of nutrient management, tillage and their interactions were found to be significant at both sampling depths (Table 50 c). At 0- 20 cm depth, lowest BD was noted for s$_6$ (1.27 Mg m^{-3}) followed by s$_5$ (1.28 Mg m^{-3}), m$_2$ (1.28 Mg m^{-3}) trailed by m$_1$ (1.30 Mg m^{-3}) and m$_3$-s$_6$ (1.26 Mg m^{-3}) remained superior among subplot, main plot treatments and their interactions respectively. At second depth of soil sampling higher values were noted for BD than surface soil, and lowest BD was noted for s$_6$ (1.42 Mg m^{-3}) followed by s$_5$ (1.44 Mg m^{-3}), m$_2$ (1.49 Mg m^{-3}) trailed by m$_1$ (1.50 Mg m^{-3}) and m$_2$s$_6$ (1.42 Mg m^{-3}) remained superior among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.1.4 BD of soil at the sowing of fodder maize (root residue incorporation)

The nutrient management and tillage levels differed significantly while their interaction effects remained similar for soil BD at both depths of sampling (Table 50 d). At 0- 20 cm depth, lowest BD was observed for s$_6$ (1.31 Mg m^{-3}) which was on par with s$_5$ and m$_2$ (1.31 Mg m^{-3}) trailed by m$_1$ (1.32 Mg m^{-3}) among subplot treatments and main plot treatments respectively. Similarly for second depth (20-60 cm) of sampling, lowest BD was noted for s$_6$ (1.43 Mg m^{-3}) followed by s$_5$ (1.45 Mg m^{-3}), and m$_2$ (1.50 Mg m^{-3}) was found to be superior among subplot treatments and main plot treatments respectively.

4.3.4.1.5 BD of soil at the harvest of fodder maize (root residue incorporation)

Soil BD differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 50 e. At 0- 20 cm depth, lowest BD was noted for s$_6$ (1.29 Mg m^{-3}) followed by s$_5$ (1.31 Mg m^{-3}), m$_2$ (1.30 Mg m^{-3}) trailed by m$_1$ (1.32 Mg m^{-3}) and m$_2$s$_6$ (1.27 Mg m^{-3}) remained superior among subplot treatments, main plot treatments and their interactions respectively. At second depth of soil sampling higher values were noted for BD than surface soil, and lowest BD was noted for s_6 (1.42 Mg m^{-3}) followed by s_5 (1.44 Mg m^{-3}), m_2 (1.48 Mg m^{-3}) trailed by m_1 (1.49 Mg m^{-3}) and m_2s_6 (1.42 Mg m^{-3}) remained superior among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.2 Water stable aggregates (WSA)

The impact of tillage and nutrient management on water stable aggregates at different depths of soil in a grain cowpea - fodder maize sequence are outlined in Table 51. ***4.3.4.2.1 WSA of soil at the harvest of grain cowpea***

Soil WSA differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 51 a. At 0-20 cm depth, among nutrient management s_6 (76.67 %) recorded highest WSA followed by s_5 (75.62 %), for tillage levels m_3 (69.25 %) was found to be superior trailed by m_1 (68.25 %) and for interactions highest effect was observed for m_3s_6 (77.80 %) followed by m_3s_5 (76.76 %). For 20-60 cm depth, s_6 (82.26 %) recorded highest value trailed by s_5 (81.70 %) and m_3 (76.49 %) remained superior followed by m_1 (75.95 %) among subplot treatments and main plot treatments respectively. The interaction effect of m_3s_6 (83.82 %) was found to be superior and on par with m_3s_5 (83.03 %)

4.3.4.2.2 WSA of soil at the sowing of fodder maize (total residue incorporation)

The effect of nutrient management, tillage and their interaction effects were found to be significant at both sampling depths (Table 51 b). At 0- 20 cm depth, highest WSA was noted for s_6 (79.53 %) followed by s_5 (78.22 %), m_3 (72.15 %) trailed by m_1 (71.23 %) and m_3-s_6 (81.35 %) remained superior and statistically significant among subplot treatments, main plot treatments and their interactions respectively. Similar trend was noted for WSA at second depth of soil sampling but with higher values ie. highest WSA was noted for s_6 (88.20 %) followed by s_5 (87.19 %), m_3 (82.07 %) trailed by m_1 (81.01 %) and m_3s_6 (90.10 %) remained superior among subplot treatments, main plot treatments and their interactions respectively.

Table 50 c. Bulk density of soil (Mg m^{-3}) at the time of harvest of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.32	1.30	1.32	1.31^b	1.54	1.54	1.55	1.54^a
s_2	1.30	1.29	1.30	1.30^c	1.53	1.53	1.54	1.53^b
s_3	1.28	1.28	1.29	1.28^e	1.51	1.51	1.52	1.51^c
s_4	1.29	1.28	1.30	1.29^d	1.48	1.48	1.49	1.48^d
s_5	1.30	1.27	1.29	1.28^e	1.44	1.44	1.44	1.44^e
s_6	1.28	1.25	1.28	1.27^f	1.42	1.42	1.42	1.42^f
s_7	1.32	1.31	1.33	1.32^a	1.53	1.53	1.54	1.53^b
Mean	1.30^b	1.28^c	1.31^a		1.50^b	1.49^c	1.51^a	
SEm±	m 0.002		s 0.003	m x s 0.0042	m 0.002		s 0.003	m x s 0.0046
CD (0.05)	m 0.005		s 0.007	m x s 0.0088	m 0.005		s 0.008	m x s 0.0096

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 50 d. Bulk density of soil (Mg m^{-3}) at the time of sowing of fodder maize that received root residue of cowpea

0- 20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.34	1.34	1.36	1.34^a	1.55	1.55	1.55	1.55^a
s_2	1.32	1.32	1.34	1.32^b	1.54	1.54	1.54	1.54^b
s_3	1.31	1.31	1.34	1.32^b	1.52	1.52	1.52	1.52^c
s_4	1.32	1.32	1.34	1.32^b	1.49	1.49	1.49	1.49^d
s_5	1.32	1.32	1.33	1.31^b	1.45	1.45	1.45	1.45^e
s_6	1.32	1.32	1.33	1.31^b	1.43	1.43	1.43	1.43^f
s_7	1.34	1.34	1.36	1.35^a	1.54	1.54	1.54	1.54^b
Mean	1.32^b	1.31^c	1.34^a		1.50^b	1.50^b	1.51^a	
SEm±	m 0.0036		s 0.004	m x s 0.008	m 0.0025		s 0.0033	m x s 0.008
CD (0.05)	m 0.0098		s 0.012	m x s NS	m 0.007		s 0.009	m x s NS

M_1: Conventional tillage; M_2: Deep tillage; M_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 50 e. Bulk density of soil (Mg m^{-3}) at the time of harvest of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.34	1.32	1.34	1.33^b	1.54	1.54	1.54	1.54^a
s_2	1.32	1.31	1.32	1.32^c	1.53	1.53	1.53	1.53^b
s_3	1.30	1.30	1.31	1.30^f	1.51	1.51	1.51	1.51^c
s_4	1.31	1.30	1.32	1.31^d	1.48	1.48	1.48	1.48^d
s_5	1.32	1.29	1.31	1.31^e	1.44	1.44	1.44	1.44^e
s_6	1.30	1.27	1.30	1.29^f	1.42	1.42	1.42	1.42^f
s_7	1.34	1.33	1.35	1.34^a	1.53	1.53	1.53	1.53^b
Mean	1.32^b	1.30^c	1.33^a		1.49^b	1.48^c	1.50^a	
SEm±	m 0.0018		s 0.0024	m x s 0.0029	m 0.0010	s 0.0031	m x s 0.0033	
CD (0.05)	m 0.005		s 0.007	m x s 0.008	m 0.003	s 0.008	m x s 0.009	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 51. Effect of tillage and nutrient management on percentage of water stable aggregates at different depths in a grain cowpea – fodder maize cropping sequence

Table 51 a. Water stable aggregate percentage of soil at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	61.29	60.18	62.29	61.25^f	70.10	67.99	70.51	69.54^f
s_2	63.75	62.47	64.75	63.65^e	72.13	69.85	72.52	71.50^e
s_3	68.65	67.31	69.65	68.53^d	76.42	74.08	76.99	75.83^d
s_4	71.96	70.59	72.96	71.83^c	78.70	76.33	79.38	78.14^c
s_5	75.76	74.35	76.76	75.62^b	82.23	79.82	83.03	81.70^b
s_6	76.80	75.42	77.80	76.67^a	82.66	80.28	83.82	82.26^a
s_7	59.56	58.32	60.56	59.48^g	69.39	67.15	69.16	68.57^g
Mean	68.25^b	66.95^c	69.25^a		75.95^b	73.65^c	76.49^a	
SEm±	m 0.196		s 0.392	m x s 0.408	m 0.176	s 0.204	m x s 0.376	
CD (0.05)	m 0.490		s 0.980	m x s 1.020	m 0.440	s 0.510	m x s 0.940	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.4.2.3 WSA of soil at the harvest of fodder maize (total residue incorporation)

The effect of nutrient management, tillage and their interaction effects were found to be significant at both sampling depths (Table 51 c). At 0- 20 cm depth, highest WSA was noted for s_6 (81.23 %) followed by s_5 (79.95 %), m_3 (73.78 %) trailed by m_1 (72.83 %) and m_3s_6 (83.06 %) remained superior and on par with m_1s_6 (82.11 %) among subplot treatments, main plot treatments and their interactions respectively. Similar trend was noted for WSA at second depth of soil sampling but with higher values ie. highest WSA was noted for s_6 (89.61 %) followed by s_5 (88.63 %), m_3 (83.34 %) trailed by m_1 (82.39 %) and m_3s_6 (91.44 %) remained superior among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.2.4 WSA of soil at the sowing of fodder maize (root residue incorporation)

Soil WSA differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 51 d. At 0-20 cm depth, among nutrient management s_6 (78.13 %) recorded highest WSA followed by s_5 (76.79 %), for tillage levels m_3 (70.49 %) was found to be superior trailed by m_1 (69.56 %) and for interactions highest effect was observed for m_3s_6 (79.62 %) which was on par with m_1s_6 (78.68 %). For 20-60 cm depth, s_6 (83.66 %) recorded highest value trailed by s_5 (82.41 %) and m_3 (77.58 %) remained superior followed by m_1 (75.69 %) among subplot treatments and main plot treatments respectively. The interaction effect of m_3s_6 (85.53 %) was found to be superior trailed by m_3s_5 (84.38 %).

4.3.4.2.5 WSA of soil at the harvest of fodder maize (root residue incorporation)

Soil WSA differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 51 e. At 0-20 cm depth, among nutrient management s_6 (78.98 %) recorded highest WSA followed by s_5 (77.67 %), for tillage levels m_3 (71.28 %) was found to be superior trailed by m_1 (70.33 %) and for interactions highest effect was observed for m_3s_6 (80.48 %) which was on par with m_1s_6 (79.53 %). For 20-60 cm depth, s_6 (86.03 %) recorded highest value trailed by s_5 (85.02 %) and m_3 (79.50 %) remained superior followed by m_1 (78.55 %) among subplot treatments and main plot treatments respectively. The interaction effect of m_3s_6 (87.53 %) was found to be superior followed by m_1s_6 (86.58 %)

4.3.4.3 Soil pH

The impact of tillage and nutrient management on pH at different depths of soil in a grain cowpea - fodder maize sequence are outlined in Table 52.

4.3.4.3.1 pH of soil at the harvest of grain cowpea

At 0-20 cm depth, highest pH was recorded by s_6 (5.45) which was on par with s_7 (5.41) and s_5 (5.38) among various nutrient management. The interaction effects were significant and m_3s_6 (5.49) combination had highest interaction and for main plot treatments statistical significance was not found. For second depth of sampling (20-60 cm), main plot effects were similar and sub plot treatment s_6 (5.13) was superior and statistically significant to others. The interaction effect of m_3s_6 (5.17) remained superior among treatment combinations (Table 52 a).

4.3.4.3.2 pH of soil at the sowing of fodder maize (total residue incorporation)

As outlined in Table 52 b, nutrient management, tillage and their interaction effects were statistically significant for soil pH at both depths of sampling. At 0- 20 cm depth, highest pH was noted for s_6 (5.79) on par with s_7 (5.76) and s_5 (5.76), m_2 (5.69) on par with m_1 (5.63) and m_2s_6 and m_2s_7 (5.91) remained superior among subplot treatments, main plot treatments and their interactions respectively. Similar trend was there for pH at second depth of sampling but with lower values ie. highest pH was noted for s_6 (5.50) on par with s_7 (5.46) and s_5 (5.43), m_2 (5.40) on par with m_1 (5.34) and m_2s_6 (5.62) remained superior among sub plot treatments, main plot treatments and their interactions respectively.

Table 51 b. Water stable aggregate percentage of soil at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	64.10	61.52	65.02	63.54[f]	74.71	72.15	75.77	74.21[f]
s_2	66.56	63.83	67.48	65.95[e]	76.87	74.16	77.93	76.32[e]
s_3	71.67	68.70	72.59	70.98[d]	81.58	78.63	82.64	80.95[d]
s_4	75.10	71.99	76.02	74.37[c]	84.11	81.02	85.17	83.43[c]
s_5	79.01	75.74	79.93	78.22[b]	87.92	84.67	88.98	87.19[b]
s_6	80.43	76.83	81.35	79.53[a]	89.04	85.46	90.10	88.20[a]
s_7	61.74	59.67	62.66	61.35[g]	72.85	70.80	73.91	72.52[g]
Mean	71.23[b]	68.32[c]	72.15[a]		81.01[b]	78.12[c]	82.07[a]	
SEm±	m 0.36		s 0.42	m x s 0.46	m 0.26	s 0.35		m x s 0.38
CD (0.05)	m 0.89		s 1.05	m x s 1.14	m 0.64	s 0.87		m x s 0.96

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 51 c. Water stable aggregate percentage of soil at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	65.51	62.94	66.46	64.97[f]	75.89	73.32	76.84	75.35[f]
s_2	68.14	65.42	69.09	67.55[e]	78.22	75.50	79.17	77.63[e]
s_3	73.31	70.35	74.26	72.64[d]	82.99	80.03	83.94	82.32[d]
s_4	76.77	73.67	77.72	76.05[c]	85.55	82.45	86.50	84.84[c]
s_5	80.72	77.46	81.67	79.95[b]	89.40	86.14	90.35	88.63[b]
s_6	82.11	78.52	83.06	81.23[a]	90.49	86.90	91.44	89.61[a]
s_7	63.28	61.22	64.23	62.91[g]	74.16	72.10	75.11	73.79[g]
Mean	72.83[b]	69.94[c]	73.78[a]		82.39[b]	79.50[c]	83.34[a]	
SEm±	m 0.316		s 0.336	m x s 0.396	m 0.328	s 0.34		m x s 0.368
CD (0.05)	m 0.790		s 0.840	m x s 0.990	m 0.820	s 0.850		m x s 0.920

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 51 d. Water stable aggregate percentage of soil at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	62.62	61.04	63.56	62.41^f	69.90	65.41	71.47	68.93^f
s_2	64.91	63.18	65.85	64.65^e	71.74	67.85	73.46	71.02^e
s_3	69.96	67.99	70.90	69.62^d	76.15	73.14	78.11	75.80^d
s_4	73.36	71.25	74.30	72.97^c	78.51	76.68	80.61	78.60^c
s_5	77.23	74.96	78.17	76.79^b	82.12	80.71	84.38	82.41^b
s_6	78.68	76.08	79.62	78.13^a	82.94	82.49	85.53	83.66^a
s_7	60.13	59.06	61.07	60.09^g	68.42	62.41	69.48	66.77^g
Mean	69.56^b	67.6^c	70.49^a		75.69^b	72.67^c	77.58^a	
SEm±	m 0.36		s 0.45	m x s 0.50	m 0.38	s 0.43	m x s 0.45	
CD (0.05)	m 0.89		s 1.12	m x s 1.24	m 0.94	s 1.07	m x s 1.12	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 51 e. Water stable aggregate percentage of soil at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	63.20	61.63	64.15	62.99^f	72.25	70.68	73.20	72.04^f
s_2	65.66	63.94	66.61	65.40^e	74.41	72.69	75.36	74.15^e
s_3	70.77	68.81	71.72	70.43^d	79.12	77.16	80.07	78.78^d
s_4	74.20	72.10	75.15	73.81^c	81.65	79.55	82.60	81.27^c
s_5	78.11	75.85	79.06	77.67^b	85.46	83.20	86.41	85.02^b
s_6	79.53	76.94	80.48	78.98^a	86.58	83.99	87.53	86.03^a
s_7	60.84	59.78	61.79	60.80^g	70.39	69.33	71.34	70.35^g
Mean	70.33^b	68.43^c	71.28^a		78.55^b	76.66^c	79.50^a	
SEm±	m 0.288		s 0.332	m x s 0.384	m 0.324	s 0.336	m x s 0.360	
CD (0.05)	m 0.72		s 0.83	m x s 0.96	m 0.81	s 0.84	m x s 0.90	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 52. Effect of tillage and nutrient management on soil pH at different depths in a grain cowpea – fodder maize cropping sequence

Table 52 a. Soil pH at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5.28	5.00	5.10	5.13	4.96	4.70	4.79	4.82
s_2	5.26	5.15	5.27	5.23	4.95	4.84	4.95	4.91
s_3	5.23	5.38	5.17	5.26	4.91	5.05	4.86	4.94
s_4	5.25	5.24	5.15	5.21	4.94	4.92	4.84	4.90
s_5	5.43	5.34	5.37	5.38	5.11	5.02	5.05	5.06
s_6	5.39	5.46	5.49	5.45	5.08	5.14	5.17	5.13
s_7	5.42	5.45	5.36	5.41	5.10	5.13	5.04	5.09
Mean	5.32	5.29	5.27		5.01	4.97	4.96	
SEm±	m 0.02		s 0.03	m x s 0.05	m 0.02	s 0.03	m x s 0.05	
CD (0.05)	m NS		s 0.08	m x s 0.14	m NS	s 0.08	m x s 0.14	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 52 b. Soil pH at the time of sowing of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5.46	5.27	5.24	5.32[c]	5.16	4.98	4.95	5.03[c]
s_2	5.57	5.54	5.54	5.55[b]	5.27	5.25	5.25	5.26[b]
s_3	5.53	5.79	5.44	5.59[b]	5.24	5.48	5.15	5.29[b]
s_4	5.60	5.64	5.40	5.55[b]	5.30	5.34	5.11	5.25[b]
s_5	5.78	5.79	5.61	5.73[a]	5.48	5.49	5.32	5.43[a]
s_6	5.73	5.91	5.74	5.79[a]	5.44	5.62	5.44	5.50[a]
s_7	5.76	5.91	5.61	5.76[a]	5.46	5.61	5.31	5.46[a]
Mean	5.63[a]	5.69[a]	5.51[b]		5.34[a]	5.40[a]	5.22[b]	
SEm±	m 0.02		s 0.03	m x s 0.05	m 0.02	s 0.03	m x s 0.05	
CD (0.05)	m 0.07		s 0.09	m x s 0.15	m 0.07	s 0.08	m x s 0.15	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 52 c. Soil pH at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5.57	5.37	5.37	5.44^e	5.25	5.08	5.07	5.1^e
s_2	5.79	5.77	5.79	5.79^c	5.49	5.47	5.49	5.48^c
s_3	6.10	6.38	6.04	6.17^a	5.80	6.07	5.74	5.87^a
s_4	5.70	5.78	5.59	5.69^d	5.39	5.48	5.29	5.39^d
s_5	6.19	6.09	6.01	6.10^{ab}	5.88	5.78	5.71	5.79^{ab}
s_6	6.08	6.16	6.09	6.11^{ab}	5.78	5.86	5.79	5.81^{ab}
s_7	6.10	6.14	5.93	6.06^b	5.79	5.83	5.63	5.75^b
Mean	5.93^a	5.96^a	5.83^b		5.63^a	5.65^a	5.53^b	
SEm±	m 0.02		s 0.03	m x s 0.06	m 0.02	s 0.03		m x s 0.05
CD (0.05)	m 0.07		s 0.09	m x s 0.16	m 0.07	s 0.09		m x s 0.15

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 52 d. Soil pH at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5.30	5.11	5.03	5.15^c	4.99	4.81	4.73	4.84^c
s_2	5.41	5.39	5.33	5.38^b	5.11	5.09	5.02	5.07^b
s_3	5.38	5.62	5.23	5.41^b	5.07	5.31	4.93	5.10^b
s_4	5.44	5.48	5.19	5.37^b	5.13	5.17	4.89	5.06^b
s_5	5.62	5.58	5.40	5.53^a	5.31	5.27	5.10	5.24^a
s_6	5.57	5.72	5.52	5.60^a	5.27	5.40	5.22	5.29^a
s_7	5.60	5.70	5.39	5.56^a	5.29	5.39	5.09	5.26^a
Mean	5.48^a	5.50^a	5.30^b		5.17^a	5.21^a	5.00^b	
SEm±	m 0.02		s 0.03	m x s 0.05	m 0.02	s 0.03		m x s 0.05
CD (0.05)	m 0.07		s 0.09	m x s 0.15	m 0.06	s 0.08		m x s 0.14

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.4.3.3 pH of soil at the harvest of fodder maize (total residue incorporation)

The effect of nutrient management, tillage and their interaction effects were found to be significant at both sampling depths. At 0-20 cm depth, among nutrient managements, s_3 (6.17) recorded highest pH which was on par with s_6 (6.11) and s_5 (6.10), for tillage levels m_2 (5.96) was found to be superior and on par with m_1 (5.93) and for interactions highest effect was observed for m_1-s_5 (6.19). For 20-60 cm depth, s_3 (5.87) recorded highest value and was on par with s_6 (5.81) and s_5 (5.79) and m_2 (5.65) remained superior and was on par with m_1 (5.63) among nutrient management and tillage levels respectively. The interaction effect of m_2s_3 (6.07) was found to be superior and significant to other combinations (Table 52 c).

4.3.4.3.4 pH of soil at the sowing of fodder maize (root residue incorporation)

The nutrient management, tillage and their interaction effects were statistically significant for soil pH at both depths of sampling (Table 52 d). At 0-20 cm depth, highest pH was observed for s_6 (5.60) on par with s_7 (5.56) and s_5 (5.53), m_2 (5.50) on par with m_1 (5.48) and m_2s_6 (5.72) remained superior among subplot treatments, main plot treatments and their interactions respectively. Similarly for second depth (20-60 cm) of sampling, highest pH was noted for s_6 (5.29) on par with s_7 (5.26) and s_5 (5.24), m_2 (5.21) on par with m_1 (5.17) and m_2s_6 (5.40) remained superior among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.3.5 pH of soil at the harvest of fodder maize (root residue incorporation)

The effect of nutrient management, tillage and their interaction effects were found to be significant at both sampling depths. At 0-20 cm depth, among nutrient management s_3 (6.16) recorded highest pH which was on par with s_6 (6.10) and s_5 (6.09), for tillage levels m_2 (5.95) was found to be superior and on par with m_1 (5.94) and for interactions highest effect was observed for m_1s_5 (6.19). For 20-60 cm depth, s_3 (5.82) recorded highest value and was on par with s_6 (5.76) and s_5 (5.75) and m_2 (5.60) remained superior and on par with m_1 (5.60) among sub plot treatments and main plot treatments respectively. The interaction effect of m_2s_3 (6.02) was found to be superior and significant to other combinations (Table 52 e).

4.3.4.4 Soil EC

The impact of tillage and nutrient management on EC at different depths of soil in a grain cowpea - fodder maize sequence are outlined in Table 53.

4.3.4.4.1 EC of soil at the harvest of grain cowpea

At 0-20 cm depth, highest soil EC was recorded by s_1 (0.218 dS m^{-1}) trailed by s_4 (0.207 dS m^{-1}) for nutrient management and for tillage levels m_1 (0.202 dS m^{-1}) was found to be superior. The interaction effects were significant and m_3-s_1 (0.273 dS m^{-1}) combination was superior and statistically significant to all other combinations. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of EC, sub plot s_1 (0.178 dS m^{-1}) was superior and statistically significant to others. Among tillage highest EC was noted for m_1 (0.164 dS m^{-1}) and the interaction effect of m_3s_1 (0.230 dS m^{-1}) remained superior and significant to other treatment combinations (Table 53 a).

4.3.4.4.2 EC of soil at the sowing of fodder maize (total residue incorporation)

As outlined in Table 53 b, nutrient management, tillage and their interaction effects were statistically significant for soil EC at both depths of sampling. At 0- 20 cm depth, highest EC was noted for s_1 (0.321 dS m^{-1}) followed by s_4 (0.314 dS m^{-1}), m_3 (0.322 dS m^{-1}) trailed by m_1 (0.304 dS m^{-1}) and m_3s_1 (0.393 dS m^{-1}) remained superior and statistically significant among subplot treatments, main plot treatments and their interactions respectively. Similar trend was there for EC at second depth of soil sampling but with lower values ie. highest EC was noted for s_1 (0.290 dS m^{-1}) followed by s_4 (0.281 dS m^{-1}), m_3 (0.290 dS m^{-1}) trailed by m_1 (0.271 dS m^{-1}) and m_3s_1 (0.367 dS m^{-1}) remained superior among subplot treatments, main plot treatments and their interactions respectively.

Table 52 e. Soil pH at the time of harvest of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5.55	5.36	5.36	5.43[d]	5.20	5.03	5.02	5.09[d]
s_2	5.78	5.76	5.78	5.78[c]	5.44	5.42	5.44	5.43[c]
s_3	6.09	6.37	6.03	6.16[a]	5.75	6.02	5.69	5.82[a]
s_4	5.81	5.77	5.58	5.72[c]	5.46	5.43	5.25	5.38[c]
s_5	6.19	6.08	6.00	6.09[ab]	5.85	5.73	5.66	5.75[ab]
s_6	6.08	6.15	6.08	6.10[ab]	5.74	5.81	5.74	5.76[ab]
s_7	6.10	6.13	5.92	6.05[b]	5.75	5.78	5.58	5.70[b]
Mean	5.94[a]	5.95[a]	5.82[b]		5.60[a]	5.60[a]	5.48[b]	
SEm±	m 0.02		s 0.03	m x s 0.06	m 0.02	s 0.03	m x s 0.05	
CD (0.05)	m 0.07		s 0.09	m x s 0.16	m 0.06	s 0.09	m x s 0.15	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 53. Effect of tillage and nutrient management on soil EC (dS m^{-1}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 53 a. Soil EC (dS m^{-1}) at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.207	0.173	0.273	0.218[a]	0.170	0.133	0.230	0.178[a]
s_2	0.210	0.190	0.203	0.20[c]	0.170	0.153	0.163	0.162[c]
s_3	0.193	0.193	0.173	0.187[e]	0.150	0.153	0.133	0.14[e]
s_4	0.217	0.213	0.190	0.207[b]	0.180	0.173	0.153	0.169[b]
s_5	0.210	0.173	0.173	0.186[e]	0.173	0.140	0.140	0.151[d]
s_6	0.203	0.193	0.183	0.193[d]	0.163	0.153	0.147	0.154[d]
s_7	0.177	0.167	0.177	0.173[f]	0.140	0.127	0.140	0.136[f]
Mean	0.202[a]	0.186[c]	0.196[b]		0.164[a]	0.148[c]	0.158[b]	
SEm±	m 0.001		s 0.002	m x s 0.003	m 0.001	s 0.001	m x s 0.003	
CD (0.05)	m 0.004		s 0.005	m x s 0.008	m 0.004	s 0.004	m x s 0.007	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 53 b. Soil EC (dS m^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.310	0.260	0.393	0.321^a	0.277	0.227	0.367	0.290^a
s_2	0.313	0.280	0.333	0.309^c	0.280	0.247	0.300	0.276^c
s_3	0.293	0.283	0.303	0.293^{de}	0.263	0.250	0.273	0.262^d
s_4	0.323	0.300	0.320	0.314^b	0.290	0.270	0.283	0.281^b
s_5	0.320	0.260	0.303	0.294^d	0.283	0.233	0.270	0.262^d
s_6	0.293	0.270	0.303	0.289^e	0.263	0.240	0.270	0.258^d
s_7	0.277	0.253	0.300	0.277^f	0.243	0.217	0.270	0.243^e
Mean	0.304^b	0.272^c	0.322^a		0.271^b	0.240^c	0.290^a	
SEm±	m 0.002		s 0.002	m x s 0.003	m 0.002	s 0.002	m x s 0.003	
CD (0.05)	m 0.006		s 0.005	m x s 0.009	m 0.007	s 0.005	m x s 0.009	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 53 c. Soil EC (dS m^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.427	0.307	0.503	0.412^a	0.380	0.263	0.460	0.368^a
s_2	0.380	0.283	0.397	0.353^c	0.337	0.240	0.353	0.310^c
s_3	0.407	0.333	0.410	0.383^b	0.363	0.287	0.367	0.339^b
s_4	0.357	0.280	0.373	0.337^{de}	0.310	0.233	0.330	0.291^e
s_5	0.367	0.260	0.377	0.33^e	0.320	0.213	0.333	0.289^e
s_6	0.357	0.280	0.390	0.34^d	0.313	0.237	0.347	0.299^d
s_7	0.317	0.237	0.363	0.306^f	0.273	0.193	0.320	0.262^f
Mean	0.373^b	0.283^c	0.402^a		0.328^b	0.238^b	0.359^a	
SEm±	m 0.004		s 0.002	m x s 0.004	m 0.004	s 0.002	m x s 0.003	
CD (0.05)	m 0.014		s 0.007	m x s 0.012	m 0.015	s 0.006	m x s 0.010	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.4.4.3 EC of soil at the harvest of fodder maize (total residue incorporation)

The effect of nutrient management, tillage and their interaction effects were found to be significant at both sampling depths. At 0-20 cm depth, among nutrient management s_1 (0.412 dS m^{-1}) recorded highest EC followed by s_3 (0.383 dS m^{-1}), for tillage levels m_3 (0.402 dS m^{-1}) was found to be superior trailed by m_1 (0.373 dS m^{-1}) and for interactions highest effect was observed for m_3s_1 (0.503 dS m^{-1}). For 20-60 cm soil depth, s_1 (0.368 dS m^{-1}) recorded highest value followed by s_3 (0.339 dS m^{-1}), and m_3 (0.359 dS m^{-1}) remained superior trailed by m_1 (0.328 dS m^{-1}) among different nutrient management and tillage levels respectively. The interaction effect of m_3s_1 (0.460 dS m^{-1}) was found to be superior and significant to other combinations (Table 53 c).

4.3.4.4.4 EC of soil at the sowing of fodder maize (root residue incorporation)

The nutrient management, tillage and their interaction effects were statistically significant for soil EC at both depths of sampling (Table 53 d). At 0-20 cm depth, highest EC was observed for s_1 (0.243 dS m^{-1}) followed by s_4 (0.236 dS m^{-1}), m_3 (0.248 dS m^{-1}) trailed by m_1 (0.221 dS m^{-1}) and m_3-s_1 (0.323 dS m^{-1}) remained superior among subplot treatments, main plot treatments and their interactions respectively. Similarly for second depth (20-60 cm) of sampling, highest EC was noted for s_1 (0.204 dS m^{-1}) followed by s_4 (0.194 dS m^{-1}), m_3 (0.208 dS m^{-1}) trailed by m_1 (0.181 dS m^{-1}) and m_3s_1 (0.283 dS m^{-1}) remained superior among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.4.5 EC of soil at the harvest of fodder maize (root residue incorporation)

Soil EC differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 53 e. At 0-20 cm depth, among nutrient management s_1 (0.414 dS m^{-1}) recorded highest EC followed by s_3 (0.383 dS m^{-1}), for tillage levels m_3 (0.403 dS m^{-1}) was found to be superior trailed by m_1 (0.373 dS m^{-1}) and for interactions highest effect was observed for m_3-s_1 (0.507 dS m^{-1}). For 20-60 cm soil depth, s_1 (0.374 dS m^{-1})

recorded highest value followed by s_3 (0.342 dS m^{-1}) and m_3 (0.362 dS m^{-1}) remained superior trailed by m_1 (0.332 dS m^{-1}) among sub plot treatments and main plot treatments respectively. The interaction effect of m_3s_1 (0.467 dS m^{-1}) was found to be superior and significant to other combinations.

4.3.4.5 Soil C fractions

4.3.4.5.1 Total Organic Carbon (TOC)

The influence of tillage and nutrient management on soil TOC content at different depths in a grain cowpea - fodder maize sequence are outlined in Table 54.

4.3.4.5.1.1 Soil TOC content at the harvest of grain cowpea

At 0-20 cm depth, among nutrient managements, highest soil TOC content was recorded by s_6 (3.17 %) which was on par with s_4 (3.15 %) and s_5 (3.14 %) and tillage effects were found to be similar without significant difference where highest value was noted for m_1 (3.10 %). The interaction effects were significant and m_2s_3 (3.22 %) combination was superior and statistically on par with m_2s_6, m_3s_6, m_2s_4 and m_1s_4 and significantly different to all other combinations. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil TOC, sub plot s_6 (3.08 %) was superior and statistically on par with s_3 and s_4 (3.05 %) and significantly different to others. Among tillage highest TOC content was noted for m_2 (3.04 %) which was on par with m_1 (2.99 %) and the interaction effect of m_2s_3 (3.17 %) remained superior and on par with m_2s_6 and m_2s_4 and significantly different to all other combinations (Table 54 a).

4.3.4.5.1.2 Soil TOC content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 54 b, nutrient management, tillage and their interaction effects were statistically significant for soil TOC content at both depths of sampling. At 0- 20 cm depth, highest TOC was noted for s_6 (3.22 %) which was on par with s_3 (3.20 %) and s_4 (3.19 %), m_1 (3.16 %) which was on par

Table 53 d. Soil EC (dS m^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.227	0.180	0.323	0.243^a	0.187	0.143	0.283	0.204^a
s_2	0.230	0.200	0.257	0.229^c	0.190	0.163	0.213	0.189^c
s_3	0.213	0.203	0.227	0.214^d	0.173	0.163	0.190	0.17^{de}
s_4	0.240	0.223	0.243	0.236^b	0.197	0.183	0.203	0.194^b
s_5	0.233	0.183	0.230	0.216^d	0.190	0.147	0.193	0.177^d
s_6	0.213	0.193	0.230	0.212^d	0.173	0.153	0.187	0.171^e
s_7	0.193	0.170	0.227	0.197^e	0.157	0.130	0.187	0.158^f
Mean	0.221^b	0.193^c	0.248^a		0.181^b	0.155^c	0.208^a	
SEm±	m 0.002		s 0.002	m x s 0.003	m 0.002		s 0.002	m x s 0.003
CD (0.05)	m 0.007		s 0.005	m x s 0.008	m 0.006		s 0.005	m x s 0.008

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 53 e. Soil EC (dS m^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.427	0.310	0.507	0.414^a	0.387	0.270	0.467	0.374^a
s_2	0.380	0.287	0.397	0.354^c	0.340	0.243	0.353	0.312^c
s_3	0.407	0.333	0.410	0.383^b	0.367	0.293	0.367	0.342^b
s_4	0.357	0.280	0.373	0.337^{de}	0.317	0.243	0.333	0.298^{de}
s_5	0.367	0.260	0.377	0.334^e	0.323	0.223	0.337	0.294^e
s_6	0.357	0.280	0.390	0.342^d	0.317	0.240	0.350	0.302^d
s_7	0.317	0.237	0.370	0.308^f	0.277	0.197	0.327	0.267^f
Mean	0.373^b	0.284^c	0.403^a		0.332^b	0.244^c	0.362^a	
SEm±	m 0.004		s 0.002	m x s 0.004	m 0.003		s 0.002	m x s 0.004
CD (0.05)	m 0.015		s 0.006	m x s 0.010	m 0.013		s 0.006	m x s 0.011

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 54. Effect of tillage and nutrient management on the TOC content of soil (%) at different depths in a grain cowpea – fodder maize cropping sequence

Table 54 a. TOC content of soil (%) at the harvest of grain cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	3.19	3.02	3.08	3.10	3.09	2.98	2.96	3.01^{bc}
s_2	3.08	3.00	3.08	3.05	2.97	2.96	2.96	2.96^{c}
s_3	3.13	3.22	3.07	3.14	3.03	3.17	2.96	3.05^{ab}
s_4	3.18	3.17	3.09	3.15	3.06	3.12	2.97	3.05^{ab}
s_5	3.12	3.06	3.04	3.07	3.01	3.01	2.92	2.98^{c}
s_6	3.14	3.20	3.17	3.17	3.03	3.15	3.05	3.08^{a}
s_7	2.89	2.92	2.86	2.89	2.78	2.86	2.74	2.80^{d}
Mean	3.10	3.08	3.06		2.99^{a}	3.04^{a}	2.94^{b}	
SEm±	m 0.0097	s 0.01	m x s 0.0307		m 0.017	s 0.017	m x s 0.0299	
CD (0.05)	m NS	s 0.050	m x s 0.088		m 0.0418	s 0.049	m x s 0.0857	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 54 b. TOC content of soil (%) at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	3.25	3.04	3.16	3.15^{bc}	3.11	3.00	2.98	3.03^{abc}
s_2	3.13	3.02	3.16	3.11^{c}	2.99	2.98	2.97	2.98^{cd}
s_3	3.19	3.24	3.16	3.20^{ab}	3.05	3.19	2.98	3.07^{a}
s_4	3.22	3.19	3.18	3.19^{ab}	3.03	3.08	2.93	3.01^{bc}
s_5	3.18	3.07	3.13	3.13^{c}	2.97	2.96	2.88	2.94^{d}
s_6	3.20	3.22	3.26	3.22^{a}	3.00	3.11	3.01	3.04^{ab}
s_7	2.95	2.94	2.95	2.94^{d}	2.95	3.00	2.92	2.96^{d}
Mean	3.16^{a}	3.10^{b}	3.14^{ab}		3.01^{a}	3.05^{a}	2.95^{b}	
SEm±	m 0.011	s 0.018	m x s 0.031		m 0.010	s 0.017	mx s 0.029	
CD (0.05)	m 0.04	s 0.05	m x s 0.08		m 0.040	s 0.04	m x s 0.08	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

with m_3 (3.14 %) and m_3-s_6 (3.26 %) remained superior and on par with m_1s_1, m_2s_3, m_2s_6, m_1s_6, m_1s_3, m_2s_4 and m_1s_5 combinations among subplot treatments, main plot treatments and their interactions respectively. At second depth of soil sampling highest TOC content was noted for s_3 (3.07 %) which was on par with s_6 (3.04 %) and s_4 (3.03 %), m_2 (3.05 %) which was on par with m_1 (3.01 %) and m_2s_3 (3.19 %) remained superior and on par with m_1s_1 and m_2s_6 among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.5.1.3 Soil TOC content at the harvest of fodder maize (total residue incorporation)

The effect of nutrient management, tillage and their interaction effects were found to be significant for TOC content at both sampling depths. At 0-20 cm depth, among nutrient managements, s_3 (3.44 %) recorded highest TOC and was on par with s_6 (3.41 %), for tillage levels m_3 (3.39 %) was found to be superior trailed by m_1 (3.28 %) and for interactions highest effect was observed for m_3-s_6 (3.54 %) which was on par with m_3s_3 (3.49 %) and different to others. For 20-60 cm depth, s_6 (3.24 %) recorded highest value followed by s_3 (3.13 %) and m_2 (3.17 %) remained superior and on par with m_1 (3.13 %) among nutrient management and tillage levels. The interaction effect of m_2s_3 (3.39 %) was found to be superior and on par with m_2s_6 (3.31 %) and significantly different to other combinations (Table 54 c).

4.3.4.5.1.4 Soil TOC content at the sowing of fodder maize (root residue incorporation)

The nutrient management, tillage and their interaction effects were statistically significant for soil TOC content at both depths of sampling (Table 54 d). At 0- 20 cm depth, highest TOC was noted for s_6 (3.06 %) which was on par with s_4 (3.04 %) and s_3 (3.02 %), m_1 (3.01 %) which was on par with m_2 (2.97 %) and m_2-s_3 (3.10 %) remained superior and on par with m_1s_1, m_1s_4, m_2s_6, m_1s_6, m_1s_3, m_2s_4 and m_3s_6 combinations among subplot treatments, main plot treatments and their interactions respectively. At second depth of soil sampling highest TOC content was noted for s_6 (2.95 %) which was on par with s_4 and s_3 (2.93 %), m_2 (2.92 %) which was on par with m_1 (2.89 %) and m_2s_3 (3.05 %) remained superior and on par with m_1s_1, m_2s_4 and m_2s_6 among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.5.1.5 Soil TOC content at the harvest of fodder maize (root residue incorporation)

Soil TOC differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 54 e. At 0-20 cm depth, among nutrient management s_3 (3.23 %) recorded highest TOC followed by s_6 (3.22 %), for tillage levels m_3 (3.17 %) was found to be superior trailed by m_1 (3.09 %) and for interactions highest effect was observed for m_3s_6 (3.32 %) which was on par with m_3s_3 (3.27 %) and different to others. For 20-60 cm depth, s_6 (3.06 %) recorded highest value and was on par with s_3 (3.05 %) and m_2 (2.98 %) remained superior and on par with m_1 (2.94 %) among subplot treatments and main plot treatments respectively. The interaction effect of m_2s_3 (3.18 %) was found to be superior and on par with m_2s_6 (3.13 %) and significantly different to other combinations.

4.3.4.5.2 Dissolved Organic Carbon (DOC)

The influence of tillage and nutrient management on soil DOC content at different depths in a grain cowpea - fodder maize sequence are outlined in Table 55.

4.3.4.5.2.1 Soil DOC content at the harvest of grain cowpea

At 0-20 cm depth, among nutrient management, highest soil DOC content was recorded by s_1 (56.27 mg kg^{-1}) which was on par with s_2 (55.57 mg kg^{-1}) and tillage effects were found to be on par for m_1 and m_2 where highest value was noted for m_2 (46.42 mg kg^{-1}). The interaction effects were non significant and m_3s_2 had highest DOC content of 55.75 mg kg^{-1}. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil DOC, sub plot s_2 (53.45 mg kg^{-1}) was superior and statistically on par with s_1 (54.15 mg kg^{-1}) and

Table 54 c. TOC content of soil (%) at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	3.26	3.04	3.30	3.20^{d}	3.11	3.00	2.58	2.89^{d}
s_2	3.23	3.10	3.39	3.24^{cd}	3.08	3.06	2.65	2.93^{d}
s_3	3.39	3.44	3.49	3.44^{a}	3.24	3.39	2.77	3.13^{b}
s_4	3.22	3.17	3.30	3.23^{cd}	3.07	3.12	2.58	2.92^{d}
s_5	3.32	3.20	3.40	3.31^{b}	3.17	3.16	3.07	3.13^{b}
s_6	3.35	3.36	3.54	3.41^{a}	3.20	3.31	3.22	3.24^{a}
s_7	3.22	3.20	3.35	3.26^{c}	3.07	3.15	3.02	3.08^{c}
Mean	3.28^{b}	3.22^{c}	3.39^{a}		3.13^{a}	3.17^{a}	2.84^{b}	
SEm±	M 0.013	s 0.018	M x s 0.031		M 0.010	s 0.017	M x s 0.030	
CD (0.05)	M 0.052	s 0.051	M x s 0.088		M 0.037	s 0.049	M x s 0.086	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 54 d. TOC content of soil (%) at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	3.06	2.91	2.97	2.98^{bc}	2.97	2.86	2.85	2.89^{bc}
s_2	2.95	2.88	2.97	2.93^{c}	2.86	2.84	2.85	2.85^{c}
s_3	3.00	3.10	2.97	3.02^{ab}	2.91	3.05	2.85	2.94^{ab}
s_4	3.07	3.05	2.99	3.04^{ab}	2.95	3.00	2.87	2.94^{a}
s_5	3.02	2.93	2.93	2.96^{c}	2.90	2.89	2.82	2.87^{c}
s_6	3.04	3.06	3.07	3.06^{a}	2.91	3.01	2.93	2.95^{a}
s_7	2.90	2.89	2.75	2.85^{d}	2.77	2.84	2.73	2.78^{d}
Mean	3.01^{a}	2.97^{ab}	2.94^{b}		2.89^{a}	2.92^{a}	2.84^{b}	
SEm±	m 0.010		s 0.017	m x s 0.029	m 0.009		s 0.016	m x s 0.028
CD (0.05)	m 0.037		s 0.047	m x s 0.08	m 0.037		s 0.046	m x s 0.080

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 54 e. TOC content of soil (%) at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	3.06	2.84	3.08	2.99^d	2.90	2.80	2.78	2.83^d
s_2	3.03	2.90	3.16	3.03^{cd}	2.87	2.86	2.86	2.86^{cd}
s_3	3.20	3.23	3.27	3.23^a	3.04	3.18	2.97	3.05^a
s_4	3.03	2.99	3.08	3.03^{cd}	2.89	2.95	2.81	2.88^c
s_5	3.12	3.03	3.18	3.11^b	2.99	2.98	2.90	2.96^b
s_6	3.15	3.18	3.32	3.22^a	3.02	3.13	3.04	3.06^a
s_7	3.03	3.02	3.13	3.06^c	2.89	2.97	2.85	2.90^c
Mean	3.09^b	3.03^c	3.17^a		2.944^b	2.98^a	2.89^c	
SEm±	m 0.012	s 0.017	m x s 0.029		m 0.009	s 0.016	m x s 0.028	
CD (0.05)	m 0.046	s 0.048	m x s 0.084		m 0.036	s 0.047	m x s 0.081	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 55. Effect of tillage and nutrient management on the DOC content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 55 a. DOC content of soil (mg kg^{-1}) at the harvest of grain cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	57.64	55.47	55.71	56.27^a	56.04	54.79	51.63	54.15^a
s_2	55.63	55.34	55.75	55.57^a	54.07	54.65	51.62	53.45^a
s_3	46.40	48.66	46.03	47.03^b	44.85	47.95	41.97	44.92^b
s_4	40.92	41.59	39.99	40.83^d	39.32	40.89	35.92	38.71^d
s_5	38.77	38.90	37.97	38.55^e	37.16	38.20	33.85	36.40^e
s_6	37.67	39.05	38.12	38.28^e	36.10	38.33	33.99	36.14^e
s_7	44.59	45.97	44.10	44.89^c	42.98	45.25	39.97	42.73^c
Mean	45.94^{ab}	46.42^a	45.38^b		44.36^b	45.72^a	41.28^c	
SEm±	m 0.256	s 0.482	m x s 0.835		m 0.185	s 0.335	m x s 0.58	
CD (0.05)	m 0.711	s 0.978	m x s ns		m 0.726	s 0.963	m x s ns	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 55 b. DOC content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	53.12	50.48	51.27	51.62	50.35	49.76	46.32	48.81^a
s_2	49.26	48.38	49.30	48.98	46.55	47.66	44.28	46.16^b
s_3	48.12	49.68	47.66	48.49	45.06	48.55	42.36	45.32^b
s_4	40.18	40.08	39.24	39.83	34.92	38.97	33.85	35.91^d
s_5	38.16	37.53	37.43	37.71	32.86	36.43	32.26	33.85^e
s_6	43.74	44.43	44.35	44.17	39.25	43.07	38.91	40.41^c
s_7	36.03	36.56	35.69	36.10	31.44	35.18	30.25	32.29^f
Mean	44.09	43.88	43.56		40.06^b	42.80^a	38.32^c	
SEm±	m 0.153	s 0.313	m x s 0.543		m 0.187	s 0.307	m x s 0.531	
CD (0.05)	m ns	s 0.899	m x s ns		m 0.735	s 0.88	m x s 1.52	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 55 c. DOC content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	38.59	39.21	38.22	38.67	35.59	38.41	32.90	35.64^a
s_2	39.05	37.16	37.52	37.91	36.00	36.44	32.31	34.92^b
s_3	35.97	35.40	35.84	35.74	33.00	34.67	30.56	32.74^d
s_4	32.59	33.73	32.13	32.82	29.64	32.97	26.94	29.85^f
s_5	37.31	37.29	36.22	36.94	34.36	36.55	31.23	34.04^c
s_6	34.34	33.84	33.67	33.95	31.33	33.07	28.37	30.92^e
s_7	30.43	31.00	30.85	30.76	27.51	30.22	25.53	27.75^g
Mean	35.47	35.38	34.92		32.49^b	34.61^a	29.69^c	
SEm±	m 0.122	s 0.204	m x s 0.353		m 0.147	s 0.193	m x s 0.335	
CD (0.05)	m NS	s 0.585	m x s 0.585		m 0.579	s 0.555	m x s 0.961	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 55 d. DOC content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	57.78	56.44	53.27	55.83^a	47.42	57.14	43.71	49.42^a
s_2	53.82	54.41	51.33	53.10^b	43.68	55.12	41.63	46.81^b
s_3	52.65	55.97	49.65	52.76^b	42.58	56.72	40.12	46.47^b
s_4	44.67	46.24	41.14	44.02^c	34.58	46.97	31.70	37.75^c
s_5	38.54	39.57	35.28	37.80^d	32.15	40.30	29.80	34.08^d
s_6	35.03	37.27	31.00	34.43^e	37.89	38.00	36.69	37.53^c
s_7	27.96	30.14	23.20	27.10^f	30.04	30.88	28.03	29.65^e
Mean	44.34^b	45.72^a	40.69^c		38.33^b	46.45^a	35.95^c	

SEm±	m	s	m x s	m	s	m x s
	0.185	0.405	0.702	0.321	0.350	0.607
CD (0.05)	m	s	m x s	m	s	m x s
	0.729	1.16	ns	1.26	1.09	1.74

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 55 e. DOC content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	33.44	30.41	30.15	31.33^a	29.48	29.72	25.82	28.34^a
s_2	30.49	28.57	28.37	29.14^c	26.61	27.88	23.97	26.16^d
s_3	27.14	26.60	24.79	26.18^e	23.30	25.88	20.47	23.22^e
s_4	31.81	30.78	28.88	30.49^b	28.40	30.05	25.00	27.82^b
s_5	28.79	29.55	26.38	28.24^d	27.22	28.83	24.29	26.78^c
s_6	25.04	26.62	23.53	25.06^f	23.45	25.90	21.38	23.58^e
s_7	33.07	24.38	30.91	29.45^c	21.13	23.64	18.56	21.11^f
Mean	29.97^a	28.13^b	27.57^c		25.65^b	27.41^a	22.78^c	

SEm±	m	s	m x s	m	s	m x s
	0.064	0.173	0.300	0.127	0.171	0.297
CD (0.05)	m	s	m x s	m	s	m x s
	0.253	0.497	0.862	0.499	0.492	0.852

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

significantly different to others. Among tillage highest DOC content was noted for m_2 (45.72 mg kg^{-1}) which was on par with m_1 (44.36 mg kg^{-1}) and the interaction effects were non significant and highest interaction was noted for m_1s_1 (56.04 mg kg^{-1}) combination (Table 55 a).

4.3.4.5.2.2 Soil DOC content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 55 b, at 0-20 cm depth, tillage and interaction effects were similar for soil DOC content and the nutrient management effects were found to be significant. The highest DOC was noted for s_1 (51.62 mg kg^{-1}) followed by s_2 (48.98 mg kg^{-1}) for subplot treatments. At second depth of soil (20-60 cm) sampling, highest DOC content was noted for s_1 (48.81 mg kg^{-1}) trailed by s_2 (46.16 mg kg^{-1}), m_2 (42.80 mg kg^{-1}) followed by m_1 (40.06 mg kg^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant.

4.3.4.5.2.3 Soil DOC content at the harvest of fodder maize (total residue incorporation)

At 0-20 cm depth, main plot effects remained similar and among nutrient management s_1 (38.67 mg kg^{-1}) recorded highest DOC trailed by s_2 (37.91 mg kg^{-1}). For interactions highest effect was observed for m_2s_1 (39.21 mg kg^{-1}) which was statistically different to others. At 20-60 cm depth, s_1 (35.64 mg kg^{-1}) recorded highest value followed by s_2 (34.92 mg kg^{-1}) and m_2 (34.61 mg kg^{-1}) remained superior and was on par with m_1 (32.49 mg kg^{-1}) among different nutrient management and tillage levels respectively. The interaction effect of m_2-s_1 (35.64 mg kg^{-1}) was found to be superior and significantly different to other combinations (Table 55 c).

4.3.4.5.2.4 Soil DOC content at the sowing of fodder maize (root residue incorporation)

The nutrient management and tillage effects were statistically significant while their interaction effects remained non significant for soil DOC content at first level of sampling depth, 0-20 cm (Table 55 d). Highest DOC was noted for s_1 (55.83 mg kg^{-1}) followed by s_2 (53.10 mg kg^{-1}), m_2 (45.72 mg kg^{-1}) trailed by m_1 (44.34 mg kg^{-1}) among subplot treatments and main plot treatments respectively. At second depth of soil sampling highest DOC content was noted for s_1 (49.42 mg kg^{-1}) followed by s_2 (46.81 mg kg^{-1}), m_2 (46.45 mg kg^{-1}) followed by m_1 (38.33 mg kg^{-1}) and m_2s_1 (57.14 mg kg^{-1}) remained superior and on par with m_2-s_3 among subplot treatments, main plot treatments and their interactions respectively.

4.3.4.5.2.5 Soil DOC content at the harvest of fodder maize (root residue incorporation)

Soil DOC differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 55 e. At 0-20 cm depth, among nutrient management s_1 (31.33 mg kg^{-1}) recorded highest DOC followed by s_4 (30.49 mg kg^{-1}), for tillage levels m_1 (29.97 mg kg^{-1}) was found to be superior trailed by m_2 (28.13 mg kg^{-1}) and for interactions highest effect was observed for m_1s_1 (33.44 mg kg^{-1}) which was on par with m_1s_7 (33.07 mg kg^{-1}) and different to others. For 20-60 cm depth, s_1 (28.34 mg kg^{-1}) recorded highest value trailed by s_4 (27.82 mg kg^{-1}) and m_2 (27.41 mg kg^{-1}) remained superior followed by m_1 (25.65 mg kg^{-1}) among tillage and nutrient management respectively. The interaction effect of m_2s_1 (39.72 mg kg^{-1}) was found to be superior and significantly different to other combinations.

4.3.4.5.3 Labile Carbon (LC)

The influence of tillage and nutrient management on soil LC content at different depths in a grain cowpea - fodder maize sequence are outlined in Table 56.

4.3.4.5.3.1 Soil LC content at the harvest of grain cowpea

At 0-20 cm depth, highest soil LC content was recorded by s_6 (678.07 mg kg^{-1}) which was on par with s_5 (588.11 mg kg^{-1}), m_3 (585.80 mg kg^{-1}) followed by m_1 (558.26 mg kg^{-1}) and m_3s_6 (735.18 mg kg^{-1}) followed by m_2s_6 (703.73 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second

Table 56. Effect of tillage and nutrient management on the labile carbon content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping

Table 56 a. Labile carbon content of soil (mg kg^{-1}) at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	555.20	501.51	540.15	532.29^{e}	414.14	479.47	355.06	416.22^{e}
s_2	556.25	518.92	561.00	545.39^{d}	418.17	496.77	373.23	429.39^{d}
s_3	554.78	544.60	553.25	550.88^{d}	417.69	521.32	368.84	435.95^{d}
s_4	577.39	548.85	569.87	565.37^{c}	435.07	526.06	384.97	448.70^{c}
s_5	583.00	574.87	606.47	588.11^{b}	467.85	552.25	414.94	478.34^{b}
s_6	595.29	703.73	735.18	678.07^{a}	579.29	681.03	542.95	601.09^{a}
s_7	485.92	514.56	534.70	511.72^{f}	392.62	491.45	342.47	408.85^{e}
Mean	558.26^{b}	558.15^{b}	585.80^{a}		446.40^{b}	535.48^{a}	397.49^{c}	
SEm±	m 2.35		s 3.48	m x s 6.03	m 3.45		s 3.32	m x s 5.75
CD (0.05)	m 9.25		s 9.99	m x s 17.31	m 13.55		s 9.52	m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 56 b. Labile carbon content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	705.93	613.69	807.11	708.91^{d}	610.93	602.53	480.41	564.62^{d}
s_2	703.81	632.49	831.85	722.71^{c}	610.81	621.20	500.40	577.47^{c}
s_3	701.28	663.00	819.24	727.84^{c}	608.95	651.23	493.73	584.63^{c}
s_4	711.10	646.72	829.53	729.12^{c}	617.77	637.52	490.77	582.02^{c}
s_5	746.82	673.00	869.94	763.25^{b}	652.82	663.86	527.47	614.72^{b}
s_6	850.35	802.22	999.60	884.05^{a}	759.02	793.04	655.89	735.98^{a}
s_7	670.61	614.82	799.11	694.85^{e}	576.94	605.48	455.41	545.94^{e}
Mean	727.10^{b}	663.70^{c}	850.90^{a}		633.90^{b}	653.60^{a}	514.90^{c}	
SEm±	m 5.74		s 4.46	m x s 7.73	m 3.11		s 4.02	m x s 6.97
CD (0.05)	m 22.55		s 12.81	m x s 22.19	m 12.22		s 11.54	m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 56 c. Labile carbon content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	789.16	697.95	857.17	781.43^e	626.26	686.54	561.38	624.73^e
s_2	834.67	765.99	932.02	844.23^d	675.19	754.45	631.93	687.19^d
s_3	853.63	825.45	939.80	872.96^c	695.30	813.41	645.09	717.93^c
s_4	899.88	833.90	967.68	900.49^b	729.57	822.11	671.15	740.94^b
s_5	967.93	889.26	1040.03	965.74^a	791.39	874.12	736.81	800.77^a
s_6	949.90	902.30	1053.34	968.51^a	778.38	887.10	749.03	804.84^a
s_7	711.58	655.15	792.39	719.71^f	535.68	639.68	488.08	554.48^f
Mean	858.1^b	795.7^c	940.4^a		690.3^b	782.5^a	640.5^c	
SEm±	m 4.97	s 5.44	m x s 9.43		m 3.87	s 4.82	m x s 8.35	
CD (0.05)	m 19.54	s 15.62	m x s NS		m 15.19	s 13.83	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 56 d. Labile carbon content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	644.18	533.23	725.16	634.19^e	411.62	501.37	368.21	427.06^e
s_2	643.36	551.13	748.71	647.73^d	415.69	518.92	386.56	440.39^d
s_3	641.26	578.08	737.59	652.31^d	415.23	544.45	381.94	447.21^d
s_4	650.43	581.62	747.33	659.79^c	445.34	553.82	403.09	467.42^c
s_5	679.14	608.37	786.84	691.45^b	479.17	580.76	435.14	498.35^b
s_6	784.59	737.35	916.20	812.71^a	590.29	709.64	563.23	621.05^a
s_7	603.17	548.78	715.71	622.55^e	403.90	520.58	362.74	429.07^e
Mean	663.70^b	591.20^c	768.20^a		451.60^b	561.40^a	441.40^c	
SEm±	m 5.21	s 4.08	m x s 7.08		m 3.83	s 3.43	m x s 5.93	
CD (0.05)	m 20.49	s 11.72	m x s 20.30		m 15.07	s 9.83	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil LC, sub plot s_6 (601.09 mg kg^{-1}) was superior followed by s_5 (478.34 mg kg^{-1}) and significantly different to others. Among tillage highest LC content was noted for m_2 (535.48 mg kg^{-1}) trailed by m_1 (446.40 mg kg^{-1}) and the interaction effects were found to be non significant (Table 56 a).

4.3.4.5.3.2 Soil LC content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 56 b, at 0-20 cm depth, highest LC was noted for s_6 (884.05 mg kg^{-1}) followed by s_5 (763.25 mg kg^{-1}), m_3 (850.90 mg kg^{-1}) followed by m_1 (721.10 mg kg^{-1}) and m_3s_6 (999.60 mg kg^{-1}) followed by m_3s_5 (869.94 mg kg^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest LC content was noted for s_6 (735.98 mg kg^{-1}) trailed by s_5 (614.72 mg kg^{-1}), m_2 (653.60 mg kg^{-1}) followed by m_1 (633.90 mg kg^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant.

4.3.4.5.3.3 Soil LC content at the harvest of fodder maize (total residue incorporation)

Soil LC content differed significantly for nutrient management and tillage while their interaction effects remained non significant at both sampling depths as evidenced in Table 56 c. At 0-20 cm depth, among nutrient management, s_6 (968.51 mg kg^{-1}) recorded highest LC and was on par with s_5 (965.74 mg kg^{-1}) and for tillage levels m_3 (940.40 mg kg^{-1}) recorded highest value followed by m_1 (858.10 mg kg^{-1}). For second depth of sampling, s_6 (804.84 mg kg^{-1}) recorded highest value and was on par with s_5 (800.77 mg kg^{-1}) and m_2 (782.5 mg kg^{-1}) remained superior trailed by m_1 (690.30 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.5.3.4 Soil LC content at the sowing of fodder maize (root residue incorporation)

As outlined in Table 56 d, at 0-20 cm depth, highest LC was noted for s_6 (812.71 mg kg^{-1}) followed by s_5 (691.45 mg kg^{-1}),), m_3 (768.20 mg kg^{-1}) followed by m_1 (663.70 mg kg^{-1}) and m_3s_6 (916.20 mg kg^{-1}) followed by m_3-s_5 (786.84 mg kg^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest LC content was noted for s_6 (621.05 mg kg^{-1}) trailed by s_5 (498.35 mg kg^{-1}), m_2 (561.40 mg kg^{-1}) followed by m_1 (451.60 mg kg^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant.

4.3.4.5.3.5 Soil LC content at the harvest of fodder maize (root residue incorporation)

Soil LC differed significantly for nutrient management, tillage while their interaction effects remained non significantat both sampling depths as evidenced in Table 56 e. At 0-20 cm depth, among nutrient management, s_6 (749.03 mg kg^{-1}) recorded highest LC and was on par with s_5 (736.81 mg kg^{-1}) and for tillage levels m_3 (855.40 mg kg^{-1}) recorded highest value followed by m_1 (788.80 mg kg^{-1}). For second depth of sampling, s_6 (723.61 mg kg^{-1}) recorded highest value and was on par with s_5 (718.96 mg kg^{-1}) and m_2 (701.20 mg kg^{-1}) remained superior trailed by m_1 (609.80 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.5.4 Recalcitrant Carbon (RC)

The influence of tillage and nutrient management on soil RC content at different depths in a grain cowpea - fodder maize sequence are outlined in Table 57.

4.3.4.5.4.1 Soil RC content at the harvest of grain cowpea

At 0-20 cm depth, highest soil RC content was recorded by s_6 (1.21 %) followed by s_5 (1.15 %), m_3 (1.17 %) followed by m_1 (0.97 %) and m_3-s_6 (1.43 %)

Table 56 e. Labile carbon content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	720.26	629.87	771.63	561.38^e	547.68	607.77	484.83	546.76^e
s_2	765.75	696.22	843.51	631.93^d	598.26	674.81	554.25	609.11^d
s_3	783.14	750.35	851.03	645.09^c	618.92	730.27	568.81	639.33^c
s_4	830.72	761.88	880.53	671.15^b	644.99	739.88	594.04	659.64^b
s_5	897.00	815.72	947.98	736.81^a	708.30	793.05	655.52	718.96^a
s_6	879.81	827.02	959.77	749.03^a	697.64	805.74	667.44	723.61^a
s_7	645.12	582.90	733.66	488.08^f	452.88	556.85	406.49	472.07^f
Mean	788.8^b	723.4^c	855.4^a		609.8^b	701.2^a	561.6^c	
SEm±	m 4.43	s 5.03	m x s 8.72		m 3.69	s 4.43	m x s 7.68	
CD (0.05)	m 17.40	s 14.45	m x s NS		m 14.49	s 12.72	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 57. Effect of tillage and nutrient management on the recalcitrant carbon (RC) content of soil (%) at different depths in a grain cowpea – fodder maize

Table 57 a. RC content of soil (%) at the harvest of grain cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.78	0.42	1.05	0.75^f	0.54	0.20	0.82	0.52^f
s_2	0.85	0.48	1.14	0.82^e	0.62	0.26	0.92	0.60^e
s_3	0.89	0.54	1.16	0.86^d	0.66	0.31	0.93	0.63^d
s_4	1.14	0.92	1.19	1.08^c	0.91	0.70	0.96	0.85^c
s_5	1.22	0.92	1.30	1.15^b	0.99	0.70	1.07	0.92^b
s_6	1.23	0.98	1.43	1.21^a	1.01	0.75	1.20	0.98^a
s_7	0.68	0.62	0.93	0.74^f	0.45	0.39	0.70	0.51^f
Mean	0.97^b	0.70^c	1.17^a		0.74^b	0.47^c	0.94^a	
SEm±	m 0.012	s 0.007	m x s 0.013		m 0.012	s 0.006	m x s 0.012	
CD (0.05)	m 0.048	s 0.021	m x s 0.037		m 0.045	s 0.019	m x s 0.033	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 57 b. RC content of soil (%) at the time of sowing of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.10	0.80	1.32	1.07^{f}	0.87	0.58	1.09	0.85^{f}
s_2	1.16	0.90	1.42	1.16^{e}	0.93	0.68	1.19	0.93^{e}
s_3	1.20	0.98	1.43	1.20^{d}	0.97	0.74	1.21	0.97^{d}
s_4	1.66	1.35	1.85	1.62^{c}	1.19	0.93	1.19	1.10^{c}
s_5	1.79	1.46	1.98	1.74^{b}	1.28	1.00	1.29	1.19^{b}
s_6	1.80	1.51	2.02	1.78^{a}	1.30	1.05	1.33	1.23^{a}
s_7	1.01	0.75	1.21	0.99^{g}	0.78	0.51	0.98	0.75^{g}
Mean	1.34^{b}	1.11^{c}	1.60^{a}		1.05^{b}	0.78^{c}	1.18^{a}	
SEm±	m 0.013	s 0.012	m x s 0.021		m 0.010	s 0.007	m x s 0.013	
CD (0.05)	m 0.052	s 0.034	m x s NS		m 0.040	s 0.022	m x s 0.030	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 57 c. RC content of soil (%) at the time of harvest of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	1.14	0.81	1.27	1.07^{f}	0.90	0.59	1.05	0.85^{e}
s_2	1.38	1.08	1.55	1.34^{e}	1.00	0.86	1.23	1.03^{d}
s_3	1.67	1.43	1.82	1.64^{c}	1.23	1.14	1.24	1.20^{b}
s_4	1.60	1.32	1.76	1.56^{d}	1.17	1.09	1.23	1.17^{c}
s_5	1.92	1.62	2.03	1.86^{b}	1.21	1.10	1.32	1.21^{b}
s_6	1.95	1.70	2.10	1.92^{a}	1.23	1.14	1.40	1.25^{a}
s_7	1.04	0.83	1.18	1.02^{g}	0.81	0.60	0.95	0.78^{f}
Mean	1.53^{b}	1.26^{c}	1.67^{a}		1.08^{b}	0.93^{c}	1.20^{a}	
SEm±	m 0.012	s 0.013	m x s 0.022		m 0.008	s 0.007	m x s 0.013	
CD (0.05)	m 0.047	s 0.037	m x s ns		m 0.032	s 0.022	m x s 0.038	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

followed by m_3s_5 (1.30 %) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil RC, sub plot s_6 (0.98 %) was superior followed by s_5 (0.92 %) and significantly different to others. Among tillage highest RC content was noted for m_3 (0.94 %) trailed by m_1 (0.74 %) and for the interaction effects, highest value was noted for m_3s_6 (1.20 %) followed by m_3s_5 (1.07 %) (Table 57 a).

4.3.4.5.4.2 Soil RC content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 57 b, at 0-20 cm depth, highest RC was noted for s_6 (1.78 %) followed by s_5 (1.74 %) and m_3 (1.60 %) followed by m_1 (1.34 %) among sub plot treatments and main plot treatments respectively and the interaction effects were found to be non significant. At second depth of soil (20-60 cm) sampling, highest RC content was noted for s_6 (1.23 %) trailed by s_5 (1.19 %), m_3 (1.18 %) followed by m_1 (1.05 %) and m_3s_6 (1.33 %) followed by m_3s_5 (1.29 %) among nutrient management, tillage and their interaction effects respectively.

4.3.4.5.4.3 Soil RC content at the harvest of fodder maize (total residue incorporation)

Soil RC content differed significantly for nutrient management and tillage while their interaction effects remained non significant at first depth of sampling while remained significant at second sampling depth as evidenced in Table 57 c. At 0-20 cm depth, among nutrient management, s_6 (1.92 %) recorded highest RC trailed by s_5 (1.86 %) and for tillage levels m_3 (1.67 %) recorded highest value followed by m_1 (1.53 %). For second depth of sampling, s_6 (1.25 %) recorded highest value followed by s_5 (1.21 %), m_3 (1.20 %) remained superior trailed by m_1 (1.08 %) and m_3s_6 (1.40 %) followed by m_3s_5 (1.32 %) among different nutrient management, tillage levels and interaction effects respectively.

4.3.4.5.4.4 Soil RC content at the sowing of fodder maize (root residue incorporation)

As outlined in Table 57 d, at 0-20 cm depth, highest RC was noted for s_6 (1.29 %) followed by s_5 (1.23 %),), m_3 (1.25 %) followed by m_1 (1.06 %) and m_3-s_6 (1.50 %) followed by m_3-s_5 (1.38 %) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest RC content was noted for s_6 (1.29 %) trailed by s_5 (1.23 %), m_2 (1.02 %) followed by m_1 (0.83 %) and m_3s_6 (1.27 %) followed by m_3s_5 (1.15 %) among sub plot treatments, main plot treatments and their interaction effects respectively.

4.3.4.5.4.5 Soil RC content at the harvest of fodder maize (root residue incorporation)

Soil RC content differed significantly for nutrient management and tillage while their interaction effects remained non significant at first depth of sampling while remained significant at second sampling depth as evidenced in Table 57 e. At 0-20 cm depth, among nutrient management, s_6 (1.72 %) recorded highest RC trailed by s_5 (1.66 %) and for tillage levels m_3 (1.49 %) recorded highest value followed by m_1 (1.34 %). For second depth of sampling, s_6 (1.29 %) recorded highest value followed by s_5 (1.24 %), m_3 (1.12 %) remained superior trailed by m_1 (1.02 %) and m_3s_6 (1.36 %) followed by m_3s_5 (1.30 %) among different nutrient management tillage levels and interaction effects respectively.

4.3.4.6 Soil N fractions

4.3.4.6.1 Total Nitrogen (TN)

Effect of tillage and nutrient management on total nitrogen content of soil at different depths in a grain cowpea - fodder maize sequence are presented in Table 58

4.3.4.6.1.1 Soil TN content at the harvest of grain cowpea

At 0-20 cm depth, highest soil TN content was recorded by s_5 (7306 mg kg^{-1}) followed by s_6 (6709 mg kg^{-1}) and m_3 (6370 mg kg^{-1}) which was on par with

Table 57 d. RC content of soil (%) at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.87	0.50	1.12	0.83[f]	1.12	0.28	0.89	0.83[f]
s_2	0.94	0.56	1.22	0.91[e]	1.22	0.34	0.99	0.91[e]
s_3	0.98	0.63	1.23	0.95[d]	1.23	0.39	1.01	0.95[d]
s_4	1.23	1.00	1.26	1.17[c]	1.26	0.77	1.03	1.17[c]
s_5	1.32	1.01	1.38	1.23[b]	1.38	0.78	1.15	1.23[b]
s_6	1.32	1.06	1.50	1.29[a]	1.50	0.83	1.27	1.29[a]
s_7	0.76	0.51	1.00	0.76[g]	1.00	0.27	0.77	0.76[g]
Mean	1.06[b]	0.75[c]	1.25[a]		0.83[b]	0.52[c]	1.02[a]	
SEm±	m 0.012	s 0.008	m x s 0.013		m 0.012	s 0.007	m x s 0.012	
CD (0.05)	m 0.049	s 0.023	m x s 0.040		m 0.047	s 0.021	m x s 0.036	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 57 e. RC content of soil (%) at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	0.94	0.59	1.10	0.88[f]	0.70	0.37	0.87	0.65[e]
s_2	1.18	0.86	1.38	1.14[e]	0.95	0.64	1.14	0.91[d]
s_3	1.48	1.20	1.64	1.44[c]	1.13	0.97	1.16	1.09[c]
s_4	1.42	1.09	1.58	1.36[d]	1.19	0.86	1.27	1.10[c]
s_5	1.74	1.39	1.85	1.66[b]	1.26	1.16	1.30	1.24[b]
s_6	1.77	1.47	1.92	1.72[a]	1.30	1.20	1.36	1.29[a]
s_7	0.86	0.59	0.99	0.81[g]	0.63	0.36	0.76	0.58[f]
Mean	1.34[b]	1.03[c]	1.49[a]		1.02[b]	0.79[c]	1.12[a]	
SEm±	m 0.012	s 0.012	m x s 0.021		m 0.009	s 0.009	m x s 0.016	
CD (0.05)	m 0.048	s 0.035	m x s ns		m 0.036	s 0.027	m x s 0.047	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 58. Effect of tillage and nutrient management on total nitrogen content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping

Table 58 a. TN content of soil (mg kg^{-1}) at the harvest of grain cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5834	5468	5710	5671^e	5501	5243	4930	5225^c
s_2	6821	6617	6903	6780^b	6486	6362	6084	6311^a
s_3	6189	6305	6203	6233^c	5858	6052	5413	5774^b
s_4	6125	6046	6078	6083^d	6425	5777	5266	5822^b
s_5	7383	7196	7338	7306^a	5820	6919	6506	6415^a
s_6	6635	6675	6817	6709^b	6817	6406	5992	6405^a
s_7	5513	5496	5538	5516^f	5178	5243	4733	5051^d
Mean	6357^a	6258^b	6370^a		6012^a	6000^a	5561^b	
SEm±	m 20.74	s 39.79	m x s 68.92		m 16.18	s 37.19	m x s 64.42	
CD (0.05)	m 81.43	s 114.13	m x s ns		m 63.53	s 106.67	m x s 184.76	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 58 b. TN content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	6261	5832	6206	6100^d	5827	5598	5602	5676
s_2	7187	6966	7062	7072^b	6420	6619	6471	6503
s_3	6651	6736	6760	6716^c	6125	6402	6099	6208
s_4	6511	6387	6806	6568^c	6123	6178	5997	6099
s_5	7553	7561	7831	7648^a	7114	7158	7055	7109
s_6	7217	6989	7258	7155^b	6787	6889	6786	6820
s_7	5902	5840	6001	5914^d	5429	5732	5482	5547
Mean	6755^a	6616^b	6846^a		6260	6368	6213	
SEm±	m 23.38	s 84.66	m x s 146.64		m 82.85	s 104.12	m x s 180.34	
CD (0.05)	m 91.80	s 242.82	m x s NS		m ns	s 298.64	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

m_1 (6357 mg kg^{-1}) among nutrient management and tillage levels respectively and their interactions remained non significant. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil TN, sub plot s_5 (6415 mg kg^{-1}) was superior and on par with s_6 (6405 mg kg^{-1}) and tillage level, m_1 (6012 mg kg^{-1}) recorded highest value and was on par with m_2 (6000 mg kg^{-1}) and significantly different to others. The interaction effects were found to be significant and highest interaction was noted for m_2s_5 (6919 mg kg^{-1}) combination which was on par with m_1s_6 (6817 mg kg^{-1}) and significantly different to others (Table 58 a).

4.3.4.6.1.2 Soil TN content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 58 b, at 0-20 cm depth, highest TN was noted for s_5 (7648 mg kg^{-1}) followed by s_6 (7155 mg kg^{-1}) and m_3 (6846 mg kg^{-1}) which was on par with m_1 (6755 mg kg^{-1}) among nutrient management and tillage levels respectively and the interaction effects remained non significant. At second depth of soil (20-60 cm) sampling, among sub plot treatments highest TN content was noted for s_5 (7109 mg kg^{-1}) which was on par with s_6 (6820 mg kg^{-1}) and significantly different to others. The main plot treatments and interaction effects were found to be non significant.

4.3.4.6.1.3 Soil TN content at the harvest of fodder maize (total residue incorporation)

Soil TN content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 58 c. At 0-20 cm depth, highest TN was recorded for s_5 (8416 mg kg^{-1}) trailed by s_6 (7810 mg kg^{-1}), m_3 (7572 mg kg^{-1}) on par with m_1 (7480 mg kg^{-1}) and m_1s_5 (8568 mg kg^{-1}) on par with m_3s_5 (8495 mg kg^{-1}) among sub plot treatments, main plot treatments and interaction effects respectively. For second depth of sampling, highest TN was recorded for s_5 (7950 mg kg^{-1}) trailed by s_6 (7322 mg kg^{-1}), m_3 (7121 mg kg^{-1}) on par with m_1 (7031 mg kg^{-1}) and m_1s_5 (8094 mg kg^{-1}) on par with m_3s_5 (8027 mg kg^{-1}) among different nutrient management, tillage levels and interaction effects respectively.

4.3.4.6.1.4 Soil TN content at the sowing of fodder maize (root residue incorporation)

As outlined in Table 58 d, at 0-20 cm depth, highest TN was noted for s_5 (7431 mg kg^{-1}) followed by s_2 (6954 mg kg^{-1}),), m_1 (6519 mg kg^{-1}) on par with m_3 (6514 mg kg^{-1}) and m_1s_5 (7538 mg kg^{-1}) on par with m_3s_5 (7437 mg kg^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest TN content was noted for s_5 (6865 mg kg^{-1}) trailed by s_2 (6417 mg kg^{-1}), m_1 (6097 mg kg^{-1}) followed by m_2 (5998 mg kg^{-1}) and m_1s_5 (7087 mg kg^{-1}) on par with m_2s_5 (6901 mg kg^{-1}) among sub plot treatments, main plot treatments and interaction effects respectively.

4.3.4.6.1.5 Soil TN content at the harvest of fodder maize (root residue incorporation)

Soil TN differed significantly for nutrient management and tillage while their interaction effects remained similar at both sampling depths as evidenced in Table 58 e. At 0-20 cm depth, among nutrient management, s_5 (7963 mg kg^{-1}) recorded highest TN followed by s_6 (7362 mg kg^{-1}) and for tillage levels m_1 (7027 mg kg^{-1}) recorded highest value and was on par with m_3 (6982 mg kg^{-1}). For second depth of sampling, s_5 (7206 mg kg^{-1}) recorded highest value followed by s_6 (6613 mg kg^{-1}) and m_1 (6252 mg kg^{-1}) remained superior trailed by m_3 (6025 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.6.2 Ammoniacal nitrogen - NH_4-N

Effect of tillage and nutrient management on NH_4-N content of soil at different depths in a grain cowpea - fodder maize sequence are presented in Table 59

Table 58 c. TN content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	6907	6317	6973	6732^d	6478	5921	6547	6316^d
s_2	7871	7476	8182	7843^b	7440	7064	7738	7414^b
s_3	7232	7202	7459	7298^c	6783	6751	7003	6846^c
s_4	7303	7042	7223	7189^c	6853	6604	6780	6746^c
s_5	8568	8184	8495	8416^a	8094	7729	8027	7950^a
s_6	7786	7665	7979	7810^b	7300	7183	7483	7322^b
s_7	6691	6503	6694	6629^d	6266	6087	6272	6208^d
Mean	7480^a	7198^b	7572^a		7031^a	6763^b	7121^a	
SEm±	m 25.96	s 44.99	m x s 77.93		m 24.48	s 42.53	m x s 73.67	
CD (0.05)	m 101.94	s 129.05	m x s 223.52		m 96.12	s 121.99	m x s 211.3	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 58 d. TN content of soil (mg kg^{-1})at the time of sowing of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	6011	5609	5914	5845^f	5604	5251	5137	5331^f
s_2	6993	6759	7110	6954^b	6574	6376	6300	6417^b
s_3	6360	6454	6406	6407^d	5963	6074	5630	5889^d
s_4	6278	6169	6177	6208^e	5849	5769	5373	5664^e
s_5	7538	7317	7437	7431^a	7087	6901	6606	6865^a
s_6	6784	6800	6917	6833^c	6359	6393	6096	6283^c
s_7	5668	5619	5638	5642^g	5246	5221	4831	5099^g
Mean	6519^a	6389^b	6514^a		6097^a	5998^b	5711^c	
SEm±	m 20.95	s 40.5	m x s 70.14		m 15.74	s 38.21	m x s 66.19	
CD (0.05)	m 82.26	s 116.16	m x s 201.19		m 61.80	s 109.61	m x s 189.85	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 58 e. TN content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	6459	5957	6267	6228^d	5676	5676	5323	5493^d
s_2	7432	7110	7466	7336^b	6657	6657	6499	6591^b
s_3	6797	6823	6757	6792^c	6028	6028	5808	6049^c
s_4	6840	6651	6727	6740^c	6060	6060	5774	5994^c
s_5	8102	7795	7992	7963^a	7309	7309	7022	7206^a
s_6	7334	7277	7474	7362^b	6566	6566	6504	6613^b
s_7	6228	6103	6194	6175^d	5467	5467	5248	5442^d
Mean	7027^a	6817^b	6982^a		6252^a	6318^b	6025^b	
SEm±	m 21.67	s 42.89	m x s 74.28		m 18.98	s 39.43	m x s 68.29	
CD (0.05)	m 85.12	s 123.01	m x s NS		m 74.54	s 113.09	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 59. Effect of tillage and nutrient management on NH_4-N content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping

Table 59 a. NH_4-N content of soil (mg kg^{-1}) at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	238.95	222.83	234.52	232.10^e	190.80	199.71	183.29	191.27^f
s_2	243.78	235.01	247.79	242.19^d	195.52	210.54	194.69	200.25^e
s_3	252.53	256.17	253.76	254.10^c	202.90	228.85	199.92	210.56^d
s_4	260.25	255.84	258.84	258.30^c	211.82	230.83	206.70	216.45^c
s_5	285.90	277.61	285.05	282.86^b	236.49	252.16	231.72	240.13^b
s_6	286.45	287.25	294.73	289.47^a	236.14	259.38	238.87	244.80^a
s_7	239.75	237.83	241.27	239.62^d	191.91	213.24	189.12	198.09^e
Mean	258.23^a	253.22^b	259.42^a		209.37^b	227.81^a	206.33^b	
SEm±	m 0.849	s 1.54	m x s 2.68		m 0.905	s 1.33	m x s 2.30	
CD (0.05)	m 3.33	s 4.43	m x s 7.68		m 3.55	s 3.82	m x s 6.62	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 59 b. NH_4-N content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	248.49	228.54	247.24	241.42^{e}	190.30	191.41	182.38	188.03^{e}
s_2	253.03	240.70	260.60	251.44^{d}	195.04	202.15	193.77	196.99^{d}
s_3	261.63	262.01	266.26	263.30^{c}	202.86	220.54	199.44	207.61^{c}
s_4	269.44	261.29	271.31	267.35^{c}	209.23	219.90	203.72	210.95^{c}
s_5	294.90	282.76	297.41	291.69^{b}	233.57	240.99	228.40	234.32^{b}
s_6	295.14	292.37	307.07	298.19^{a}	235.14	250.02	237.39	240.85^{a}
s_7	249.17	243.56	254.12	248.95^{d}	190.14	202.98	186.92	193.35^{d}
Mean	267.40^{b}	258.74^{c}	272.0^{a}		208.04^{b}	218.28^{a}	204.57^{c}	
SEm±	m 0.955	s 1.58	m x s 2.74		m 0.75	s 1.30	m x s 2.26	
CD (0.05)	m 3.74	s 4.55	m x s 7.88		m 2.94	s 3.75	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 59 c. NH_4-N content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	345.53	319.39	342.06	335.66^{d}	266.57	269.64	258.62	264.94^{e}
s_2	348.03	332.56	356.80	345.80^{c}	269.75	281.29	271.12	274.05^{d}
s_3	355.95	357.91	360.73	358.20^{b}	277.47	303.62	275.89	285.6^{c}
s_4	364.60	355.18	358.21	359.33^{b}	284.16	300.92	272.28	285.79^{c}
s_5	386.36	371.68	380.96	379.67^{a}	304.72	317.19	293.47	305.13^{b}
s_6	384.00	381.60	390.92	385.51^{a}	303.55	325.77	301.97	310.43^{a}
s_7	340.31	334.40	337.97	337.56^{d}	261.80	281.59	252.98	265.46^{e}
Mean	360.68^{a}	350.38^{b}	361.09^{a}		281.12^{b}	297.14^{a}	275.19^{c}	
SEm±	m 1.18	s 2.05	m x s 3.55		m 1.07		s 1.67	m x s 2.89
CD (0.05)	m 4.65	s 5.88	m x s 10.18		m 4.21		s 4.79	m x s 8.30

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 59 d. NH_4-N content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	242.58	223.05	241.24	235.62^{f}	191.15	191.33	181.99	188.16^{f}
s_2	247.25	235.14	254.52	245.64^{d}	195.69	201.89	193.20	196.93^{d}
s_3	255.88	256.22	260.28	257.46^{c}	204.29	221.08	199.65	208.34^{c}
s_4	263.40	255.54	258.80	259.25^{c}	211.18	221.09	198.12	210.13^{c}
s_5	288.80	277.05	284.75	283.53^{b}	235.84	242.47	223.03	233.78^{b}
s_6	289.21	286.63	294.37	290.07^{a}	237.30	251.47	231.97	240.25^{a}
s_7	243.10	237.72	241.42	240.75^{e}	191.64	203.72	180.78	192.05^{e}
Mean	261.46^{a}	253.04^{b}	262.19^{a}		209.58^{b}	219.00^{a}	201.20^{c}	
SEm±	m 0.85	s 1.54	m x s 2.68		m 0.72	s 1.30	m x s 2.26	
CD (0.05)	m 3.35	s 4.43	m x s 7.68		m 2.83	s 3.75	m x s 6.50	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 59 e. NH_4-N content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	334.27	309.55	329.23	324.35^{e}	268.48	264.86	248.91	260.75^{e}
s_2	337.00	322.60	328.39	329.33^{e}	272.21	277.04	246.49	265.25^{e}
s_3	344.99	347.51	332.17	341.56^{d}	279.58	298.83	250.66	276.35^{d}
s_4	353.45	345.00	347.21	348.56^{c}	286.67	296.69	265.06	282.81^{c}
s_5	374.61	361.06	369.32	368.33^{b}	307.27	313.01	286.19	302.15^{b}
s_6	372.59	370.95	379.25	374.26^{a}	306.88	322.44	295.53	308.29^{a}
s_7	328.60	323.55	326.30	326.15^{e}	262.47	275.44	243.82	260.58^{e}
Mean	349.35^{a}	340.03^{c}	344.55^{b}		283.36^{b}	292.61^{a}	262.37^{c}	
SEm±	m 1.04	s 2.00	m x s 3.46		m 0.93	s 1.68	m x s 2.91	
CD (0.05)	m 4.10	s 5.74	m x s 9.94		m 3.67	s 4.82	m x s 8.35	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.4.6.2.1 Soil NH_4-N content at the harvest of grain cowpea

At 0-20 cm depth, highest soil NH_4-N content was recorded by s_6 (289.47 mg kg^{-1}) followed by s_5 (282.86 mg kg^{-1}), m_3 (259.42 mg kg^{-1}) followed by m_1 (258.23 mg kg^{-1}) and m_3s_6 (294.73 mg kg^{-1}) on par with m_2s_6 (287.25 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil NH_4-N, sub plot s_6 (244.80 mg kg^{-1}) was superior and significantly different to others followed by s_5 (240.13 mg kg^{-1}). Among main plot treatments highest NH_4-N content was noted for m_2 (227.81 mg kg^{-1}) trailed by m_1 (209.37 mg kg^{-1}) and the interaction effects were significant and highest interaction was noted for m_2s_6 (259.38 mg kg^{-1}) combination (Table 59 a).

4.3.4.6.2.2 Soil NH_4-N content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 59 b, at 0-20 cm depth, highest soil NH_4-N content was recorded by s_6 (298.19 mg kg^{-1}) followed by s_5 (291.69 mg kg^{-1}), m_3 (272.00 mg kg^{-1}) followed by m_1 (267.40 mg kg^{-1}) and m_3s_6 (307.07 mg kg^{-1}) followed by m_1s_6 (295.14 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil NH_4-N, sub plot s_6 (240.85 mg kg^{-1}) was superior and significantly different to others followed by s_5 (234.32 mg kg^{-1}). Among main plot treatments highest NH_4-N content was noted for m_2 (218.28 mg kg^{-1}) trailed by m_1 (208.04 mg kg^{-1}) and the interaction effects remained non significant and highest interaction was noted for m_2s_6 (250.02 mg kg^{-1}) combination.

4.3.4.6.2.3 Soil NH_4-N content at the harvest of fodder maize (total residue incorporation)

As evidenced in Table 59 c, soil NH_4-N content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths. At 0-20 cm depth, highest soil NH_4-N content was recorded by s_6 (385.51 mg kg^{-1}) on par with s_5 (379.67 mg kg^{-1}), m_3 (361.09 mg kg^{-1}) on par with m_1

(360.68 mg kg^{-1}) and m_3s_6 (390.92 mg kg^{-1}) on par with m_1s_6 (384.00 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil NH_4-N, sub plot s_6 (310.43 mg kg^{-1}) was superior and significantly different to others followed by s_5 (305.13 mg kg^{-1}). Among main plot treatments highest NH_4-N content was noted for m_2 (297.14 mg kg^{-1}) trailed by m_1 (281.12 mg kg^{-1}) and highest interaction effect was noted for m_2s_6 (325.77 mg kg^{-1}).

4.3.4.6.2.4 Soil NH_4-N content at the sowing of fodder maize (root residue incorporation)

Soil NH_4-N content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 59 d. At 0-20 cm depth, highest soil NH_4-N content was recorded by s_6 (290.07 mg kg^{-1}) followed by s_5 (283.53 mg kg^{-1}), m_1 (261.46 mg kg^{-1}) on par with m_3 (262.19 mg kg^{-1}) and m_3s_6 (294.37 mg kg^{-1}) on par with m_1s_6 (289.21 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil NH_4-N, sub plot s_6 (240.25 mg kg^{-1}) was superior and significantly different to others followed by s_5 (233.78 mg kg^{-1}). Among main plot treatments highest NH_4-N content was noted for m_2 (219.00 mg kg^{-1}) trailed by m_1 (209.58 mg kg^{-1}) and highest interaction effect was noted for m_2s_6 (251.47 mg kg^{-1}).

4.3.4.6.2.5 Soil NH_4-N content at the harvest of fodder maize (root residue incorporation)

The soil NH_4-N content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths (Table 59 e). At 0-20 cm depth, highest soil NH_4-N content was recorded by s_6 (374.26 mg kg^{-1}) followed by s_5 (368.33 mg kg^{-1}), m_1 (349.35 mg kg^{-1}) trailed by m_3 (344.55 mg kg^{-1}) and m_3-s_6 (379.25 mg kg^{-1}) on par with m_1-s_5 (374.61 mg kg^{-1}) and m_1s_6 (372.59 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted

Table 60. Effect of tillage and nutrient management on NO_3-N content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 60 a. NO_3-N content of soil (mg kg^{-1}) at the harvest of grain cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	71.55	66.70	70.24	69.50^{f}	62.88	62.99	57.30	61.06
s_2	71.93	69.29	73.17	71.46^{e}	63.32	65.42	59.92	62.89
s_3	82.75	83.89	83.00	83.21^{b}	74.11	79.75	69.89	74.58
s_4	74.07	72.63	73.69	73.46^{d}	65.30	68.49	60.53	64.77
s_5	76.25	73.69	76.11	75.35^{c}	52.15	69.55	62.74	61.48
s_6	91.14	91.28	93.72	92.05^{a}	82.10	86.75	79.92	82.92
s_7	72.67	72.04	73.06	72.59^{de}	63.89	67.92	59.74	63.85
Mean	77.19^{a}	75.64^{b}	77.57^{a}		66.25	71.55	64.29	
SEm±	m 0.254	s 0.478	m x s 0.828		m 1.51	s 2.61	m x s 4.52	
CD (0.05)	m 0.998	s 1.37	m x s NS		m NS	s 7.48	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 60 b. NO_3-N content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	74.16	68.41	74.12	72.23^{f}	59.95	62.33	56.84	59.71^{f}
s_2	74.47	71.03	77.16	74.22^{e}	60.62	64.76	59.46	61.61^{e}
s_3	84.50	85.68	86.25	85.48^{b}	70.69	79.07	68.84	72.86^{b}
s_4	76.50	74.30	77.57	76.12^{d}	62.10	67.38	59.72	63.06^{d}
s_5	78.66	75.32	80.04	78.01^{c}	64.07	68.37	61.93	64.79^{c}
s_6	93.42	92.85	97.67	94.65^{a}	78.78	85.40	79.01	81.06^{a}
s_7	75.01	73.67	76.95	75.21^{de}	60.57	66.66	58.86	62.03^{de}
Mean	79.53^{b}	77.32^{c}	81.39^{a}		70.56^{a}	65.25^{b}	63.52^{c}	
SEm±	m 0.29	s 0.48	m x s 0.84		m 0.26	s 0.42	m x s 0.74	
CD (0.05)	m 1.15	s 1.39	m x s 2.42		m 1.05	s 1.22	m x s 2.12	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 60 c. NO_3-N content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	83.01	76.19	83.59	80.93^e	64.91	68.22	63.15	65.43^e
s_2	83.14	78.86	86.70	82.90^d	65.23	70.66	65.77	67.22^d
s_3	93.13	93.22	95.71	94.02^b	76.92	84.38	74.88	78.73^b
s_4	85.55	82.41	84.63	84.20^d	67.20	73.65	63.70	68.19^d
s_5	87.79	83.39	87.22	86.13^c	69.20	74.60	65.96	69.92^c
s_6	102.39	100.96	104.88	102.74^a	83.93	91.72	83.13	86.26^a
s_7	84.21	81.86	84.02	83.36^d	66.23	73.43	63.23	67.63^d
Mean	88.46^a	85.30^b	89.54^a		70.52^b	76.67^a	68.55^c	
SEm±	m 0.30	s 0.53	m x s 0.91		m 0.30	s 0.45	m x s 0.78	
CD (0.05)	m 1.21	s 1.52	m x s 2.63		m 1.18	s 1.30	m x s 2.25	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 60 d. NO_3-N content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	72.19	67.11	71.34	70.21^f	61.73	62.60	58.03	60.79^f
s_2	72.54	69.70	74.24	72.16^e	62.17	65.01	60.62	62.60^e
s_3	82.66	83.67	83.40	83.24^b	72.28	78.69	69.93	73.63^b
s_4	74.45	72.86	74.52	73.94^d	63.92	67.95	61.02	64.30^d
s_5	76.62	74.01	76.91	75.85^c	65.96	69.08	63.21	66.08^c
s_6	91.47	91.54	94.44	92.48^a	80.63	86.10	80.19	82.31^a
s_7	73.13	72.17	73.21	72.84^{de}	62.63	67.26	60.28	63.39^{de}
Mean	77.58^a	75.86^b	78.29^a		67.05^b	70.95^a	64.75^c	
SEm±	m 0.26	s 0.47	m x s 0.83		m 0.24	s 0.43	m x s 0.75	
CD (0.05)	m 1.02	s 1.37	m x s 2.38		m 0.96	s 1.24	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

but with lower values of soil NH_4-N, sub plot s_6 (308.29 mg kg^{-1}) was superior and significantly different to others followed by s_5 (302.15 mg kg^{-1}). Among main plot treatments highest NH_4-N content was noted for m_2 (292.61 mg kg^{-1}) trailed by m_1 (283.36 mg kg^{-1}) and highest interaction effect was noted for m_2s_6 (322.44 mg kg^{-1}).

4.3.4.6.3 Nitrate nitrogen – NO_3-N

Effect of tillage and nutrient management on NO_3-N content of soil at different depths in a grain cowpea - fodder maize sequence are presented in Table 60.

4.3.4.6.3.1 Soil NO_3-N content at the harvest of grain cowpea

At 0-20 cm depth, highest soil NO_3-N content was recorded by s_6 (92.05 mg kg^{-1}) followed by s_3 (83.21 mg kg^{-1}) and m_3 (77.57 mg kg^{-1}) on par with m_1 (77.19 mg kg^{-1}) among nutrient management and tillage respectively and their interaction effects remained non significant. For second depth of sampling (20-60 cm), main plot treatments and interaction effects remained similar and among sub plot treatments s_6 (82.92 mg kg^{-1}) was found to be superior and on par with s_3 (74.58 mg kg^{-1}) (Table 60 a).

4.3.4.6.3.2 Soil NO_3-N content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 60 b, at 0-20 cm depth, highest soil NO_3-N content was recorded by s_6 (94.65 mg kg^{-1}) followed by s_3 (85.48 mg kg^{-1}), m_3 (81.39 mg kg^{-1}) followed by m_1 (79.53 mg kg^{-1}) and m_3s_6 (97.67 mg kg^{-1}) followed by m_1s_6 (93.42 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil NO_3-N, sub plot s_6 (81.06 mg kg^{-1}) was superior and significantly different to others followed by s_3 (72.86 mg kg^{-1}). Among main plot treatments highest NO_3-N content was noted for m_1 (70.56 mg kg^{-1}) trailed by m_2 (65.25 mg kg^{-1}) and the interaction effects remained significant and highest interaction was noted for m_2s_6 (85.40 mg kg^{-1}) combination.

4.3.4.6.3.3 Soil NO_3-N content at the harvest of fodder maize (total residue incorporation)

As evidenced in Table 60 c, soil NO_3-N content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths. At 0-20 cm depth, highest soil NO_3-N content was recorded by s_6 (102.74 mg kg^{-1}) followed by s_3 (94.02 mg kg^{-1}), m_3 (89.54 mg kg^{-1}) on par with m_1 (88.46 mg kg^{-1}) and m_3s_6 (104.88 mg kg^{-1}) on par with m_1s_6 (102.39 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil NO_3-N**,** sub plot s_6 (86.26 mg kg^{-1}) was superior and significantly different to others followed by s_3 (78.73 mg kg^{-1}). Among main plot treatments highest NO_3-N content was noted for m_2 (76.67 mg kg^{-1}) trailed by m_1 (70.52 mg kg^{-1}) and highest interaction effect was noted for m_2-s_6 (91.72 mg kg^{-1}).

4.3.4.6.3.4 Soil NO_3-N content at the sowing of fodder maize (root residue incorporation)

Soil NO_3-N content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 60 d. At 0-20 cm depth, highest soil NO_3-N content was recorded by s_6 (92.48 mg kg^{-1}) followed by s_3 (83.24 mg kg^{-1}), m_3 (78.29 mg kg^{-1}) on par with m_1 (77.58 mg kg^{-1}) and m_3-s_6 (94.44 mg kg^{-1}) followed by m_2s_6 (91.54 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil NO_3-N, sub plot s_6 (82.31 mg kg^{-1}) was superior and significantly different to others followed by s_3 (73.63 mg kg^{-1}). Among main plot treatments highest NO_3-N content was noted for m_2 (70.95 mg kg^{-1}) trailed by m_1 (67.05 mg kg^{-1}) and the interaction effects remained non significant.

Table 60 e. NO_3-N content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	79.31	73.19	77.26	76.59^e	63.15	66.88	59.80	63.28^e
s_2	79.53	75.92	80.30	78.58^d	63.58	69.41	62.45	65.15^d
s_3	89.57	90.14	89.31	89.68^b	73.65	83.27	71.71	76.21^b
s_4	81.69	79.43	81.07	80.73^d	65.46	72.57	63.33	67.12^d
s_5	84.12	80.57	83.71	82.80^c	67.65	73.63	65.65	68.98^c
s_6	98.76	98.14	101.29	99.39^a	82.34	90.74	82.73	85.27^a
s_7	80.41	78.93	80.68	80.01^d	64.26	72.10	62.81	66.39^d
Mean	84.77^a	82.33^b	84.80^a		68.58^b	75.51^a	66.92^c	
SEm±	m 0.27	s 0.513	m x s 0.88		m 0.31	s 0.44	m x s 0.77	
CD (0.05)	m 1.06	s 1.47	m x s 2.54		m 1.22	s 1.28	m x s 2.22	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 61. Effect of tillage and nutrient management on organic N content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 61 a. Organic N content of soil (mg kg^{-1}) at the harvest of grain cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5523	5179	5405	5369^f	5247	4980	4690	4972^d
s_2	6505	6313	6582	6467^b	6227	6086	5830	6047^a
s_3	5854	5965	5867	5895^d	5581	5744	5143	5489^c
s_4	5790	5717	5746	5751^e	6148	5477	4998	5541^c
s_5	7021	6845	6977	6948^a	4868	6597	6212	5892^b
s_6	6257	6297	6429	6328^c	6499	6060	5673	6077^a
s_7	5201	5186	5224	5203^g	4922	4962	4485	4789^e
Mean	6022^a	5929^b	6033^a		5642^a	5701^a	5290^b	
SEm±	m 19.60	s 37.90	m x s 65.65		m 16.25	s 35.15	m x s 60.88	
CD (0.05)	m 77.16	s 108.71	m x s NS		m 63.82	s 100.81	m x s 174.61	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 61 b. Organic N content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5939	5535	5885	5786^d	5577	5344	5363	5428
s_2	6859	6655	6724	6746^b	6164	6352	6218	6245
s_3	6305	6388	6407	6367^c	5851	6102	5830	5928
s_4	6165	6052	6457	6224^c	5852	5891	5734	5825
s_5	7179	7203	7454	7279^a	6816	6848	6765	6810
s_6	6829	6604	6854	6762^b	6473	6553	6470	6499
s_7	5578	5523	5670	5590^d	5178	5462	5236	5292
Mean	6407^a	6493^a	6280^b		5987	6079	5945	
SEm±	m 22.14	s 84.12	m x s 145.70		m 83.22	s 104.00	m x s 180.15	
CD (0.05)	m 86.94	s 241.28	m x s NS		m NS	s 298.31	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 61 c. Organic N content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	6478	5921	6547	6316^d	5464	5331	5303	5366^e
s_2	7440	7064	7738	7414^b	6434	6454	6463	6450^b
s_3	6783	6751	7003	6846^c	5788	6120	5756	5888^c
s_4	6853	6604	6780	6746^c	5834	5973	5519	5775^d
s_5	8094	7729	8027	7950^a	7020	7054	6704	6926^a
s_6	7300	7183	7483	7322^b	6303	6553	6203	6353^b
s_7	6266	6087	6272	6208^d	5264	5466	5013	5248^f
Mean	7031^a	6763^b	7121^a		6016^b	6136^a	5852^c	
SEm±	m 24.48	s 42.53	m x s 73.67		m 19.53	s 37.96	m x s 65.75	
CD (0.05)	m 96.12	s 121.99	m x s 211.30		m 76.71	s 108.8	m x s 188.58	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.4.6.3.5 Soil NO_3-N content at the harvest of fodder maize (root residue incorporation)

The soil NO_3-N content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths (Table 60 e). At 0-20 cm depth, highest soil NO_3-N content was recorded by s_6 (99.39 mg kg^{-1}) followed by s_3 (89.68 mg kg^{-1}), m_3 (84.80 mg kg^{-1}) on par with m_1 (84.77 mg kg^{-1}) and m_3s_6 (101.29 mg kg^{-1}) followed by m_1s_6 (98.76 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil NO_3-N, sub plot s_6 (85.27 mg kg^{-1}) was superior and significantly different to others followed by s_3 (76.21 mg kg^{-1}). Among main plot treatments highest NO_3-N content was noted for m_2 (75.51 mg kg^{-1}) trailed by m_1 (68.58 mg kg^{-1}) and highest interaction effect was noted for m_2s_6 (90.74 mg kg^{-1}).

4.3.4.6.4 Organic Nitrogen (ON)

Effect of tillage and nutrient management on organic nitrogen content of soil at different depths in a grain cowpea - fodder maize sequence are presented in Table 61.

4.3.4.6.4.1 Soil ON content at the harvest of grain cowpea

At 0-20 cm depth, highest soil ON content was recorded by s_5 (6948 mg kg^{-1}) followed by s_2 (6467 mg kg^{-1}) and m_3 (6033 mg kg^{-1}) which was on par with m_1 (6022 mg kg^{-1}) among nutrient management and tillage levels respectively and their interactions remained non significant. For second depth of sampling (20-60 cm), a decrease in ON content was noted, sub plot s_6 (6077 mg kg^{-1}) was superior and on par with s_2 (6047 mg kg^{-1}) and tillage level, m_2 (5701 mg kg^{-1}) recorded highest value and was on par with m_1 (5642 mg kg^{-1}) and significantly different to others. The interaction effects were found to be significant and highest interaction was noted for m_2s_5 (6597 mg kg^{-1}) combination which was on par with m_1s_6 (6499 mg kg^{-1}) and significantly different to others (Table 61 a).

4.3.4.6.4.2 Soil ON content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 61 b, at 0-20 cm depth, highest ON was noted for s_5 (7279 mg kg^{-1}) followed by s_6 (6762 mg kg^{-1}) and m_2 (6493 mg kg^{-1}) which was on par with m_1 (6407 mg kg^{-1}) among nutrient management and tillage levels respectively and the interaction effects remained non significant. At second depth of soil (20-60 cm) sampling, among sub plot treatments highest ON content was noted for s_5 (6810 mg kg^{-1}) which was on par with s_6 (6499 mg kg^{-1}) and significantly different to others. The main plot treatments and interaction effects were found to be non significant.

4.3.4.6.4.3 Soil ON content at the harvest of fodder maize (total residue incorporation)

Soil ON content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 61 c. At 0-20 cm depth, highest ON was recorded for s_5 (7950 mg kg^{-1}) trailed by s_2 (7414 mg kg^{-1}), m_3 (7121 mg kg^{-1}) on par with m_1 (7031 mg kg^{-1}) and m_1s_5 (8094 mg kg^{-1}) on par with m_3s_5 (8027 mg kg^{-1}) among sub plot treatments, main plot treatments and interaction effects respectively. For second depth of sampling, highest ON was recorded for s_5 (6926 mg kg^{-1}) trailed by s_2 (6450 mg kg^{-1}), m_2 (6136 mg kg^{-1}) followed by m_1 (6016 mg kg^{-1}) and m_2s_5 (7054 mg kg^{-1}) on par with m_1s_5 (7020 mg kg^{-1}) among different nutrient management, tillage levels and interaction effects respectively.

4.3.4.6.4.4 Soil ON content at the sowing of fodder maize (root residue incorporation)

As outlined in Table 61 d, at 0-20 cm depth, highest ON was noted for s_5 (7071 mg kg^{-1}) followed by s_2 (6636 mg kg^{-1}),), m_1 (6180 mg kg^{-1}) on par with m_3 (6174 mg kg^{-1}) and m_1s_5 (7173 mg kg^{-1}) on par with m_2s_5 (7172 mg kg^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest ON content was noted for s_5 (6565 mg kg^{-1}) trailed

Table 61 d. Organic N content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	5696	5696	5602	5539^{f}	5351	4997	4897	5082^{f}
s_2	6673	6673	6781	6636^{b}	6316	6110	6046	6157^{b}
s_3	6021	6021	6063	6066^{d}	5686	5774	5360	5607^{d}
s_4	5940	5940	5843	5875^{e}	5574	5480	5114	5390^{e}
s_5	7173	7172	7076	7071^{a}	6785	6589	6320	6565^{a}
s_6	6403	6403	6528	6451^{c}	6041	6055	5784	5960^{c}
s_7	5352	5352	5324	5328^{g}	4992	4950	4590	4844^{g}
Mean	6180^{a}	6061^{b}	6174^{a}		5821^{a}	5708^{b}	5445^{c}	
SEm±	m 19.85	s 54.59	m x s 94.56		m 14.83	s 36.60	m x s 63.40	
CD (0.05)	m 77.97	s 110.72	m x s 191.78		m 58.25	s 104.99	m x s 181.85	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 61 e. Organic N content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	6045	5574	5861	5827^{d}	5345	5148	5014	5169^{d}
s_2	7016	6711	7058	6928^{b}	6321	6271	6190	6261^{b}
s_3	6362	6385	6335	6361^{c}	5675	5929	5485	5696^{c}
s_4	6405	6227	6298	6310^{c}	5708	5777	5446	5644^{c}
s_5	7643	7354	7539	7512^{a}	6934	6900	6670	6835^{a}
s_6	6862	6808	6994	6888^{b}	6177	6357	6126	6220^{b}
s_7	5819	5700	5787	5769^{d}	5140	5264	4942	5115^{d}
Mean	6593^{a}	6394^{b}	6553^{a}		5900^{a}	5950^{a}	5696^{b}	
SEm±	m 20.37	s 40.5	m x s 70.16		m 17.83	s 37.43	m x s 64.88	
CD (0.05)	m 79.98	s 116.19	m x s NS		m 70.04	s 107.36	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute

Table 62. Effect of tillage and nutrient management on total P content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 62 a. Total P content of soil (mg kg^{-1}) at the harvest of grain cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	466.54	432.80	454.63	451.32[f]	514.55	473.49	537.48	508.51[f]
s_2	772.67	745.09	778.16	765.31[c]	824.07	788.04	863.36	825.16[c]
s_3	622.31	629.76	620.14	624.07[e]	671.47	673.73	703.66	682.95[e]
s_4	741.67	726.02	730.32	732.67[d]	795.07	770.65	814.39	793.37[d]
s_5	894.66	865.33	883.56	881.18[a]	949.45	911.69	974.95	945.36[a]
s_6	828.19	827.33	845.82	833.78[b]	880.29	872.77	933.23	895.43[b]
s_7	400.05	392.14	399.18	397.12[g]	448.73	430.01	478.98	452.57[g]
Mean	675.15[a]	659.78[b]	673.11[a]		726.23[b]	702.91[c]	758.00[a]	
SEm±	m 1.95	s 6.37	m x s 11.04		m 2.80	s 6.61	m x s 11.46	
CD (0.05)	m 7.658	s 18.284	m x s NS		m 10.98	s 18.97	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 62 b. Total P content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	552.86	496.28	551.52	533.55[f]	687.83	588.58	707.73	661.38[f]
s_2	774.45	725.27	797.54	765.75[c]	923.13	825.59	959.59	902.77[c]
s_3	594.37	578.08	609.27	593.91[e]	736.82	680.50	766.95	728.09[e]
s_4	745.04	704.95	752.10	734.03[d]	895.13	810.56	912.98	872.89[d]
s_5	898.22	837.93	884.12	873.42[a]	1059.73	947.28	1050.55	1019.19[a]
s_6	832.21	802.04	865.51	833.25[b]	985.23	908.86	1030.99	975.03[b]
s_7	406.26	378.83	420.78	401.96[g]	539.55	478.72	579.25	532.51[g]
Mean	686.20[b]	646.19[c]	697.26[a]		832.48[b]	748.58[c]	858.29[a]	
SEm±	m 2.37	s 6.14	m x s 10.64		m 3.60	s 6.17	m x s 10.68	
CD (0.05)	m 9.29	s 17.62	m x s NS		m 14.141	s 17.69	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

by s_2 (6157 mg kg^{-1}), m_1 (5821 mg kg^{-1}) followed by m_2 (5708 mg kg^{-1}) and m_1s_5 (6785 mg kg^{-1}) trailed by m_2s_5 (6589 mg kg^{-1}) among sub plot treatments, main plot treatments and interaction effects respectively.

4.3.4.6.4.5 Soil ON content at the harvest of fodder maize (root residue incorporation)

Soil ON differed significantly for nutrient management and tillage while their interaction effects remained similar at both sampling depths as evidenced in Table 61 e. At 0-20 cm depth, among nutrient management, s_5 (7512 mg kg^{-1}) recorded highest ON followed by s_2 (6928 mg kg^{-1}) and for tillage levels m_1 (6593 mg kg^{-1}) recorded highest value and was on par with m_3 (6553 mg kg^{-1}). For second depth of sampling, s_5 (6835 mg kg^{-1}) recorded highest value followed by s_6 (6220 mg kg^{-1}) and m_2 (5950 mg kg^{-1}) remained superior and on par with m_1 (5900 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.7 Soil P fractions

4.3.4.7.1 Total Phosphorus (TP)

Effect of tillage and nutrient management on total phosphorus content of soil at different depths in a grain cowpea - fodder maize sequence are presented in Table 62.

4.3.4.7.1.1 Soil TP content at the harvest of grain cowpea

At 0-20 cm depth, highest soil TP content was recorded by s_5 (881.18 mg kg^{-1}) followed by s_6 (833.78 mg kg^{-1}) and m_1 (675.15 mg kg^{-1}) which was on par with m_3 (673.11 mg kg^{-1}) among nutrient management and tillage levels respectively and their interactions remained non significant. For second depth of sampling (20-60 cm), a similar trend was noted but with higher values of soil TP, sub plot s_5 (945.36 mg kg^{-1}) was superior trailed by s_6 (895.43 mg kg^{-1}) and tillage level, m_3 (758.00 mg kg^{-1}) recorded highest value and significantly different to others followed by m_1 (726.23 mg kg^{-1}). The interaction effects were found to be non significant and highest interaction was noted for m_3s_5 (974.95 mg kg^{-1}) combination (Table 62 a).

4.3.4.7.1.2 Soil TP content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 62 b, at 0-20 cm depth, highest TP was noted for s_5 (873.42 mg kg^{-1}) followed by s_6 (833.25 mg kg^{-1}) and m_3 (697.26 mg kg^{-1}) trailed by m_1 (686.20 mg kg^{-1}) among nutrient management and tillage levels respectively and the interaction effects remained non significant. At second depth of soil (20-60 cm) sampling, among sub plot treatment highest TP content was noted for s_5 (1019.19 mg kg^{-1}) trailed by s_6 (975.03 mg kg^{-1}), for main plot treatments highest value was observed for m_3 (858.29 mg kg^{-1}) followed by m_1 (832.48 mg kg^{-1}) and interaction effects were found to be non significant.

4.3.4.7.1.3 Soil TP content at the harvest of fodder maize (total residue incorporation)

Soil TP content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 62 c. At 0-20 cm depth, highest TP was recorded for s_5 (1023.16 mg kg^{-1}) trailed by s_6 (984.26 mg kg^{-1}), m_3 (853.39 mg kg^{-1}) followed by m_1 (815.24 mg kg^{-1}) and m_1s_5 (1065.95 mg kg^{-1}) trailed by m_1s_4 (1020.51 mg kg^{-1}) among sub plot treatments, main plot treatments and interaction effects respectively. For second depth of sampling, highest TP was recorded for s_5 (1189.76 mg kg^{-1}) trailed by s_6 (1146.504 mg kg^{-1}), m_1 (1016.78 mg kg^{-1}) followed by m_3 (994.38 mg kg^{-1}) and m_1s_5 (1234.57 mg kg^{-1}) on par with m_3s_5 (1212.70 mg kg^{-1}) among different nutrient management, tillage levels and interaction effects respectively.

4.3.4.7.1.4 Soil TP content at the sowing of fodder maize (root residue incorporation)

As outlined in Table 62 d, at 0-20 cm depth, highest TP was noted for sub plot s_5 (928.50 mg kg^{-1}) followed by s_6 (878.02 mg kg^{-1}), tillage m_3 (721.03 mg kg^{-1}) was superior and on par with m_1 (719.33 mg kg^{-1}) and interaction effects

Table 62 c. Total P content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m$_1$	m$_2$	m$_3$	Mean	m$_1$	m$_2$	m$_3$	Mean
s$_1$	631.36	552.95	552.95	595.48^{f}	793.10	680.08	776.55	749.90^{f}
s$_2$	889.43	810.31	810.31	857.53^{d}	1051.47	946.91	1054.08	1017.48^{d}
s$_3$	741.84	707.31	707.31	723.69^{e}	906.52	848.15	897.76	884.14^{e}
s$_4$	1020.51	838.65	838.65	910.76^{c}	1185.13	983.05	1052.33	1073.50^{c}
s$_5$	1065.95	974.07	974.07	1023.16^{a}	1234.57	1122.02	1212.70	1189.76^{a}
s$_6$	1003.30	947.52	947.52	984.26^{b}	1166.06	1088.70	1184.75	1146.50^{b}
s$_7$	621.40	576.71	576.71	601.14^{f}	780.67	709.95	782.51	757.71^{f}
Mean	853.39^{a}	772.50^{c}	815.24^{b}		1016.78^{a}	911.26^{c}	994.38^{b}	
SEm±	m 2.28	s 6.72	m x s 11.65		m 3.28	s 7.42	m x s 12.85	
CD (0.05)	m 8.95	s 19.28	m x s 33.40		m 12.88	s 21.28	m x s 36.86	

m$_1$: Conventional tillage; m$_2$: Deep tillage; m$_3$: No till; s$_1$: POP; s$_2$: Soil test based POP; s$_3$: TOF-F; s$_4$: POP+AMF; s$_5$: Soil test based POP+AMF; s$_6$: TOF-F+AMF; s$_7$: Absolute control

Table 62 d. Total P content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m$_1$	m$_2$	m$_3$	Mean	m$_1$	m$_2$	m$_3$	Mean
s$_1$	505.46	460.05	496.60	487.37^{f}	601.01	505.85	607.75	571.54^{f}
s$_2$	817.06	775.93	826.22	806.40^{c}	916.12	825.66	946.12	895.97^{c}
s$_3$	663.39	660.14	665.43	662.99^{e}	759.65	710.48	779.21	749.78^{e}
s$_4$	788.22	760.42	779.69	776.11^{d}	891.14	815.26	898.95	868.45^{d}
s$_5$	945.85	901.84	937.80	928.50^{a}	1057.68	964.82	1063.17	1028.56^{a}
s$_6$	875.25	862.26	896.56	878.02^{b}	885.81	918.38	1017.26	940.49^{b}
s$_7$	440.10	421.93	444.92	435.65^{g}	551.57	471.19	559.89	527.55^{g}
Mean	719.33^{a}	691.79^{b}	721.03^{a}		809.00^{b}	744.52^{c}	838.90^{a}	
SEm±	m 2.18	s 6.59	m x s 11.42		m 3.43	s 6.82	m x s 11.81	
CD (0.05)	m 8.55	s 18.91	m x s ns		m 13.45	s 19.56	m x s 33.88	

m$_1$: Conventional tillage; m$_2$: Deep tillage; m$_3$: No till; s$_1$: POP; s$_2$: Soil test based POP; s$_3$: TOF-F; s$_4$: POP+AMF; s$_5$: Soil test based POP+AMF; s$_6$: TOF-F+AMF; s$_7$: Absolute control

Table 62 e. Total P content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	564.70	496.67	580.10	547.15^f	707.44	595.67	736.16	679.75^f
s_2	809.77	744.33	838.31	797.47^c	958.14	849.79	1005.11	937.68^c
s_3	665.87	642.46	692.23	666.85^d	809.25	749.41	849.54	802.73^d
s_4	823.24	769.85	833.93	809.00^c	972.80	878.52	998.82	950.05^c
s_5	1029.23	956.47	1038.87	1008.19^a	1188.33	1067.25	1213.32	1156.30^a
s_6	969.59	931.03	1012.91	971.18^b	1119.60	1041.91	1184.11	1115.21^b
s_7	591.86	557.14	621.56	590.19^e	733.52	661.15	779.48	724.72^e
Mean	779.18^b	728.28^c	802.56^a		927.01^b	834.81^c	966.65^a	
SEm±	m 2.98	s 6.56	m x s 11.36		m 4.28	s 7.20	m x s 12.46	
CD (0.05)	m 11.71	s 18.81	m x s NS		m 16.82	s 20.64	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 63. Effect of tillage and nutrient management on labile P content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping

Table 63 a. Labile P content of soil (mg kg^{-1}) at the harvest of grain cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	24.90	22.62	26.24	24.59^c	31.57	27.13	39.00	32.57^c
s_2	23.48	21.54	25.81	23.61^d	30.23	26.98	37.84	31.68^{cd}
s_3	37.86	37.01	40.88	38.58^b	45.30	42.87	52.21	46.79^b
s_4	22.39	19.54	24.69	22.21^e	30.08	26.12	37.58	31.26^d
s_5	41.16	37.59	44.01	40.92^a	49.58	44.96	58.42	50.98^a
s_6	40.75	37.57	43.96	40.76^a	48.98	45.86	59.74	51.53^a
s_7	18.94	17.12	20.25	18.77^f	25.76	22.59	36.17	28.17^e
Mean	29.92^b	27.57^c	32.26^a		37.36^b	33.79^c	45.85^a	
SEm±	m 2.98	s 6.56	m x s 11.36		m 4.28	s 7.20	m x s 12.46	
CD (0.05)	m 11.71	s 18.81	m x s NS		m 16.82	s 20.64	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

remained similar. At second depth of soil (20-60 cm) sampling, highest TP content was noted for s_5 (1028.56 mg kg^{-1}) trailed by s_6 (940.49 mg kg^{-1}), m_3 (838.90 mg kg^{-1}) followed by m_1 (809.00 mg kg^{-1}) and m_3s_5 (1063.17 mg kg^{-1}) on par with m_1s_5 (1057.68 mg kg^{-1}) among sub plot treatments, main plot treatments and interaction effects respectively.

4.3.4.7.1.5 Soil TP content at the harvest of fodder maize (root residue incorporation)

Soil TP differed significantly for nutrient management and tillage while their interaction effects remained similar at both sampling depths as evidenced in Table 62 e. At 0-20 cm depth, among nutrient management, s_5 (1008.19 mg kg^{-1}) recorded highest TP followed by s_6 (971.18 mg kg^{-1}) and for tillage levels m_3 (802.56 mg kg^{-1}) recorded highest value trailed by m_1 (779.18 mg kg^{-1}). For second depth of sampling, s_5 (1156.30 mg kg^{-1}) recorded highest value followed by s_6 (1115.21 mg kg^{-1}) and m_3 (966.65 mg kg^{-1}) remained superior trailed by m_1 (927.01 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.7.2 Labile Phosphorus (LP)

The influence of tillage and nutrient management on soil LP content at different depths in a grain cowpea - fodder maize sequence are outlined in Table 63.

4.3.4.7.2.1 Soil LP content at the harvest of grain cowpea

As evidenced in Table 63 a, soil LP differed significantly for nutrient management and tillage while their interaction effects remained similar at both sampling depths. At 0-20 cm depth, highest soil LP content was recorded by s_5 (40.92 mg kg^{-1}) which was on par with s_6 (40.76 mg kg^{-1}) and m_3 (32.26 mg kg^{-1}) followed by m_1 (29.92 mg kg^{-1}) among nutrient management and tillage levels respectively. For second depth of sampling (20-60 cm), higher values for soil LP content was noted than surface soil, sub plot s_6 (51.53 mg kg^{-1}) was superior followed by s_5 (50.98 mg kg^{-1}) and among tillage highest LP content was noted for m_3 (45.85 mg kg^{-1}) trailed by m_1 (37.36 mg kg^{-1}).

4.3.4.7.2.2 Soil LP content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 63 b, at 0-20 cm depth, highest LP content was noted for s_6 (76.36 mg kg^{-1}) trailed by s_5 (67.39 mg kg^{-1}), m_3 (61.02mg kg^{-1}) followed by m_1 (56.94 mg kg^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant.

At second depth of soil (20-60 cm) sampling, highest LP was noted for s_6 (106.41 mg kg^{-1}) followed by s_5 (94.74 mg kg^{-1}), m_3 (94.98 mg kg^{-1}) followed by m_1 (83.59 mg kg^{-1}) and m_3s_6 (121.37 mg kg^{-1}) followed by m_3s_5 (110.12 mg kg^{-1}) among nutrient management, tillage and interactions respectively.

4.3.4.7.2.3 Soil LP content at the harvest of fodder maize (total residue incorporation)

As outlined in Table 63 c, Soil LP differed significantly for nutrient management and tillage while their interaction effects remained similar at both sampling depths. At 0-20 cm depth, among nutrient management, s_6 (215.94 mg kg^{-1}) recorded highest LP followed by s_5 (157.19 mg kg^{-1}) and for tillage levels m_3 (111.94 mg kg^{-1}) recorded highest value trailed by m_1 (116.90 mg kg^{-1}). For second depth of sampling, s_6 (250.71 mg kg^{-1}) recorded highest value followed by s_5 (191.57 mg kg^{-1}) and m_3 (153.12 mg kg^{-1}) remained superior trailed by m_1 (149.72 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.7.2.4 Soil LP content at the sowing of fodder maize (root residue incorporation)

Soil LP differed significantly for nutrient management and tillage while their interaction effects remained similar at both sampling depths as evidenced in Table 63 d. At 0-20 cm depth, among nutrient management, s_6 (53.25 mg kg^{-1})

Table 63 b. Labile P content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	45.05	33.45	48.65	42.38^{e}	48.65	47.14	80.75	65.68^{e}
s_2	49.23	37.27	53.80	46.77^{d}	53.80	52.14	87.35	71.24^{d}
s_3	63.22	54.04	67.68	61.65^{c}	67.68	70.47	101.88	86.88^{c}
s_4	49.93	38.09	52.84	46.95^{d}	52.84	55.74	87.61	72.89^{d}
s_5	70.65	57.43	74.09	67.39^{b}	74.09	74.98	110.12	94.74^{b}
s_6	78.80	66.07	84.22	76.36^{a}	84.22	84.48	121.37	106.41^{a}
s_7	41.70	30.77	45.88	39.45^{f}	45.88	45.87	75.77	62.44^{f}
Mean	56.94^{b}	45.31^{c}	61.02^{a}		83.59^{b}	61.55^{c}	94.98^{a}	
SEm±	m 0.426		s 0.498	m x s 0.862	m 0.86	s 0.65	m x s 1.12	
CD (0.05)	m 1.67		s 1.43	m x s NS	m 3.38	s 1.85	m x s 3.21	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 63 c. Labile content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	84.27	61.71	77.04	74.34^{d}	117.54	84.73	113.93	105.40^{e}
s_2	83.84	67.64	84.23	78.57^{d}	117.54	91.61	123.83	110.99^{d}
s_3	97.48	78.55	91.84	89.29^{c}	130.97	104.99	132.01	122.66^{c}
s_4	98.76	76.19	91.30	88.75^{c}	132.90	103.10	134.11	123.3^{c}
s_5	168.23	142.87	160.48	157.19^{b}	203.93	165.09	205.67	191.57^{b}
s_6	223.04	203.14	221.65	215.94^{a}	258.90	226.21	267.01	250.71^{a}
s_7	62.67	42.93	57.04	54.21^{e}	86.22	67.31	95.26	82.93^{f}
Mean	116.90^{b}	96.15^{c}	111.94^{a}		149.72^{b}	120.44^{c}	153.12^{a}	
SEm±	m 0.50		s 1.72	m x s 2.99	m 0.89	s 1.85	m x s 3.20	
CD (0.05)	m 1.97		s 4.95	m x s NS	m 3.49	s 5.30	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 63 d. Labile P content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	26.11	23.97	28.69	26.25^d	40.58	32.83	47.25	40.22^f
s_2	26.14	23.72	29.89	26.58^d	41.37	33.96	50.68	42.00^e
s_3	41.62	39.90	45.28	42.27^c	57.36	52.13	66.33	58.60^c
s_4	27.12	23.23	30.30	26.89^d	44.15	35.93	51.91	43.99^d
s_5	46.42	41.36	49.62	45.80^b	64.53	54.51	71.73	63.59^b
s_6	52.77	48.93	58.05	53.25^a	71.17	63.05	82.04	72.08^a
s_7	21.91	19.07	24.33	21.77^e	36.49	29.99	43.83	36.77^g
Mean	34.59^b	31.45^c	38.02^a		50.81^b	43.20^c	59.11^a	
SEm±	m 0.21		s 0.39	m x s 0.67	m 0.44	s 0.47	m x s 0.82	
CD (0.05)	m 0.82		s 1.12	m x s NS	m 1.74	s 1.35	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 63 e. Labile P content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	60.46	43.50	67.35	57.10^d	79.46	61.53	90.83	77.27^e
s_2	63.52	47.10	72.36	60.99^d	83.64	66.26	96.54	82.15^d
s_3	68.37	54.00	76.75	66.37^c	89.29	74.94	101.39	88.54^c
s_4	71.34	53.83	79.00	68.06^c	93.03	75.82	104.03	90.96^c
s_5	138.32	118.34	145.92	134.1^b	160.45	140.52	171.26	157.41^b
s_6	191.88	176.27	203.23	190.46^a	214.27	199.42	228.79	214.16^a
s_7	38.20	42.80	47.59	42.8^e	58.31	44.29	75.62	59.40^f
Mean	90.30^b	76.55^c	98.88^a		111.21^b	94.68^c	124.07^a	
SEm±	m 0.60		s 1.58	m x s 2.73	m 0.78	s 1.66	m x s 2.88	
CD (0.05)	m 2.34		s 4.53	m x s 7.84	m 3.06	s 4.77	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

recorded highest LP followed by s_5 (45.80 mg kg^{-1}) and for tillage levels m_3 (38.02 mg kg^{-1}) recorded highest value trailed by m_1 (34.59 mg kg^{-1}). For second depth of sampling, s_6 (72.08 mg kg^{-1}) recorded highest value followed by s_5 (63.59 mg kg^{-1}) and m_3 (59.11 mg kg^{-1}) remained superior trailed by m_1 (50.81 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.7.2.5 Soil LP content at the harvest of fodder maize (root residue incorporation)

At 0-20 cm depth, highest LP was noted for s_6 (190.46 mg kg^{-1}) followed by s_5 (134.19 mg kg^{-1}), m_3 (98.88 mg kg^{-1}) followed by m_1 (90.30 mg kg^{-1}) and m_3s_6 (203.23 mg kg^{-1}) followed by m_1s_6 (191.88 mg kg^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest LP content was noted for s_6 (214.16 mg kg^{-1}) trailed by s_5 (157.41 mg kg^{-1}) and m_3 (124.07 mg kg^{-1}) followed by m_1 (111.21 mg kg^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant (Table 63 e).

4.3.4.7.3 Non Labile Phosphorus (NLP)

Effect of tillage and nutrient management on non labile phosphorus content of soil at different depths in a grain cowpea - fodder maize sequence are presented in Table 64

4.3.4.7.3.1 Soil NLP content at the harvest of grain cowpea

At 0-20 cm depth, highest soil NLP content was recorded by s_5 (840.28 mg kg^{-1}) followed by s_6 (793.02 mg kg^{-1}) and m_1 (645.23 mg kg^{-1}) which was on par with m_3 (640.86 mg kg^{-1}) among nutrient management and tillage levels respectively and their interactions remained non significant. For second depth of sampling (20-60 cm), a similar trend was noted but with higher values of soil NLP, sub plot s_5 (894.38 mg kg^{-1}) was superior trailed by s_6 (843.90 mg kg^{-1}) and tillage level, m_3 (712.16 mg kg^{-1}) recorded highest value and significantly different to others followed by m_1 (688.88 mg kg^{-1}). The interaction effects were found to be non significant and highest interaction was noted for m_3s_5 (916.53 mg kg^{-1}) combination (Table 64 a).

4.3.4.7.3.2 Soil NLP content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 64 b, at 0-20 cm depth, highest NLP was noted for s_5 (806.03 mg kg^{-1}) followed by s_6 (756.89 mg kg^{-1}) and m_3 (636.24 mg kg^{-1}) trailed by m_1 (629.26 mg kg^{-1}) among nutrient management and tillage levels respectively and the interaction effects remained non significant. At second depth of soil (20-60 cm) sampling, among sub plot treatments highest NLP content was noted for s_5 (924.44 mg kg^{-1}) trailed by s_6 (868.62 mg kg^{-1}), for main plot treatments highest value was observed for m_3 (763.31 mg kg^{-1}) followed by m_1 (748.90 mg kg^{-1}) and interaction effects were found to be non significant.

4.3.4.7.3.3 Soil NLP content at the harvest of fodder maize (total residue incorporation)

Soil NLP content differed significantly for nutrient management, tillage and their interaction effects at both sampling depths as evidenced in Table 64 c. At 0-20 cm depth, highest NLP was recorded for s_5 (676.36 mg kg^{-1}) trailed by s_6 (736.50 mg kg^{-1}), m_1 (736.50 mg kg^{-1}) followed by m_3 (703.31 mg kg^{-1}) and m_1s_5 (921.75 mg kg^{-1}) trailed by m_1s_5 (897.72 mg kg^{-1}) among sub plot treatments, main plot treatments and interaction effects respectively. For second depth of sampling, highest NLP was recorded for s_5 (998.20 mg kg^{-1}) trailed by s_6 (950.14 mg kg^{-1}), m_1 (867.07mg kg^{-1}) followed by m_3 (841.27 mg kg^{-1}) and m_1s_6 (1052.23 mg kg^{-1}) on par with m_1s_5 (1030.64 mg kg^{-1}) among different nutrient management, tillage levels and interaction effects respectively.

4.3.4.7.3.4 Soil NLP content at the sowing of fodder maize (root residue incorporation)

As outlined in Table 64 d, at 0-20 cm depth, highest NLP was noted for sub plot s_5 (882.70 mg kg^{-1}) followed by s_6 (824.77 mg kg^{-1}), tillage m_1 (684.75 mg kg^{-1}) was superior and on par with m_3 (683.01 mg kg^{-1}) and interaction effects

Table 64. Effect of tillage and nutrient management on non labile Pcontent of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 64 a. Non labile P content of soil (mg kg^{-1}) at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	441.63	410.19	428.39	426.74^f	482.98	446.36	498.48	475.94^f
s_2	749.19	723.55	752.35	741.70^c	793.85	761.06	825.52	793.48^c
s_3	584.45	592.75	579.26	585.49^e	626.17	630.86	651.45	636.16^e
s_4	719.28	706.48	705.63	710.47^d	764.99	744.52	776.82	762.11^d
s_5	853.49	827.74	839.61	840.28^a	899.87	866.73	916.53	894.38^a
s_6	787.44	789.76	801.85	793.02^b	831.31	826.91	873.48	843.90^b
s_7	381.11	375.02	378.93	378.36^g	422.97	407.42	442.81	424.40^g
Mean	645.23^a	632.21^b	640.86^a		688.88^b	669.12^c	712.16^a	
SEm±	m 1.83		s 6.14	m x s 10.64	m 2.54	s 6.33	m x s 10.96	
CD (0.05)	m 7.17		s 17.62	m x s NS	m 9.96	s 18.15	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 64 b. Non labile P content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	507.81	462.82	502.88	491.17^f	618.69	541.44	626.98	595.70^f
s_2	725.21	688.00	743.74	718.98^c	848.90	773.45	872.24	831.53^c
s_3	531.15	524.04	541.59	532.26^e	648.55	610.03	665.07	641.22^e
s_4	695.10	666.86	699.26	687.07^d	819.80	754.82	825.37	800.00^d
s_5	827.57	780.50	810.03	806.03^a	960.61	872.29	940.43	924.44^a
s_6	753.41	735.97	781.29	756.89^b	871.87	824.37	909.62	868.62^b
s_7	364.56	348.06	374.90	362.51^g	473.87	432.85	503.48	470.07^g
Mean	629.26^a	600.89^b	636.24^a		748.90^b	687.04^c	763.31^a	
SEm±	m 2.06		s 5.74	m x s 9.94	m 2.88	s 5.66	m x s 9.80	
CD (0.05)	m 8.10		s 16.46	m x s NS	m 11.32	s 11.32	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 64 c. Non labile P content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	547.08	491.23	525.11	736.50^f	675.56	595.34	662.61	644.50^f
s_2	805.59	742.67	788.62	676.36^c	933.92	855.30	930.25	906.40^c
s_3	644.37	628.77	630.07	703.31^d	775.55	743.16	765.76	761.49^d
s_4	780.26	744.39	780.31	703.30^c	907.16	862.50	917.73	895.80^c
s_5	897.72	831.20	868.98	676.36^a	1030.64	956.93	1007.03	998.20^a
s_6	921.75	762.46	781.83	736.50^b	1052.23	879.95	918.23	950.14^b
s_7	558.73	533.78	548.25	736.50^e	694.45	642.65	687.25	674.78^e
Mean	736.50^a	676.36^c	703.31^b		867.07^a	790.83^c	841.27^b	
SEm±	m 1.89		s 5.47	m x s 9.48	m 2.52	s 6.02	m x s 10.43	
CD (0.05)	m 7.44		s 15.70	m x s 27.19	m 9.88	s 17.26	m x s 29.90	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 64 d. Non labile P content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	479.35	436.09	467.91	461.12^f	560.42	473.02	560.50	531.31^e
s_2	790.92	752.21	796.33	779.82^c	874.76	791.70	895.44	853.97^b
s_3	621.76	620.24	620.14	620.72^e	702.29	658.35	712.89	691.18^d
s_4	761.10	737.18	749.38	749.22^d	846.99	779.33	847.04	824.45^c
s_5	899.43	860.48	888.18	882.70^a	993.15	910.31	991.44	964.97^a
s_6	822.48	813.33	838.51	824.77^b	814.65	855.33	935.22	868.40^b
s_7	418.19	402.86	420.59	413.88^g	515.07	441.20	516.06	490.78^f
Mean	684.75^a	660.34^b	683.01^a		758.19^b	701.32^c	779.80^a	
SEm±	m 2.01		s 6.30	m x s 10.91	m 3.02	s 6.45	m x s 11.17	
CD (0.05)	m 7.89		s 18.06	m x s NS	m 11.85	s 18.49	m x s 32.03	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

remained similar. At second depth of soil (20-60 cm) sampling, highest NLP content was noted for s_5 (964.97 mg kg^{-1}) trailed by s_6 (868.40 mg kg^{-1}), m_3 (779.80 mg kg^{-1}) followed by m_1 (758.19 mg kg^{-1}) and m_1s_5 (993.15 mg kg^{-1}) on par with m_3s_5 (991.44 mg kg^{-1}) among sub plot treatments, main plot treatments and interaction effects respectively.

4.3.4.7.3.5 Soil NLP content at the harvest of fodder maize (root residue incorporation)

Soil NLP differed significantly for nutrient management and tillage while their interaction effects remained similar at both sampling depths as evidenced in Table 64 e. At 0-20 cm depth, among nutrient management, s_5 (874.00 mg kg^{-1}) recorded highest NLP followed by s_6 (780.72 mg kg^{-1}) and for tillage levels m_3 (703.68 mg kg^{-1}) recorded highest value trailed by m_1 (688.88 mg kg^{-1}). For second depth of sampling, s_5 (998.80 mg kg^{-1}) recorded highest value followed by s_6 (901.05 mg kg^{-1}) and m_3 (842.58 mg kg^{-1}) remained superior trailed by m_1 (815.81 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.8 Dehydrogenase activity

The influence of tillage and nutrient management on soil dehydrogenase activity at different depths in a grain cowpea - fodder maize sequence are outlined in Table 65.

4.3.4.8.1 Soil dehydrogenase activity at the harvest of grain cowpea

At 0-20 cm depth, highest soil dehydrogenase activity was recorded by s_6 (28.56 µg TPF g^{-1} soil 24 hr^{-1}) followed by s_5 (24.77 µg TPF g^{-1} soil 24 hr^{-1}), m_3 (24.68 µg TPF g^{-1} soil 24 hr^{-1}) followed by m_1 (23.52 µg TPF g^{-1} soil 24 hr-^{1}) and m_3-s_6 (30.97 µg TPF g^{-1} soil 24 hr^{-1}) followed by m_2-s_6 (29.64 µg TPF g^{-1} soil 24 hr^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil dehydrogenase activity, sub plot s_6 (25.32 µg TPF g^{-1} soil 24 hr^{-1}) was superior followed by s_5 (20.15 µg TPF g^{-1} soil 24 hr^{-1}) and significantly different to others. Among tillage highest dehydrogenase activity was noted for m_2 (22.56 µg TPF g^{-1} soil 24 hr^{-1}) trailed by m_1 (18.80 µg TPF g^{-1} soil 24 hr^{-1}) and the interaction effects were non significant and highest interaction was noted for m_2s_6 (28.69 µg TPF g^{-1} soil 24 hr^{-1}) combination (Table 65 a).

4.3.4.8.2 Soil dehydrogenase activity at the sowing of fodder maize (total residue incorporation)

As outlined in Table 65 b, at 0-20 cm depth, highest dehydrogenase activity was noted for s_6 (37.24 µg TPF g-^{1} soil 24 hr^{-1}) followed by s_5 (32.15 µg TPF g^{-1} soil 24 hr^{-1}),), m_3 (35.84 µg TPF g-^{1} soil 24 hr^{-1}) followed by m_1 (30.63 µg TPF g^{-1} soil 24 hr^{-1}) and m_3s_6 (42.11 µg TPF g^{-1} soil 24 hr^{-1}) followed by m_3s_5 (36.64 µg TPF g^{-1} soil 24 hr^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest dehydrogenase activity was noted for s_6 (31.00 µg TPF g-^{1} soil 24 hr^{-1}) trailed by s_5 (25.89 µg TPF g^{-1} soil 24 hr^{-1}), m_2 (27.53 µg TPF g-^{1} soil 24 hr-^{1}) followed by m_1 (26.70 µg TPF g^{-1} soil 24 hr^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant.

4.3.4.8.3 Soil dehydrogenase activity at the harvest of fodder maize (total residue incorporation)

Soil dehydrogenase activity differed significantly for nutrient management and tillage while their interaction effects remained non significant at both sampling depths as evidenced in Table 65 c. At 0-20 cm depth, among nutrient management, s_6 (40.80 µg TPF g^{-1} soil 24 hr^{-1}) recorded highest dehydrogenase activity and was on par with s_5 (40.68 µg TPF g^{-1} soil 24 hr^{-1}) and for tillage levels m_3 (39.61 µg TPF g^{-1} soil 24 hr^{-1}) recorded highest value followed by m_1 (36.15 µg TPF g^{-1} soil 24 hr^{-1}). For second depth of sampling, s_6 (33.90 µg TPF g^{-1} soil 24 hr^{-1}) recorded highest value and was on par with s_5 (33.70 µg TPF g^{-1} soil 24 hr^{-1}) and m_2 (32.96 µg TPF g^{-1} soil 24 hr^{-1}) remained superior trailed by m_1 (29.08

Table 64 e. Non labile P content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	504.24	453.17	512.75	490.05^f	627.98	534.13	645.32	602.48^f
s_2	746.25	697.22	765.96	736.48^c	874.50	783.53	908.56	855.5^c
s_3	597.50	588.46	615.49	600.48^d	719.96	674.46	748.15	714.19^d
s_4	751.89	716.02	754.93	740.95^c	879.77	802.69	894.79	859.08^c
s_5	890.91	838.14	892.96	874.00^a	1027.88	926.73	1042.07	998.80^a
s_6	777.71	754.76	809.69	780.72^b	905.33	842.49	955.33	901.05^b
s_7	553.66	514.34	573.98	547.33^e	675.21	616.85	703.86	665.31^e
Mean	688.88^b	651.73^c	703.68^a		815.81^b	740.13^c	842.58^a	
SEm±	m 2.48		s 5.35	m x s 9.27	m 3.54	s 5.89		m x s 10.20
CD (0.05)	m 9.72		s 15.35	m x s NS	m 13.89	s 16.89		m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 65. Effect of tillage and nutrient management on soil dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 65 a. Soil dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1}) at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	23.39	21.12	22.75	22.42^e	17.44	20.20	14.96	17.53^e
s_2	23.43	21.86	23.63	22.97^d	17.61	20.92	15.72	18.09^d
s_3	23.37	22.94	23.30	23.20^d	17.59	21.96	15.54	18.36^d
s_4	24.32	23.12	24.00	23.81^c	18.33	22.16	16.22	18.90^c
s_5	24.56	24.21	25.55	24.77^b	19.71	23.26	17.48	20.15^b
s_6	25.07	29.64	30.97	28.56^a	24.40	28.69	22.87	25.32^a
s_7	20.47	21.68	22.52	21.55^f	16.54	20.70	14.43	17.22^e
Mean	23.52^b	23.51^b	24.68^a		18.80^b	22.56^a	16.74^c	
SEm±	m 0.10		s 0.15	m x s 0.25	m 0.15	s 0.14		m x s 0.24
CD (0.05)	m 0.39		s 0.42	m x s 0.73	m 0.57	s 0.40		m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 65 b. Soil dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	29.74	25.85	34.00	29.86^{d}	25.73	25.38	20.23	23.78^{d}
s_2	29.65	26.64	35.04	30.44^{c}	25.73	26.17	21.08	24.32^{c}
s_3	29.54	27.93	34.51	30.66^{c}	25.65	27.43	20.80	24.63^{c}
s_4	29.95	27.24	34.94	30.71^{c}	26.02	26.85	20.67	24.52^{c}
s_5	31.46	28.35	36.64	32.15^{b}	27.50	27.96	22.22	25.89^{b}
s_6	35.82	33.79	42.11	37.24^{a}	31.97	33.40	27.63	31.00^{a}
s_7	28.25	25.89	33.66	29.27^{e}	24.30	25.50	19.18	23.00^{e}
Mean	30.63^{b}	27.96^{c}	35.84^{a}		26.70^{b}	27.53^{a}	21.69^{e}	
SEm±	m		s	m x s	m	s		m x s
	0.24		0.19	0.33	0.13	0.17		0.29
CD (0.05)	m		s	m x s	m	s		m x s
	0.95		0.54	0.94	0.52	0.49		NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 65 c. Soil dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	33.24	29.40	36.11	32.92^{e}	26.38	28.92	23.65	26.32^{e}
s_2	35.16	32.26	39.26	35.56^{d}	28.44	31.78	26.62	28.95^{d}
s_3	35.96	34.77	39.59	36.77^{c}	29.29	34.26	27.17	30.24^{c}
s_4	37.90	35.13	40.76	37.93^{b}	30.73	34.63	28.27	31.21^{b}
s_5	40.77	37.46	43.80	40.68^{a}	33.33	36.82	31.04	33.70^{a}
s_6	40.01	38.00	44.37	40.80^{a}	32.79	37.36	31.55	33.90^{a}
s_7	29.97	27.59	33.38	30.32^{f}	22.56	26.94	20.56	23.36^{f}
Mean	36.15^{b}	33.52^{c}	39.61^{a}		29.08^{b}	32.96^{a}	26.98^{c}	
SEm±	m		s	m x s	m	s		m x s
	0.21		0.23	0.40	0.16	0.20		0.35
CD (0.05)	m		s	m x s	m	s		m x s
	0.82		0.66	NS	0.64	0.58		NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 65 d. Soil dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	27.13	22.46	30.54	26.71^{e}	17.34	21.12	15.51	17.99^{e}
s_2	27.10	23.21	31.54	27.28^{d}	17.51	21.86	16.28	18.55^{d}
s_3	27.01	24.35	31.07	27.48^{cd}	17.49	22.93	16.09	18.84^{d}
s_4	27.39	24.50	31.48	27.79^{c}	18.76	23.33	16.98	19.69^{c}
s_5	28.61	25.63	33.14	29.12^{b}	20.18	24.46	18.33	20.99^{b}
s_6	33.05	31.06	38.59	34.23^{a}	24.86	29.89	23.72	26.16^{a}
s_7	25.40	23.11	30.15	26.22^{e}	17.01	21.92	15.28	18.07^{e}
Mean	27.96^{b}	24.90^{c}	32.36^{a}		19.02^{b}	23.65^{a}	17.46^{c}	
SEm±	m 0.22		s 0.17	m x s 0.30	m 0.16	s 0.14		m x s 0.25
CD (0.05)	m 0.87		s 0.49	m x s 0.86	m 0.63	s 0.41		m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 65 e. Soil dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	30.34	26.53	32.50	29.79^{e}	23.07	25.60	20.42	23.03^{e}
s_2	32.25	29.33	35.53	32.37^{d}	25.20	28.42	23.34	25.65^{d}
s_3	32.99	31.61	35.85	33.48^{c}	26.07	30.76	23.96	26.93^{c}
s_4	34.99	32.09	37.09	34.72^{b}	27.17	31.16	25.02	27.78^{b}
s_5	37.78	34.36	39.93	37.36^{a}	29.84	33.40	27.61	30.28^{a}
s_6	37.06	34.83	40.43	37.44^{a}	29.39	33.94	28.11	30.48^{a}
s_7	27.17	24.55	30.90	27.54^{f}	19.08	23.45	17.12	19.89^{f}
Mean	33.23^{b}	30.47^{c}	36.03^{a}		25.69^{b}	29.53^{a}	23.66^{c}	
SEm±	m 0.19		s 0.21	m x s 0.37	m 0.16	s 0.19		m x s 0.32
CD (0.05)	m 0.73		s 0.61	m x s NS	m 0.61	s 0.54		m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 66. Effect of tillage and nutrient management on microbial biomass carbon (MBC) content of soil (mg kg^{-1}) at different depths in a grain cowpea – fodder maize cropping sequence

Table 66 a. MBC content of soil (mg kg^{-1}) at the harvest of grain cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	16.82	15.20	16.37	16.13^{e}	12.55	14.53	10.76	12.61^{e}
s_2	16.86	15.72	17.00	16.53^{d}	12.67	15.05	11.31	13.01^{d}
s_3	16.81	16.50	16.77	16.69^{d}	12.66	15.80	11.18	13.21^{d}
s_4	17.50	16.63	17.27	17.13^{c}	13.19	15.94	11.66	13.60^{c}
s_5	17.67	17.42	18.38	17.82^{b}	14.18	16.73	12.57	14.49^{b}
s_6	18.04	21.32	22.28	20.55^{a}	17.55	20.64	16.45	18.21^{a}
s_7	14.72	15.59	16.20	15.51^{f}	11.90	14.89	10.38	12.39^{e}
Mean	16.92^{b}	16.91^{b}	17.75^{a}		13.53^{b}	16.23^{a}	12.05^{c}	
SEm±	m 0.07		s 0.11	m x s 0.18	m 0.10	s 0.10		m x s 0.17
CD (0.05)	m 0.28		s 0.30	m x s 0.52	m 0.41	s 0.29		m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 66 b. MBC content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received total crop residue of cowpea

0-20 cm					20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	21.39	18.60	24.46	21.48^{d}	18.51	18.26	14.56	17.11^{d}
s_2	21.33	19.17	25.21	21.90^{c}	18.51	18.82	15.16	17.50^{c}
s_3	21.25	20.09	24.82	22.05^{c}	18.46	19.73	14.96	17.72^{c}
s_4	21.55	19.60	25.14	22.09^{c}	18.72	19.32	14.87	17.64^{c}
s_5	22.63	20.40	26.36	23.13^{b}	19.78	20.12	15.98	18.63^{b}
s_6	25.77	24.31	30.29	26.79^{a}	23.00	24.03	19.88	22.30^{a}
s_7	20.32	18.63	24.21	21.06^{e}	17.48	18.35	13.80	16.54^{e}
Mean	22.03^{b}	20.11^{c}	25.78^{a}		19.21^{b}	19.80^{a}	15.60^{c}	
SEm±	m 0.17		s 0.14	m x s 0.23	m 0.09	s 0.12		m x s 0.21
CD (0.05)	m 0.68		s 0.39	m x s 0.67	m 0.37	s 0.35		m x s NS

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

µg TPF g^{-1} soil 24 hr^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.8.4 Soil dehydrogenase activity at the sowing of fodder maize (root residue incorporation)

As outlined in Table 65 d, at 0-20 cm depth, highest dehydrogenase activity was noted for s_6 (34.23 µg TPF g^{-1} soil 24 hr^{-1}) followed by s_5 (29.12 µg TPF g^{-1} soil 24 hr^{-1}),), m_3 (32.36 µg TPF g^{-1} soil 24 hr^{-1}) followed by m_1 (27.96 µg TPF g^{-1} soil 24 hr^{-1}) and m_3-s_6 (38.59 µg TPF g-^{1} soil 24 hr^{-1}) followed by m_3-s_5 (33.14 µg TPF g^{-1} soil 24 hr^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest dehydrogenase activity was noted for s_6 (26.16 µg TPF g^{-1} soil 24 hr^{-1}) trailed by s_5 (20.99 µg TPF g^{-1} soil 24 hr^{-1}), m_2 (23.65 µg TPF g^{-1} soil 24 hr^{-1}) followed by m_1 (19.02 µg TPF g^{-1} soil 24 hr^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant.

4.3.4.8.5 Soil dehydrogenase activity at the harvest of fodder maize (root residue incorporation)

Soil dehydrogenase activity differed significantly for nutrient management, tillage while their interaction effects remained similar at both sampling depths as evidenced in Table 65 e. At 0-20 cm depth, among nutrient management, s_6 (37.44 µg TPF g^{-1} soil 24 hr^{-1}) recorded highest dehydrogenase activity and was on par with s_5 (37.66 µg TPF g^{-1} soil 24 hr^{-1}) and for tillage levels m_3 (36.03 µg TPF g^{-1} soil 24 hr^{-1}) recorded highest value followed by m_1 (33.23 µg TPF g^{-1} soil 24 hr^{-1}). For second depth of sampling, s_6 (30.48 µg TPF g^{-1} soil 24 hr^{-1}) recorded highest value and was on par with s_5 (30.28 µg TPF g^{-1} soil 24 hr^{-1}) and m_2 (29.53 µg TPF g^{-1} soil 24 hr^{-1}) remained superior trailed by m_1 (25.69 µg TPF g^{-1} soil 24 hr^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.9 Microbial Biomass Carbon (MBC)

The influence of tillage and nutrient management on soil MBC content at different depths in a grain cowpea - fodder maize sequence are outlined in Table 66.

4.3.4.9.1 Soil MBC content at the harvest of grain cowpea

At 0-20 cm depth, highest soil MBC content was recorded by s_6 (20.55 mg kg^{-1}) followed by s_5 (17.82 mg kg^{-1}), m_3 (17.75 mg kg^{-1}) followed by m_1 (16.92 mg kg^{-1}) and m_3s_6 (22.28 mg kg^{-1}) followed by m_2s_6 (21.32 mg kg^{-1}) among nutrient management, tillage and interactions respectively. For second depth of sampling (20-60 cm), a similar trend was noted but with lower values of soil MBC, sub plot s_6 (18.21 mg kg^{-1}) was superior followed by s_5 (14.49 mg kg^{-1}) and significantly different to others. Among tillage highest MBC content was noted for m_2 (16.23 mg kg^{-1}) trailed by m_1 (13.53 mg kg^{-1}) and the interaction effects were non significant and highest interaction was noted for m_2s_6 (20.64 mg kg^{-1}) combination (Table 66 a).

4.3.4.9.2 Soil MBC content at the sowing of fodder maize (total residue incorporation)

As outlined in Table 66 b, at 0-20 cm depth, highest MBC was noted for s_6 (26.79 mg kg^{-1}) followed by s_5 (23.13 mg kg^{-1}), m_3 (25.78 mg kg^{-1}) followed by m_1 (22.03 mg kg^{-1}) and m_3s_6 (30.29 mg kg^{-1}) followed by m_3s_5 (26.36 mg kg^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest MBC content was noted for s_6 (22.30 mg kg^{-1}) trailed by s_5 (18.63 mg kg^{-1}), m_2 (19.80 mg kg^{-1}) followed by m_1 (19.21 mg kg^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant.

Table 66 c. MBC content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received total crop residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	23.91	21.15	25.98	23.68^e	18.98	20.80	17.01	18.93^e
s_2	25.29	23.21	28.24	25.58^d	20.46	22.86	19.15	20.82^d
s_3	25.87	25.01	28.48	26.45^c	21.07	24.65	19.55	21.76^c
s_4	27.27	25.27	29.33	27.29^b	22.11	24.91	20.34	22.45^b
s_5	29.33	26.95	31.51	29.26^a	23.98	26.49	22.33	24.27^a
s_6	28.78	27.34	31.92	29.35^a	23.59	26.88	22.70	24.39^a
s_7	21.56	19.85	24.01	21.81^f	16.23	19.39	14.79	16.80^f
Mean	26.00^b	24.11^c	28.50^a		20.92^b	23.71^a	19.41^c	
SEm±	m 0.15		s 0.17	m x s 0.29	m 0.12	s 0.15	m x s 0.25	
CD (0.05)	m 0.59		s 0.47	m x s NS	m 0.46	s 0.42	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 66 d. MBC content of soil (mg kg^{-1}) at the time of sowing of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	19.52	16.16	21.97	19.22^e	12.47	15.19	11.16	12.94^e
s_2	19.50	16.70	22.69	19.63^d	12.60	15.72	11.72	13.35^d
s_3	19.43	17.52	22.35	19.77^{cd}	12.58	16.50	11.57	13.55^d
s_4	19.71	17.63	22.65	19.99^c	13.49	16.78	12.21	14.16^c
s_5	20.58	18.44	23.84	20.95^b	14.52	17.60	13.19	15.10^b
s_6	23.78	22.34	27.76	24.63^a	17.89	21.51	17.07	18.82^a
s_7	18.28	16.63	21.69	18.86^e	12.24	15.77	10.99	13.00^e
Mean	20.11^b	17.92^c	23.28^a		13.69^b	17.01^a	12.56^c	
SEm±	m 0.16		s 0.12	m x s 0.21	m 0.12	s 0.10	m x s 0.18	
CD (0.05)	m 0.62		s 0.36	m x s 0.62	m 0.46	s 0.30	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Table 66 e. MBC content of soil (mg kg^{-1}) at the time of harvest of fodder maize that received root residue of cowpea

	0-20 cm				20-60 cm			
Treatments	m_1	m_2	m_3	Mean	m_1	m_2	m_3	Mean
s_1	21.83	19.09	23.38	21.43^{e}	16.60	18.42	14.69	16.57^{e}
s_2	23.20	21.10	25.56	23.29^{d}	18.13	20.45	16.79	18.46^{d}
s_3	23.73	22.74	25.79	24.09^{c}	18.75	22.13	17.23	19.37^{c}
s_4	25.17	23.09	26.68	24.98^{b}	19.54	22.42	18.00	19.99^{b}
s_5	27.18	24.72	28.73	26.88^{a}	21.46	24.03	19.86	21.79^{a}
s_6	26.66	25.06	29.09	26.94^{a}	21.14	24.42	20.23	21.93^{a}
s_7	19.55	17.66	22.23	19.81^{f}	13.72	16.87	12.32	14.30^{f}
Mean	23.90^{b}	21.92^{c}	25.92^{a}		18.48^{b}	21.25^{a}	17.02^{c}	
SEm±	m 0.13		s 0.15	m x s 0.27	m 0.11	s 0.13	m x s 0.23	
CD (0.05)	m 0.53		s 0.44	m x s NS	m 0.44	s 0.39	m x s NS	

m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

4.3.4.9.3 Soil MBC content at the harvest of fodder maize (total residue incorporation)

Soil MBC content differed significantly for nutrient management and tillage while their interaction effects remained non significant at both sampling depths as evidenced in Table 66 c. At 0-20 cm depth, among nutrient management, s_6 (29.35 mg kg^{-1}) recorded highest MBC and was on par with s_5 (29.26 mg kg^{-1}) and for tillage levels m_3 (28.50 mg kg^{-1}) recorded highest value followed by m_1 (26.00 mg kg^{-1}). For second depth of sampling, s_6 (24.39 mg kg^{-1}) recorded highest value and was on par with s_5 (24.47 mg kg^{-1}) and m_2 (23.71 mg kg^{-1}) remained superior trailed by m_1 (20.92 mg kg^{-1}) among different nutrient management and tillage levels respectively.

4.3.4.9.4 Soil MBC content at the sowing of fodder maize (root residue incorporation)

As outlined in Table 66 d, at 0-20 cm depth, highest MBC was noted for s_6 (24.63 mg kg^{-1}) followed by s_5 (20.95 mg kg^{-1}), m_3 (23.28 mg kg^{-1}) followed by m_1 (20.11 mg kg^{-1}) and m_3s_6 (27.76 mg kg^{-1}) followed by m_3s_5 (23.84 mg kg^{-1}) among nutrient management, tillage and interactions respectively. At second depth of soil (20-60 cm) sampling, highest MBC content was noted for s_6 (18.82 mg kg^{-1}) trailed by s_5 (15.10 mg kg^{-1}), m_2 (17.01 mg kg^{-1}) followed by m_1 (13.69 mg kg^{-1}) among subplot treatments and main plot treatments respectively and the interaction effects were found to be non significant.

4.3.4.9.5 Soil MBC content at the harvest of fodder maize (root residue incorporation)

Soil MBC differed significantly for nutrient management, tillage while their interaction effects remained similar at both sampling depths as evidenced in Table 66 e. At 0-20 cm depth, among nutrient management, s_6 (26.94 mg kg^{-1}) recorded highest MBC and was on par with s_5 (26.88 mg kg^{-1}) and for tillage levels m_3 (25.92 mg kg^{-1}) recorded highest value followed by m_1 (23.90 mg kg^{-1}). For second depth of sampling, s_6 (21.93 mg kg^{-1}) recorded highest value and was on par with s_5 (21.79 mg kg^{-1}) and m_2 (21.25 mg kg^{-1}) remained superior trailed by m_1 (18.48 mg kg^{-1}) among different nutrient management and tillage levels respectively.

5. DISCUSSION

The study entitled “Exploration on the links between soil carbon storage and root biomass and elucidation of drivers of carbon stabilization” was conducted at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during November 2019 to September 2021 with the objective to study the links between soil carbon storage and root biomass in soils of different agro ecological units and to identify the key drivers of C stabilization and NP fluxes under different management practices. The salient results are discussed in this chapter.

5.1 EXPLORATION ON THE LINKS BETWEEN SOIL ORGANIC C AND NP POOLS WITH ROOT BIOMASS IN SOILS OF DIFFERENT AEUS

The soil samples and root biomass in soils from three Agro- ecological units (AEUs) of Southern Kerala namely Southern and Central Foot Hills (AEU 12), Southern High Hills (AEU 14) and Kumily High Hills (AEU 16) were collected to account for the contribution of root biomass to SOC and NP pools. The collected soil samples were analyzed for its various physical, chemical and biological parameters and regression and correlation studies were done to establish links between SOC and NP pools with root biomass in soils. The results are discussed below.

5.1.1 Soil physical and electrochemical properties

The physical properties like BD and gravel % of all the AEUs showed an increase towards depth. The mean BD increased from 1.33 to 1.66 Mg m^{-3} in AEU 12, from 1.24 to 1.48 Mg m^{-3} in AEU 14 and from 1.22 to 1.38 Mg m^{-3} in AEU 16. This was mainly because of the decrease in OM (Table 6 c, Table 8 c and Table 10 c) and lesser cultivation activity in subsoil layers (Klaus and Rattan, 2005; Lepcha *et al.*, 2020). The gravel per cent showed an increase from 35.20 to

43.60, 34.53 to 42.27 and 30.53 to 36.93 percent respectively in AEU 12, 14 and 16. Among the different AEUs, AEU 16 recorded lowest BD and gravel per cent and had a subsoil increase of 12 per cent and 17 per cent for BD and gravel per centage respectively. The dominant cropping system in AEU 16 was cardamom While in other AEUs rubber dominated. The cultivation activities and manure

Table 67. Correlation matrices for root biomass and C fractions of soil samples collected at a depth of 0-20 cm from different AEUs

	Root biomass	TOC	DOC	LC	RC
Root biomass	1				
TOC	0.917***	1			
DOC	0.976***	0.951***	1		
LC	0.788***	0.825***	0.835***	1	
RC	0.931***	0.958***	0.975***	0.842***	1

*** Correlation significant at 0.001 % level ** Correlation significant at 0.01 % level

Table 68. Correlation matrices for root biomass and C fractions of soil samples collected at a depth of 20-60 cm from different AEUs

	Root biomass	TOC	DOC	LC	RC
Root biomass	1				
TOC	0.928***	1			
DOC	0.953***	0.978***	1		
LC	0.975***	0.955***	0.982***	1	
RC	0.903***	0.91***	0.943***	0.935***	

*** Correlation significant at 0.001 % level ** Correlation significant at 0.01 % level

Table 69. Correlation matrices for root biomass and N fractions of soil samples collected at a depth of 0-20 cm from different AEUs

	Root biomass	TN	NH_4-N	NO_3-N	ON
Root biomass	1				
TN	0.804***	1			
NH_4-N	0.552***	0.918***	1		
NO_3-N	0.72***	0.77***	0.636***	1	
ON	0.814***	1***	0.91***	0.771***	1

*** Correlation significant at 0.001 % level ** Correlation significant at 0.01 % level

Table 70. Correlation matrices for root biomass and N fractions of soil samples collected at a depth of 20-60 cm from different AEUs

	Root biomass	TN	NH_4-N	NO_3-N	ON
Root biomass	1				
TN	0.809***	1			
NH_4-N	0.439**	0.848***	1		
NO_3-N	0.804***	0.705***	0.365*	1	
ON	0.82***	1***	0.834***	0.713***	1

*** Correlation significant at 0.001 % level ** Correlation significant at 0.01 % level

Table 71. Correlation matrices for root biomass and P fractions of soil samples collected at a depth of 0-20 cm from different AEUs

	Root biomass	TP	LP	NLP
Root biomass	1			
TP	0.483***	1		
LP	0.68***	0.554***	1	
NLP	0.383**	0.982***	0.389**	1

*** Correlation significant at 0.001 % level ** Correlation significant at 0.01 % level

Table 72. Correlation matrices for root biomass and P fractions of soil samples collected at a depth of 20-60 cm from different AEUs

	Root biomass	TP	LP	NLP
Root biomass	1			
TP	0.628***	1		
LP	0.775***	0.669***	1	
NLP	0.534***	0.984***	0.527***	1

*** Correlation significant at 0.001 % level ** Correlation significant at 0.01 % level

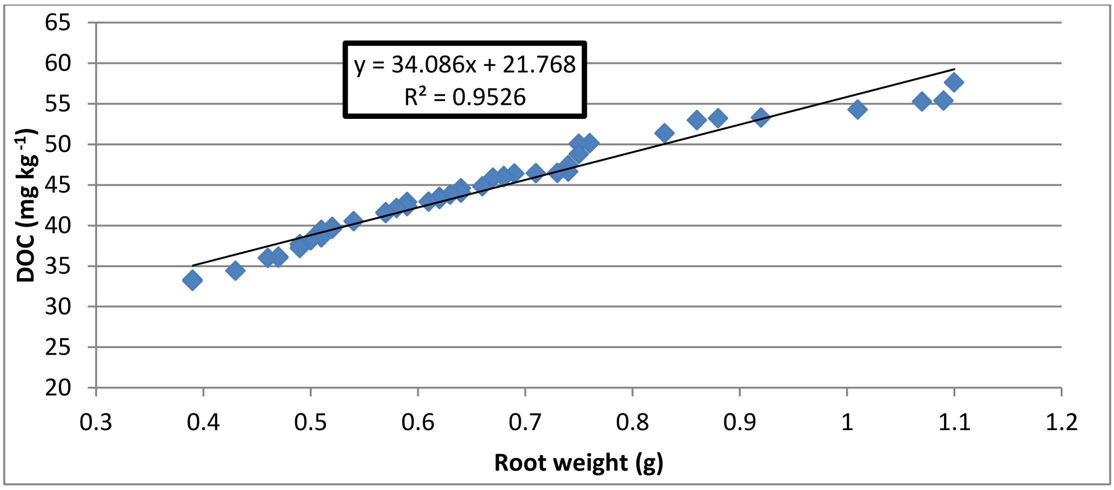


Fig 2. LRC between root biomass and soil DOC content at 0-20cm depth from different AEUs

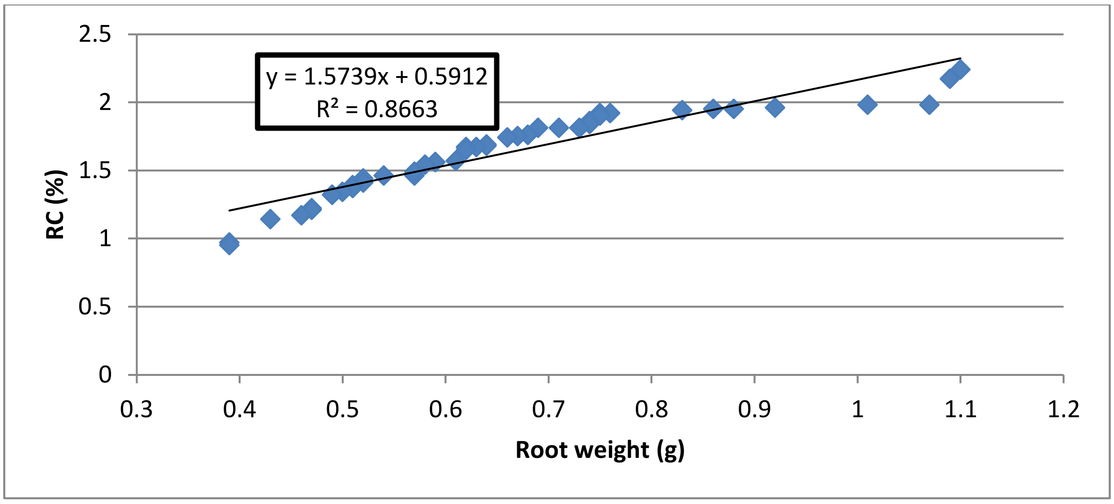


Fig 3. LRC between root biomass and soil RC content at 0-20cm depth from different AEUs

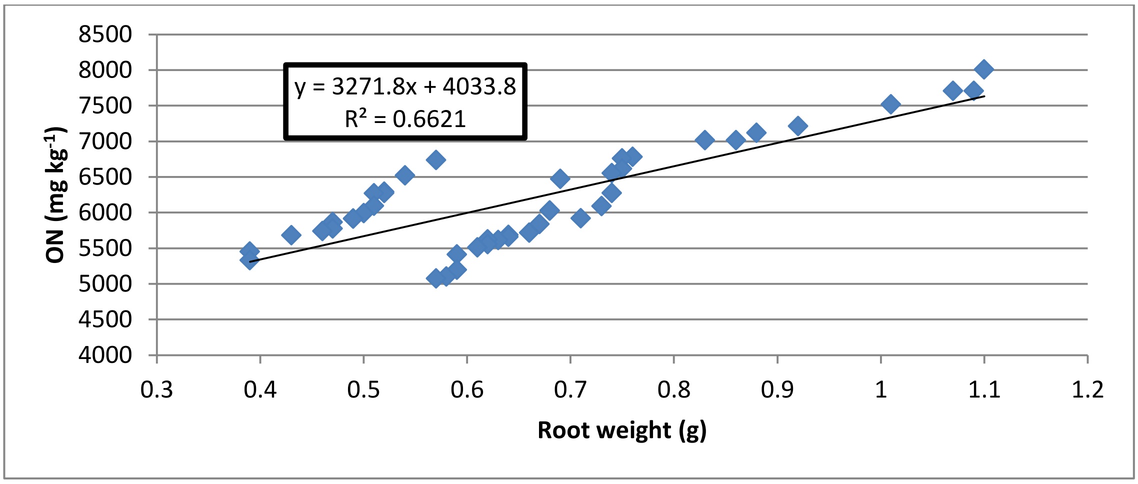


Fig 4. LRC between root biomass and soil ON content at 0-20cm depth from different AEUs

application in cardamom plantations might have improved the soil physical properties. According to many reports application of organic manures decreased the soil bulk density of soil due to increase in porosity and aggregation in soil (Acharya and Kumar, 2018; Gunjal *et al.*, 2018; Mahmood *et al.*, 2018).

Both pH and EC, showed a decrease with soil depth. The mean pH decreased from 5.59 to 5.28 in AEU 12, from 5.49 to 5.08 in AEU 14 and from 5.58 to 5.01 in AEU 16. The highest pH was noted in AEU 12 and lowest in AEU16. The mean EC decreased from 0.22 to 0.17 dS m^{-1} in AEU 12, from 0.37 to 0.15 dS m^{-1} in AEU 14 and from 0.47 to 0.22 dS m^{-1} in AEU 16. EC was highest for AEU 16 and lowest for AEU 12. The application of fertilizers for the cardamom crop might have contributed towards the higher EC values in AEU 16. The subsoil layers became more acidic in all the AEUs due to restricted effect of liming and downward movement of H^+ ions to deeper soil layers. Here also the highest pH was recorded by AEU 12 while it maintained lowest EC (Table 6 b, Table 8 b and Table 10 b). A decrease in pH and EC in subsoil compared to surface soil of cultivated crops have been reported by Zhang *et al.* (2019).

5.1.2 Soil C fractions

The different fractions of soil carbon showed a decrease with depth for all the AEUs mainly due to the decrease in OM and root biomass and associated rhizosphere priming, and microbial activity in subsoil layers. Among the AEUs selected, the mean values of TOC (%) of surface soil showed a decrease from 3.41 to 3.11, 5.94 to 4.38 and 5.68 to 3.66 per cent in subsoil respectively for AEUs 12, 14 and 16. Similarly the RC (%) of surface soil of AEUs 12, 14 and 16 decreased from 1.62 to 1.17, 1.64 to 1.14 and 1.62 to 1.13 respectively towards subsoil. Among the different AEUs, TOC and RC were highest for AEU 14 with a decrease of 26 per cent and 31 per cent respectively for subsoil (Table 6 c, Table 8 c and Table 10 c).

Among the AEUs selected, the mean values of DOC (mg kg^{-1}) of surface soil showed a decrease from 37.43 to 33.39, 50.70 to 34.85 and 54.63 to 30.21 in subsoil respectively for AEUs 12, 14 and 16. Similarly the LC (mg kg^{-1}) of Surface soil of AEUs 12, 14 and 16 decreased from 802.51 to 697.36, 871.80 to

568.84 and 877.50 to 635.77 respectively towards subsoil (Table 6 d, Table 8 d and Table 10 d). The highest DOC and LC were for AEU 16 with a subsoil decrease of 45 per cent and 27 per cent respectively. AEU 12 recorded lower values for C fractions which may be due to decreased root biomass by 38 per cent and 25 per cent in surface soil and 55 per cent and 70 per cent in subsoil than that of AEU 14 and AEU 16 respectively.

In order to establish links between root biomass and soil C fractions, correlation and regression analysis were done by combining data from all AEUs. The root biomass and soil C fractions were positively and significantly correlated at both sampling depths. As evidenced in Table 67 and Table 68, highest correlation between root biomass and soil C fractions was recorded by DOC (0.976 - Fig 2) followed by RC (0.931- Fig 3) and LC (0.975) followed by DOC (0.953) for surface and subsoil respectively. From the regression analysis perfect fit towards linear regression model, expressed as R^2 value, was highest for DOC (0.95) and LC (0.94) at sampling depths of 0-20 cm and 20-60 cm respectively (Table 73).

From the above results it is evident that root biomass is well connected to soil C pools and it is mainly by the phenomenon of rhizodeposition, composed of mucilage, exudates, lysates, secretions, volatile compounds, etc. which are mainly rich in carbon and nitrogen. (Jones *et al* 2009). Rhizospheric microorganisms utilizes these substances as easily available C and energy sources for their growth and reproduction reflecting in an increase in SOM decomposition and release of available nutrients (Blagodatsky *et al.,* 2010; Witzgall *et al.,* 2021).

The DOC content of soil consists of a wide range of molecules ranging from simple acids and sugars to complex humic substances with large molecular weights and is largely a product of decomposition of litter and humus but it may also originate directly from exudates of plant roots (Huo *et al.,* 2017). The correlation and regression results showed that DOC is the C fraction which is highly linked to root biomass mainly through rhizodeposition followed by RC and the role of roots in contributing to RC fractions of soil is mainly confined to its lower decomposition rates due to its high content of condensed tannins and lignin compounds (Kramer *et al.,* 2010). Therefore roots represents a source of recalcitrant plant detritus that is returned to the soil and can contribute to an increase in the soil organic matter pool (Personeni, and Loiseau, 2005; Germon *et al.,* 2020; Moore *et al.,* 2020).

5.1.3 Soil N and P fractions

Among the different nitrogen fractions, nitrate N was present in lowest quantity in all the AEUs preceded by ammoniacal N. The immediate removal of nitrate N by the growing plants might have resulted such lower values for nitrate N and the transformation of ammoniacal N to nitrate N might not have attained the same pace as that of crop removal due to variation in activity of nitrifiers (Balume *et al.,* 2022; Dharmakeerthi, 2021). In all the AEUs major part of N was retained as organic N as it is observed generally. AEU 12 recorded highest values for all the different fractions of N and AEU 14 the lowest and it might may be due to difference in physiographic position of AEU 12 which includes foot hills while in AEU 14 it is mainly high hills from where nutrient losses will be more.

The variation in different N fractions with depth also followed the same pattern as that of C ie. a decrease was observed with depth. This decrease is mainly due to the reduction of soil OM levels and microbial activity in deeper layers of soil as compared with surface soil layers (Dove *et al.,* 2020; Villarino *et al.,* 2021). The different fractions of N were highest for AEU 12 and surface soil showed an increase in TN by 6 per cent and NH_4-N by 20 per cent, NO_3 – N by 18 per cent and ON by 5 per cent than subsoil (Table 6 e, Table 8 e and Table 10 e).

The total P (mg kg^{-1}) content of surface soils of AEUs 12, 14 and 16 increased from 773.14 to 950.35, 681.52 to 820.00 and 722.35 to 851.00 respectively towards subsoil. The other fractions viz., labile and non labile P fractions also followed the same trend. Though P is immobile in soil, the continuous application of P fertilizer s and the tillage activities might have helped the downward movement of P in these soils. The laterite soil dominated with kaolinitic clay and Fe and Al, can hold the P tightly. Since the subsoil P is less subjected to runoff losses, it can give higher values than surface soil (Table 6 g, Table 8 g and Table 10 g).

Comparing the contribution of labile P to total P, in AEU 12 it is 13.15 per cent and 14.29 per cent in surface soil and subsoil respectively. While in AEU 14 the contribution is 9.46 per cent for surface soil and 11.58 per cent for subsoil. In AEU16 labile P occupied 10.67 per cent of total P in surface soil and 12.42 per cent in subsoil. It can be seen that the contribution of labile P to total P is highest in AEU12. A better soil pH might have influenced the proportion of labile P in soil (Mayakaduwage *et al.,* 2020)

From the correlation analysis results all N and P fractions were significantly and positively correlated to root biomass at both sampling depths (Table 69 – Table 72). Among soil N and P fractions ON and LP were found to be more correlated to root biomass at both sampling depths (Fig 4 and Fig 5). From the regression analysis R^2 value, was highest for ON (0.66: surface soil and 0.67: subsoil) and LP (0.66: surface soil and 0.61: subsoil) among N and P fractions in soil (Table 73).

In addition to direct rhizodeposition of organic N and P compounds to soil as amino acids, phospholipids etc, the rhizodeposition can also accelerate microbial activity leading to greater microbial biomass generation in which mineralized nitrogen and phosphorus compounds by SOM decomposition were immobilized and stored as organic microbial biomass N and P which will be later added to soil organic N and P pools as necromass after death of microbes (Kuzyakov, 2002; Villarino *et al.,* 2021). This temporary immobilization of N and P driven by rhizodeposition might have resulted in lesser correlation and regression effect of root biomass with soil NP pools when compared to that of C pools. Therefore we can conclude that root biomass and soil NP pools are positively linked.

5.1.4 Soil MBC and dehydrogenase activity

The soil MBC and DHA are often used as indices of microbial activity and soil fertility which is highly dependent on soil micro climate, SOM levels and quality and quantity of rhizodeposits (Heiman and Reichstein, 2008; Semchenko *et al.,* 2021). The rhizodeposits acts as a fuel for microbial growth and activity which is governing the C and NP fluxes in soil (Huo *et al.,* 2017). Among the AEUs selected, the mean values of MBC (mg kg^{-1}) of surface soil showed a decrease from 26.59 to 21.37, 26.71 to 17.44 and 26.89 to 19.5 in subsoil respectively for AEUs 12, 14 and 16 (Table 6 h, Table 8 h and Table 10 h). Similarly the DHA (µg TPF g^{-1} soil 24 hr^{-1}) of surface soil of AEUs 12, 14 and 16 decreased from 33.87 to 27.86, 34.71 to 22.62 and 34.94 to 25.00 respectively towards subsoil (Table 6 i, Table 8 i and Table 10 i). Both MBC and DHA declined with increasing soil depth in all AEUs due to reduced OM levels and root biomass in subsoil than surface soil. The MBC and DHA were highest for AEU 16 and surface soil showed an increase in MBC by 28 per cent and DHA by 30 per cent, than subsoil

Regardless of the fact that fine roots constitute only a small proportion of the total biomass in an ecosystem, but they can play a crucial role in nutrient dynamics by efficient absorption of nutrients and enrichment of the soil with organic matter and nutrients through their senescence and rhizodeposition (Tripathi *et al.,* 2005; Lalnunzira *et al.,* 2019). In a variety of ecosystems, fine roots contribute significantly (20 % to 77 %) to organic matter input (Upadhaya *et al.,* 2005) and therefore they constitute a significant pathway for the input of C and N in the soil.

5.2 ASSESSMENT OF CARBON STORAGE UNDER DIFFERENT LAND USE SYSTEM AND IDENTIFYING THE DRIVERS OF C STABILIZATION

Based on the survey conducted, most prominent land use system of each AEU ie. rubber plantations for AEU 12 and AEU 14 and cardamom plantations for AEU 16 were selected to study the carbon storage under different land use systems and to identify the major drivers of C stabilization. The collected soil, shoot and root samples were analyzed for various parameters and correlation and regression studies were done to determine main drivers of C stabilization. Besides that, total C storage of selected land use system of each AEU was also computed as suggested by Zhang *et al.* (2015).

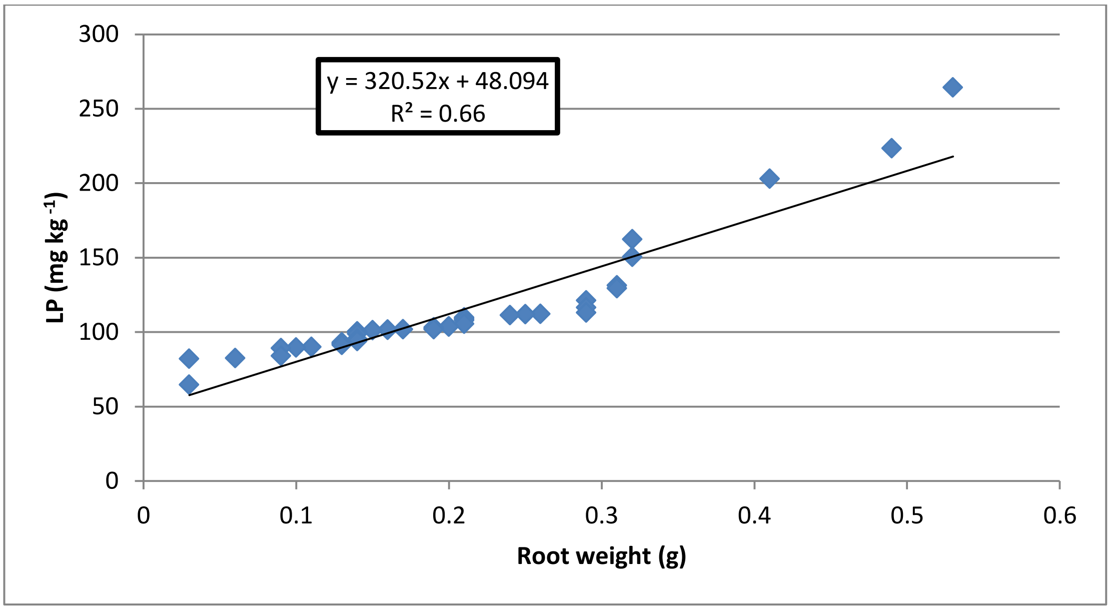


Fig 5. LRC between root biomass and soil LP content at 20 -60 cm depth from different AEUs

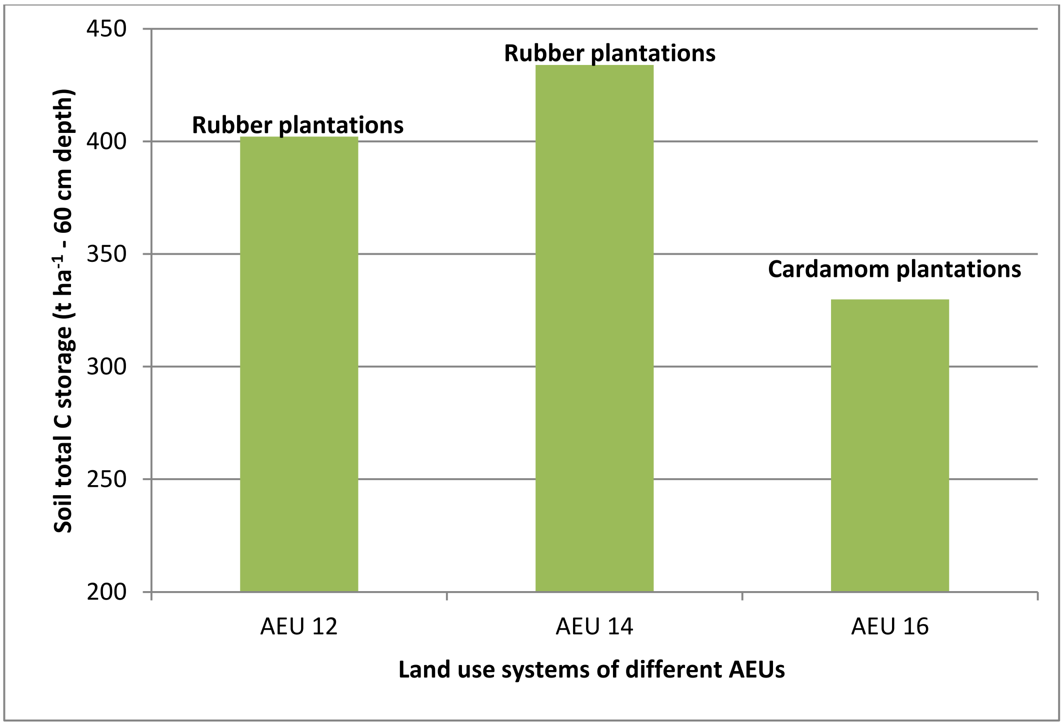


Fig 6. Total C storage of selected land use system of different AEUs

Table 73. Regression analysis between root biomass and soil parameters at different sampling depths of different AEUs

Parameters	Depth of Sampling			
	0-20 cm		20-60 cm	
	Equation	R^2 value	Equation	R^2 value
TOC	$y = 6.51\ x + 0.75$	0.84	$y = 5.78\ x + 2.58$	0.86
DOC	$y = 32.08\ x + 21.76$	0.95	$y = 1.365\ x + 0.87$	0.81
LC	$y = 324.99\ x + 647.88$	0.62	$y = 887.51\ x + 458.13$	0.94
RC	$y = 1.57\ x + 0.59$	0.86	$y = 1.36\ x + 0.87$	0.82
TN	$y = 3419.9\ x + 4331.8$	0.64	$y = 6523\ x + 4944$	0.66
NH_4- N	$y = 126.31\ x + 231.7$	0.34	$y = 313.2\ x + 197.27$	0.22
NO_3 - N	$y = 21.82\ x + 66.30$	0.52	$y = 51.83\ x + 55.61$	0.63
ON	$y = 3271.8\ x + 4033.8$	0.66	$y = 6158\ x + 4691.3$	0.67
TP	$y = 450.77\ x + 430.7$	0.23	$y = 1552.4\ x + 567.48$	0.40
LP	$y = 128.25\ x - 3.57$	0.48	$y = 320.52\ x + 48.09$	0.66
NLP	$y = 322.51\ x + 434.35$	0.24	$y = 1231.8\ x + 519.39$	0.29

R^2 value > 0.5 were significant at 0.05 % level of significance

Table 74. Total C storage of selected land use system in different AEUs, t ha^{-1} - 60 cm depth

Sample No:	Rubber plantations (AEU 12)	Rubber plantations (AEU 14)	Cardamom plantations (AEU 14)
1	393.2	449.6	337.3
2	394.8	437.2	346.7
3	409.4	439.7	340.5
4	409.8	420.3	300.8
5	407.1	420.8	311.2
Mean	402.1	434.0	329.9

Table 75. Correlation coefficients between plant biomass characteristics and soil C fractions from rubber plantations of AEU 12

	TOC	DOC	LC	RC
Root biomass	0.949*	0.89*	0.919*	0.976**
Root Lignin	0.869	0.887*	0.966**	0.999***
Root C	0.967**	0.89*	0.932*	0.848
Shoot biomass	0.654	0.95*	0.787	0.882*
Shoot Lignin	0.937*	0.843	0.911*	0.797
Shoot C	0.943*	0.846	0.901*	0.789

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

Table 76. Correlation coefficients between plant biomass characteristics and soil N fractions from rubber plantations of AEU 12

	TN	NH_4-N	NO_3-N	ON
Root biomass	0.887*	0.772	0.943*	0.878*
Shoot biomass	0.99**	0.675	0.991**	0.99**
N uptake	0.987**	0.707	0.994***	0.987**

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

Table 77. Correlation coefficients between plant biomass characteristics and soil P fractions from rubber plantations of AEU 12

	TP	LP	NLP
Root biomass	0.95*	0.96*	0.949*
Shoot biomass	0.995***	0.662	0.996***
P uptake	0.998***	0.702	0.996***

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

5.2.1 Total C storage

The changes in land use and land cover have a strong effect on the total soil organic carbon, its fractions and overall soil health and more C storage was reported in forests followed by grasslands, bare lands and agricultural lands (Sainepo *et al.,* 2018). AEU 14 with rubber plantations recorded the highest C storage (434.0 t ha^{-1}) followed by AEU 12. The lowest value was observed for AEU 16 (329.9 t ha^{-1}) with cardamom plantations. Thus more total C storage was recorded by rubber plantations than cardamom plantations ie. an increase of 24 per cent by AEU 14 and 18 per cent by AEU 12 over AEU 16 was noticed (Fig 6).

In most of the rubber plantations, legume cover of *Pueraria phaseoloides* was maintained and in addition land was also covered with several grass species but in most cardamom plantations weed free condition was maintained to decrease the disease and pest incidence to obtain higher yields. Besides that, soil disturbance is nearly nil in established rubber plantations which might have contributed to more C storage and sequestration as tillage and intercultural operations can lead to exposure of sequestered soil C to microbial attack. But in cardamom plantations soil was continuously disturbed throughout the cropping period for weeding, earthing up etc. and the clearing of the old shoots from the base of the plants leads to low litter fall in contrast to heavy litter fall in rubber plantations. This might have resulted in lower C storage in cardamom plantations.

According to Huo *et al.* (2017) woody species tend to produce more rhizodeposits followed by grasses and crops and as rubber being a tree crop can exude more carbonaceous and nitrogenous compounds and can produce more RPE effects in soil. Many reports have cited the importance of grasses and legumes in increasing soil C stocks because of their prolonged photosynthetic activity, greater root biomass, and proportionately deeper rooting (Jackson *et al.*, 2017; Kumar *et al.,* 2018)). Inclusion of legume species in cropping systems can increase the soil aggregation, nutrient storage capacity, SOM build-up and improvements in soil structure (Soussanna *et al*., 2004). Therefore, the practices such as inclusion of legume covers, minimum soil disturbance, no bare soil, heavy litter fall etc. might have contributed to more C storage in rubber plantations.

5.2.2 Soil physical and electrochemical properties

The soil physical properties like BD and gravel per cent of rubber and cardamom plantations showed an increase towards depth. The mean values of BD in the surface soil ranged from 0.97 to 1.23 Mg m^{-3} with lowest value for cardamom plantations of AEU 16. The subsoil also followed the same trend for BD with a range of 1.20 to 1.50 Mg m^{-3}. The gravel content also followed the same pattern as that of BD with AEU 16 showing the lowest value in both surface and surface soils. The range for gravel content was 28.00 to 37.11 per cent in surface soil and 33.00 to 41.04 per cent in subsurface soil. The increase in BD with depth was mainly because of the decrease in OM and lesser cultivation activity in subsoil layers. The lesser cultivation activity in subsoil might have helped to retain more gravel in sub soil layers and a minimum in highly cultivated soils of cardamom plantations (Lepcha and Devi, 2020; Schjonning *et al.*, 2020).

Among the different land use systems cardamom plantations of AEU 16 recorded lowest BD and gravel content and had a subsoil increase of 19 per cent and 15 per cent for BD and gravel content respectively. This reduction in BD and gravel content is mainly due to frequent intercultural operations in cardamom plantations. With regard to pH and EC, the reverse was noticed as these values decreased with soil depth. The subsoil layers became more acidic in all land use systems due to restricted effect of liming and downward movement of H^+ ions to deeper soil layers. The highest pH was recorded by rubber plantations of AEU 12 while it maintained lowest EC due to lesser fertilization in rubber plantations as compared to heavily fertilized cardamom plantations where development of soil acidity and salt accumulation might have occurred and reflected in their low pH and high EC.

5.2.3 Soil C fractions

The different fractions of soil carbon showed a decrease with depth for all land use systems mainly due to the decrease in OM levels and root biomass and associated rhizosphere priming, and microbial activity in subsoil layers. Among the different land use rubber plantations of AEU 14 recorded highest value for TOC (6.72 % for surface soil and 4.68 % for subsoil) and DOC (55.16 mg kg^{-1}

Table 78. Correlation coefficients between plant biomass characteristics and soil C fractions from rubber plantations of AEU 14

	TOC	DOC	LC	RC
Root biomass	0.966**	0.931*	0.76	0.894*
Root Lignin	0.818	0.957*	0.575	0.881*
Root C	0.874	0.984**	0.654	0.886*
Shoot biomass	0.773	0.904*	0.401	0.835
Shoot Lignin	0.857	0.917*	0.625	0.969**
Shoot C	0.887*	0.977**	0.661	0.912*

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

Table 79. Correlation coefficients between plant biomass characteristics and soil N fractions from rubber plantations of AEU 14

	TN	NH_4-N	NO_3-N	ON
Root biomass	0.923*	0.911*	0.989**	0.922*
Shoot biomass	0.937*	0.983**	0.826	0.935*
N uptake	0.918*	0.966**	0.923*	0.915*

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

Table 80. Correlation coefficients between plant biomass characteristics and soil P fractions from rubber plantations of AEU 14

	TP	LP	NLP
Root biomass	0.818	0.948*	0.809
Shoot biomass	0.976**	0.851	0.973**
P uptake	0.997***	0.802	0.996***

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

Table 81. Correlation coefficients between plant biomass characteristics and soil C fractions from cardamom plantations of AEU 16

	TOC	DOC	LC	RC
Root biomass	0.988**	0.955*	0.82	0.81
Root Lignin	0.956*	0.978**	0.884*	0.609
Root C	0.964**	0.941*	0.756	0.626
Shoot biomass	0.966**	0.988**	0.972**	0.804
Shoot Lignin	0.848	0.881*	0.954*	0.891*
Shoot C	0.981**	0.949*	0.782	0.725

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

Table 82. Correlation coefficients between plant biomass characteristics and soil N fractions from cardamom plantations of AEU 16

	TN	NH_4-N	NO_3-N	ON
Root biomass	0.961**	0.924*	0.813	0.96**
Shoot biomass	0.985**	0.996***	0.622	0.984**
N uptake	0.975**	0.931*	0.775	0.975**

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

Table 83. Correlation coefficients between plant biomass characteristics and soil P fractions from cardamom plantations of AEU 16

	TP	LP	NLP
Root biomass	0.975**	0.495	0.97**
Shoot biomass	0.932*	0.491	0.928*
P uptake	0.981**	0.624	0.979**

*** Correlation significant at 0.001 % level; ** Correlation significant at 0.01 % level;
* Correlation significant at 0.05 % level

for surface soil and 36.28 mg kg $^{-1}$ for subsoil) while cardamom plantations had highest soil LC (910.91 mg kg $^{-1}$ for surface soil and 703.17 mg kg $^{-1}$ for subsoil) and RC (1.92 % for surface soil and 1.18 % for subsoil) content but subsoil RC content (1.26 %) was more for rubber plantations of AEU 14 (Table 12 b, Table 15 b and table 18 b).

The decrease with depth for all land use systems mainly due to the decrease in OM levels and root biomass and associated rhizosphere priming, and microbial activity in subsoil layers. Among the different land use systems, rubber plantations of AEU 14 recorded highest value for TOC and DOC while cardamom plantations had highest soil LC and RC content but subsoil RC content was more for rubber plantations of AEU 14. The difference in decomposition pattern of fallen leaves and the rhizodeposits might have influenced the different C pools (Huo *et al.,* 2017; Sun *et al.,* 2018).

5.2.4 Drivers of C stabilization

In order to identify the drivers of C stabilization, correlation and regression analysis were done with plant biomass and soil C fractions of different land use systems (Table 75, Table 78 and Table 81). In rubber plantations of AEU 12 and AEU 14, the root biomass was significantly and positively correlated to all soil C fractions except to LC fraction in AEU 14 and highest correlation was observed for RC and TOC (Table 75 and Table 78). But in case of cardamom plantations root biomass were significantly correlated to TOC (0.98) and DOC (0.95) fractions only (Table 81). A significant and positive correlation between root lignin and soil RC was also observed in rubber plantations (0.99 for AEU 12 and 0.88 for AEU 14) while root lignin was more correlated to soil TOC (0.95) in cardamom plantations.

The shoot biomass was found to be less correlated to C fractions when compared to root biomass in all land use systems and more correlation for shoot and C fractions were recorded in cardamom plantations where all C fractions were correlated to shoot biomass except soil RC. Among root characteristics R^2 value was highest for root biomass and C fractions namely RC (0.95) in AEU 12, RC (0.81) in AEU 14 and TOC (0.97) in AEU 16 and among shoot characteristics R^2

value was highest for shoot biomass and DOC (0.90, 0.81 and 0.95 for AEU 12, 14 and 16 respectively (Table 84-86).

From the above results we can conclude that root biomass and root lignin contributed more to recalcitrant C fraction ie. stable C pool than other plant biomass characteristics like shoot biomass, shoot lignin, shoot and root C etc. This can be further confirmed and supported by many investigators who reported that the absolute contribution of roots to the total particulate organic matter occluded within soil aggregates ranges between 1.2 to 6.1 times that of shoots (Six *et al.*, 2002; Sokol *et al.*, 2019). The above ground carbon input retained in SOM averaged to an extent of 8.3 per cent while the below-ground carbon retained was as high as 46 per cent in field studies involving various crops and crop mixtures (Lajtha *et al.*, 2014; Austin *et al.*, 2017).

5.2.5 Soil N and P fractions

The variation in different N fractions with depth also followed the same pattern as that of C ie. a decrease was observed with depth in all land use systems. This decrease was mainly due to the reduction of soil OM levels and microbial activity in deeper layers of soil as compared with surface soil layers. The surface layers receive more organic additives and this naturally contribute to soil N also since major part of N is contributed by organic manures. The different fractions of N were highest for cardamom plantations of AEU 16 and surface soil showed an increase in TN by 5 per cent and NH_4-N by 14 per cent, NO_3 – N by 22 per cent and ON by 4 per cent than subsoil. But a reverse condition was observed for P fractions ie. an increase was observed with depth mainly due to leaching effect of phosphatic fertilizers to deeper soil layers. Among different land use systems, cardamom plantations recorded highest values for P fractions and a subsoil increase of TP by 12 per cent, LP by 29 per cent and NLP by 11 per cent was also observed.

From the correlation analysis results it can be seen that shoot biomass was more correlated to soil N and P fractions than root biomass in all land use systems (Table 76 - Table 83). Among N fractions shoot biomass was more correlated to ON and TN in all land use systems and in case of P fractions shoot biomass is

Table 84. Correlation coefficients between soil C storage and soil N and P fractions from selected land use system of different AEUs

Soil C storage	TN	NH_4-N	NO_3-N	ON	TP	LP	NLP
AEU12- Rubber plantation	0.73	0.983***	0.917*	0.698	0.779	0.961**	0.767
AEU14- Rubber plantation	0.937*	0.909*	0.912*	0.936*	0.858	0.702	0.855
AEU16 – Cardamom plantation	0.864*	0.815	0.95***	0.861*	0.782	0.533	0.773

*** Correlati6n significant at 0.001 % level; ** Correlation significant at 0.01 % level; * Correlation significant at 0.05 % level

Table 85. Regression analysis between plant biomass and soil parameters from rubber plantations of AEU 12

Parameters	Plant Biomass			
	Root		Shoot	
	Equation	R^2 value	Equation	R^2 value
TOC	y = 0.015 x + 3.95	0.56	y = 0.001 x + 5.48	0.42
DOC	y = 0.10 x + 35.68	0.79	y = 0.009 x + 46.2	0.90
LC	y = 1.55 x + 665.46	0.84	y = 0.10 x + 825.3	0.61
RC	y = 0.01 x + 0.21	0.95	y = 0.01 x + 1.22	0.77
TN	y = 23.81 x + 2886	0.78	y = 2.06 x + 5124.9	0.97
NH_4- N	y = 1.05 x – 131.72	0.59	y = 0.07 x + 239.18	0.45
NO_3 - N	y = 0.06 x + 70.21	0.88	y = 0.005 x + 76.56	0.94
ON	y = 22.70 x - 2683	0.77	y = 1.98 x + 4808	0.96
TP	y = 5.63 x – 102.4	0.90	y = 0.45 x + 440.04	0.91
LP	y = 0.075 x + 53.54	0.57	y = 0.005 x + 61.31	0.43
NLP	y = 5.55 x – 155.94	0.89	y = 0.45 x + 378.7	0.89

R^2 value > 0.5 were significant at 0.05 % level of significance

Table 86. Regression analysis between plant biomass and soil parameters from rubber plantations of AEU 14

Parameters	Plant Biomass			
	Root		Shoot	
	Equation	R^2 value	Equation	R^2 value
TOC	y = 0.05 x - 1.59	0.93	y = 0.006 x + 3.75	0.59
DOC	y = 0.19 x + 26.7	0.80	y = 0.03 x + 42.85	0.81
LC	y = 0.15 x + 878.9	0.57	y = 0.01 x + 896.14	0.16
RC	y = 0.01 x + 0.18	0.81	y = 0.01 x + 1.16	0.69
TN	y = 35.57 x + 1147.5	0.85	y = 5.21 x + 4024.5	0.87
NH_4- N	y = 1.20 x – 123.24	0.836	y = 0.18 x + 215.28	0.96
NO_3 - N	y = 0.27 x + 44.27	0.95	y = 0.03 x + 69.4	0.68
ON	y = 34.10 x + 979.04	0.84	y = 5.03 x + 373.9	0.85
TP	y = 8.24 x – 348.52	0.66	y = 1.42 x + 221.72	0.95
LP	y = 0.24 x + 32.14	0.89	y = 0.031 x + 53.60	0.72
NLP	y = 8.00 x – 380.66	0.65	y = 1.39 x + 168.12	0.94

R^2 value > 0.5 were significant at 0.05 % level of significance

Table 87. Regression analysis between plant biomass and soil parameters from cardamom plantations of AEU 16

Parameters	Plant Biomass			
	Root		Shoot	
	Equation	R^2 value	Equation	R^2 value
TOC	y = 0.01 x + 4.84	0.97	y = 0.008 x + 4.93	0.93
DOC	y = 0.02 x + 44.32	0.91	y = 0.013 x + 44.33	0.95
LC	y = 0.24 x + 880.48	0.67	y = 0.21 x + 876.24	0.94
RC	y = 0.001 x + 1.73	0.66	y = 0.001 x + 1.74	0.64
TN	y = 6.2 x + 5715	0.92	y = 8.61 x + 5649	0.96
NH_4- N	y = 0.18 x + 323.54	0.85	y = 0.26 x + 320.06	0.94
NO_3 - N	y = 0.02 x + 78.58	0.66	y = 0.22 x + 79.27	0.38
ON	y = 5.99 x + 5313	0.92	y = 8.31 x - 5281	0.96
TP	y = 2.11 x – 651.87	0.94	y = 14936 x + 672.6	0.86
LP	y = 0.02 x + 77.10	0.25	y = 0.016 x + 77.23	0.24
NLP	y = 2.09 x – 574.76	0.93	y = 1.47 x + 595.36	0.85

R^2 value > 0.5 were significant at 0.05 % level of significance positively correlated to TP and NLP fractions while root biomass was correlated to LP fraction clearly hinting to the rhizodeposition of malic acid, nicotinic acid etc by roots which were having P solubilizing effects contributing to more labile P fraction in soil (Jones *et al.,* 2009). A positive significant correlation was also observed between soil NP pool and plant removal in all land use systems.

Among N fractions, R^2 value was highest for shoot biomass in all land use systems namely for ON (0.96) in AEU 12, NH_4 - N (0.96) in AEU 14 and ON (0.96) in AEU 16 and among P fractions R^2 value was highest for shoot biomass and soil TP in rubber plantations but for root biomass and soil TP fraction in case of cardamom plantations (Table 85-87). The temporary immobilization by microbial biomass resulted by rhizodeposits might have contributed to lesser correlation and regression effects by root biomass for soil NP pools than shoot biomass.

5.2.6 Soil MBC and dehydrogenase activity

Both MBC and DHA declined with increasing soil depth in all land use systems due to reduced OM levels and root biomass in subsoil than surface soil. The MBC and DHA were highest for cardamom plantations of AEU 16 and surface soil showed an increase in MBC by 25 per cent and DHA by 23 per cent than subsoil. The study of soil microbial biomass and dehydrogenase activity is important for understanding early changes in biological quality of soil following changes in the land management (Palma *et al.,* 2000; Su *et al.,* 2021)

5.3 EFFECT OF TILLAGE AND NUTRIENT MANAGEMENT ON THE LINK BETWEEN ROOT AND SHOOT BIOMASS C, AND SOC AND NP POOLS

Field experiments on grain cowpea- fodder maize cropping sequence was carried out during January 2020 to September 2020 by raising grain cowpea followed by fodder maize with an interval of three months. In the field trial the effect of tillage and nutrient management on various soil properties and growth and yield of grain cowpea and fodder maize was studied using thermochemical fortified organic fertilizer as the organic source for nutrition. The results of the experiments are discussed below.

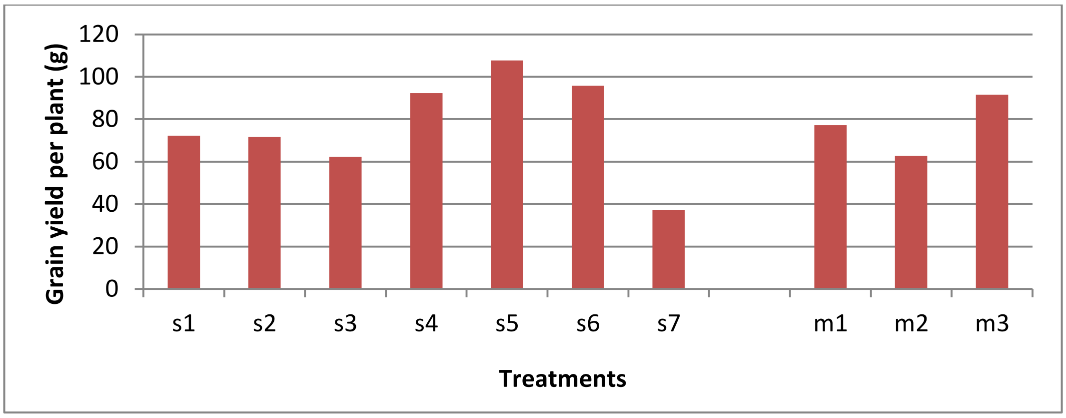
5.3.1 Effect of tillage and nutrient management on growth, yield and quality characteristics of grain cowpea - fodder maize cropping sequence

Among the various nutrient managements, soil test based POP + AMF (s_5) recorded the highest plant height and shoot biomass of grain cowpea. The treatment TOF-F + AMF (s_6) followed it in shoot biomass and showed highest value for primary branches and root characteristics like root volume, root weight and number of active nodules. In both the cases the positive influence of AMF was very much evident since the same treatments without AMF did not show the same trend.

In legumes, P stimulated nodulation, N fixation and plant growth was reported by Vance, (2001). The AMF symbiosis is particularly effective for the enhanced uptake of immobile nutrients, especially phosphorus which is needed for proper root growth and nodulation which might have resulted in better growth and yield attributes in treatments with AMF.

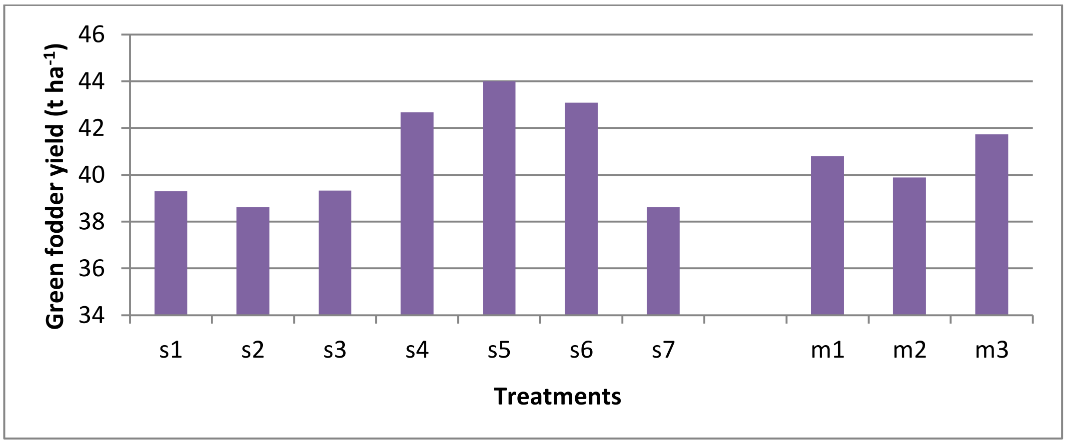
Evaluating the role of TOF-F on plant growth, its prominent role on root growth was observed. Similar results with TOF-F, highly favouring root growth was reported by Jacob (2018) and Ramesha, (2019) in maize and amaranthus respectively. The soil test based POP was found to be more efficient in total dry matter production and grain yield when applied along with AMF (Fig 7). In the absence of AMF, TOF-F had more favorable influence on growth characteristics while on yield and yield attributes it was not reflected. Though the TOF-F was applied based on the N basis, the amount of other essential nutrients present in it might not be able to meet the demand in accordance with the root biomass production mainly due to the recalcitrant nature of TOF-F (Sudharmaidevi *et al.*, 2017; Ramesha 2019; Ajayan, 2021). Somehow, it might have failed the translocation of nutrients to above ground parts and utilization for photosynthate production.

The combination of AMF with soil test based POP (s_5) and organic nutrient management TOF-F (s_6) remained superior to POP+ AMF (s_4)



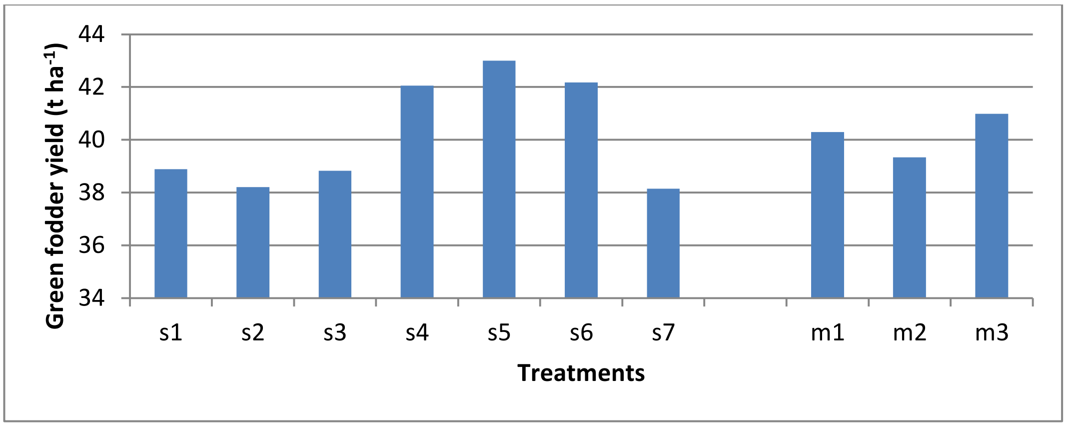
m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 7. Grain yield per plant of cowpea as affected by nutrient management and tillage



m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 8. Green fodder yield of fodder maize grown in total cowpea residue incorporated soil as affected by nutrient management and tillage



m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 9. Green fodder yield of fodder maize grown in root residue incorporated soil as affected by nutrient management and tillage combination as the excessive mineral fertilization had an inhibitory effect on AMF activity while controlled fertilization and organic manured treatments promotes AMF colonization and activity (Gryndler *et al.,* 2001; Johnson *et al.*, 2003).

Among the tillage levels, the no till treatment (m_3) performed best in connection with growth and yield characteristics. No tilled condition which might have facilitated decaying of plant residues in the site itself increasing SOM accumulation and it might have been helpful for enhanced growth and yield attributes. Besides that no till condition can result in better soil structure development leading to better aeration and absorption of nutrients and water reflecting in higher growth and yield characteristics (Nunes *et al.,* 2020)

The interaction effects on various growth and yield attributes were also significant showing a same replica of treatments for both main and sub plot treatments.ie. no till – s_5 and no till- s_6 combinations were superior. In case of no till, a minimum disturbance to soil occurs which does not disrupt the AMF hyphal network leading to better nutrient acquisition, protection of soil organic C by facilitating macro-aggregate formation etc. leading to better growth and yield rates (Galvez *et al.*, 2001; Jansa *et al.,* 2003).

The succeeding fodder maize crop grown under both conditions exhibited a similar trend as that of grain cowpea in growth and yield aspects. Among the various nutrient managements, soil test based POP + AMF (s_5) recorded the highest plant height, shoot biomass and fodder yield while for the root characteristics, TOF-F + AMF (s_6) remained superior. Among the tillage levels, the no till treatment (m_3) performed best in connection with growth and yield characteristics of fodder maize under both situations hinting to the better soil physical conditions and SOM levels in no till treatments compared to deep and conventional tillage. Interaction effects of no till with s_5 and s_6 treatments remained superior for fodder maize under both conditions similar to grain cowpea (Fig 8 and Fig 9).

Regarding the quality aspects like crude protein of cowpea grains and crude fibre and crude protein of fodder maize of different treatments, the soil test based POP along with AMF (s_5) recorded highest values and all the AMF combinations had better quality parameters than their respective treatments. The roots along with extensive hyphal network of AMF can explore vast surface area to meet up balanced nutritional requirements reflecting in the improved quality parameters. The ability of AMF to improve the quality of fruit crops and vegetables by increasing the accumulation of minerals, flavonoids, anthocyanins, carotenes, vitamins etc were already reported (Baslam *et al.,* 2011; Hart *et al.,* 2015)

Among the tillage levels, the no till treatment (m_3) performed best in connection with quality aspects of grain cowpea and of fodder maize under both situations. Interaction effect of m_3s_5 combination remained superior for quality parameters for both grain cowpea and fodder maize crop due to the balanced nutrition made possible by mineral fertilizers along with profound AMF activity under controlled fertilization (Galvez *et al.,* 2001; Jansa *et al.,* 2003; Sekaran *et al.,* 2020).

5.3.2 Effect of tillage and nutrient management on carbon, nitrogen and phosphorus content of grain cowpea - fodder maize cropping sequence

Regarding the carbon and nitrogen content, a different trend from that of growth and yield characteristics of both grain cowpea and fodder maize was observed. The treatment POP + AMF (s_4) maintained highest C content in shoot and soil test based POP + AMF (s_5) in root of grain cowpea. For the succeeding maize crop for where total crop residue was incorporated, the treatment soil test based POP + AMF (s_5) had the highest C content in both shoot and root followed by TOF-F + AMF (s_6).The root residue incorporated maize crop also gave same results.

Regarding the nitrogen content of grain cowpea a reverse order with that of carbon content was noted. The shoot nitrogen content of grain cowpea was highest for the treatment soil test based POP + AMF (s_5) and the root N content was highest for POP + AMF (s_4). The N assimilation by cowpea was further affected by atmospheric fixation of N and this might have influenced carbon assimilation also (Wang *et al.*, 2021).

Regarding the levels of tillage a varied behavior from that of growth and yield attributes were observed. The conventional tillage (m_1) gave highest C content in both shoot and root of cowpea. The N content of shoot was highest for no till (m_3) while root N was highest for deep tillage (m_2). Deep till might have promoted a temporary rise in soil microbial activity leading to more nutrient release from SOM that have facilitated better N uptake.

Coming to the fodder maize, the C and N content was highest for soil test based POP + AMF in both shoot and root for the treatment that received entire crop residue and root residue alone incorporated treatments. Better AMF activity under controlled fertilization have resulted in balanced nutrient availability which lead to more photosynthate production and protein accumulation reflecting in higher C and N contents in fodder maize. But such condition was absent during grain cowpea period as increased OM build up in soil occurred mainly due to residue incorporation.

Among the tillage levels “conventional tillage” was found to perform best for C content of fodder maize under both situations, similar for grain cowpea, as soil disturbance have resulted in SOC exposure to microbial activity leading to more nutrient availability and photosynthesis. But for N content of fodder maize no till treatment receiving AMF was found to be superior due to the enhanced AMF activity due to better and early colonization in no till leading to better nutrient absorption from deeper layers of soil **(**Wright *et al.*, 1999; Boddington and Dodd, 2000**).**

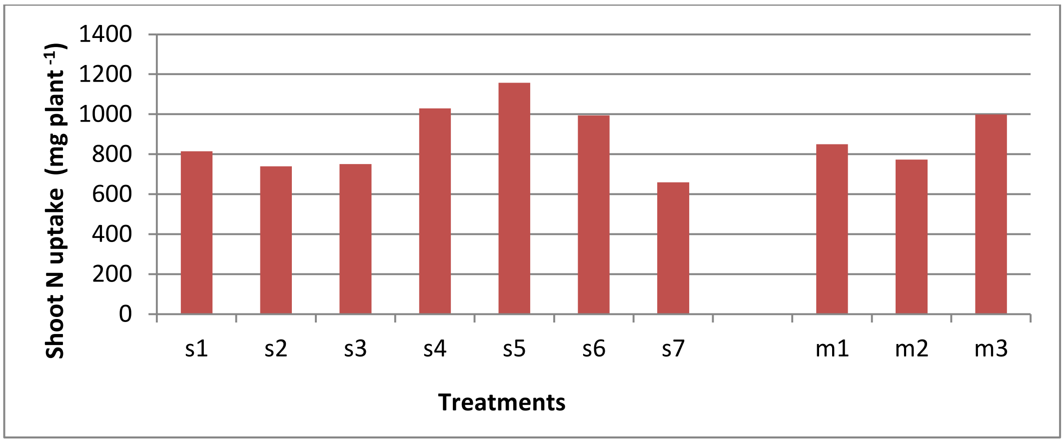
Regarding the P content of grain cowpea, among the nutrient levels, TOF-F + AMF (s_6) had highest P content in both shoot and root. Coming to the fodder maize, the highest P content in both shoot and root was for soil test based

POP + AMF for the crop that received entire cowpea residue. The crop received root residue alone also showed similar results. The AMF included treatments had more P content and among them controlled fertilized and organic manured treatments were found to be superior due to enhanced AMF activity resulting in more nutrient absorption especially P from deeper soil layers through their extensive hyphal network. Among the tillage levels, no till was found to perform best for both grain cowpea and fodder maize under two conditions as other tillage practices lead to disruption of hyphal networks affecting P acquisition.

In case of nutrient uptake by grain cowpea, the treatment s_5 (TOF-F + AMF) recorded highest shoot N uptake while s_4 recorded highest root N uptake and for P ie. both shoot and root P uptake were higher for s_6 (TOF-F + AMF) (Fig 10 to Fig 13). The fodder maize grown under both conditions exhibited a similar uptake pattern. The treatment s_5 (TOF-F + AMF) remained superior for shoot and root uptake for N and P (Fig 14 to Fig 17). Among tillage levels no till (m_3) remained superior for both N and P uptake for all crops. The balanced nutrition along with action of AMF might have resulted in higher nutrient uptake for the treatment s_5 and better physical condition and enhanced microbial activity under no tilled condition had resulted in higher nutrient uptake.

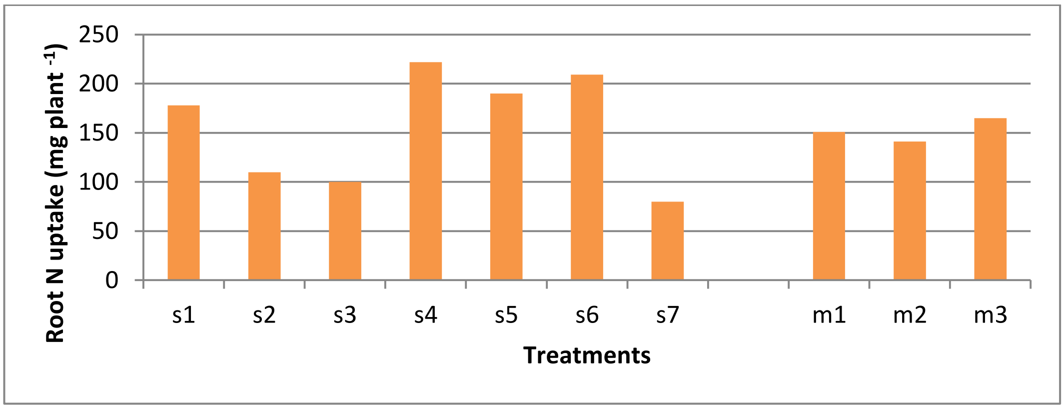
5.3.3 Effect of tillage and nutrient management on soil physical properties of grain cowpea - fodder maize cropping sequence

Tillage and nutrient management had significantly influenced the bulk density of soil under the grain cowpea – fodder maize cropping sequence. The lowest bulk density was reported by the treatment TOF-F + AMF (s_6). The positive influence of TOF-F in reducing soil bulk density was reported by Ramesha, (2019) and was mainly due to the dominance of recalcitrant C in TOF-F. The treatment receiving soil test based POP + AMF also showed a better performance. Addition of AMF together with nutrient sources had remarkably reduced the bulk density. Better soil biological activity under the influence of AMF might have resulted this. (Miller and Jastrow, 2002**).**



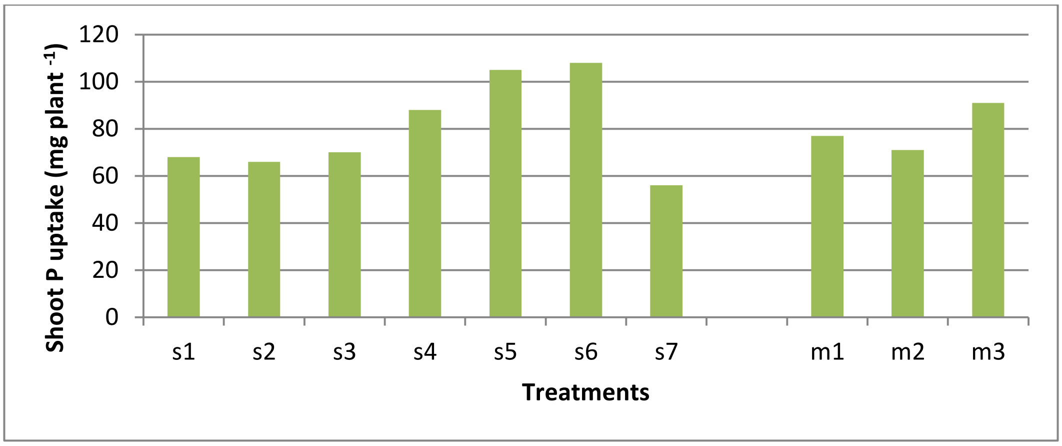
m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 10. Shoot N uptake of grain cowpea as affected by nutrient management and tillage



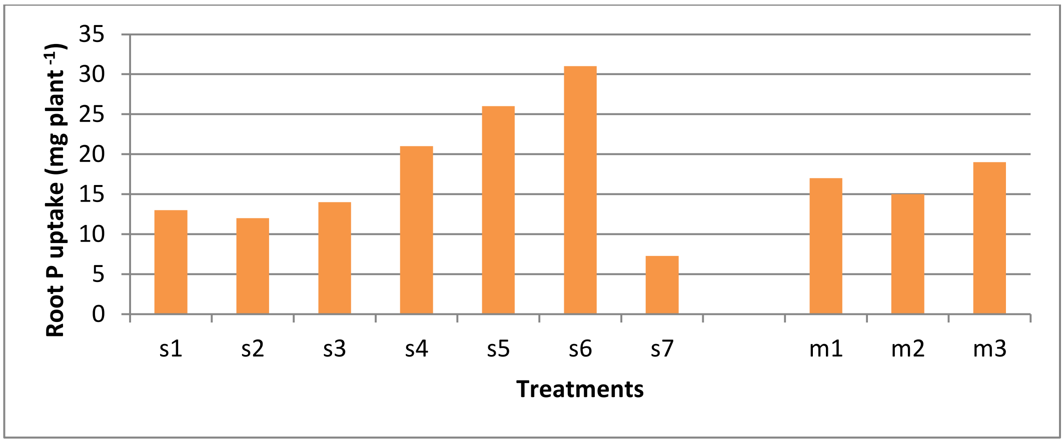
m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 11. Root N uptake of grain cowpea as affected by nutrient management and tillage



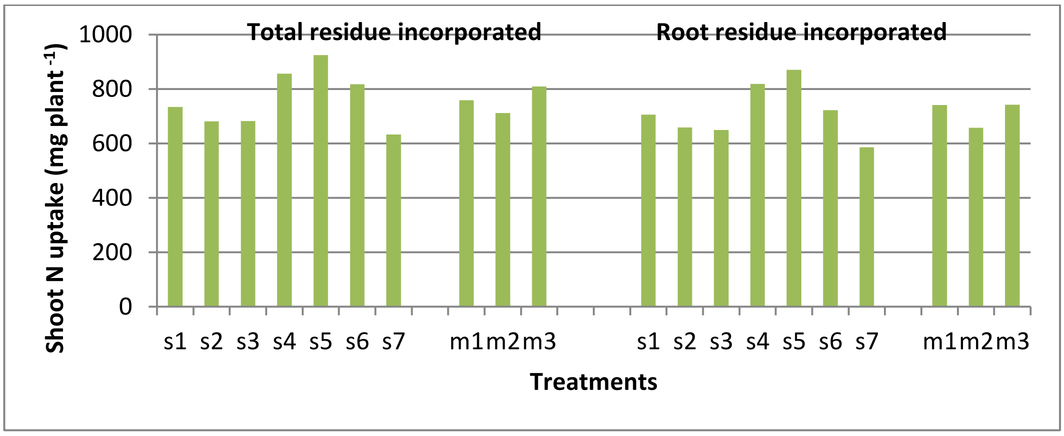
m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 12. Shoot P uptake of grain cowpea as affected by nutrient management and tillage



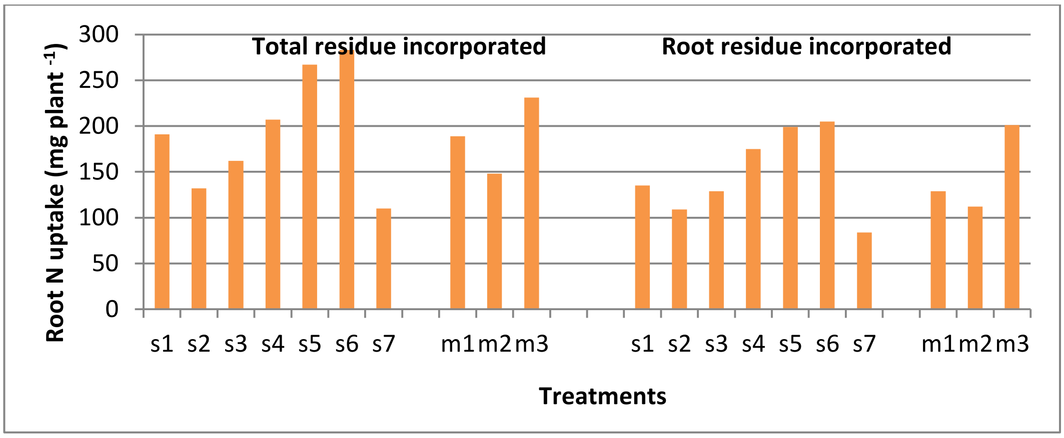
m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 13. Root P uptake of grain cowpea as affected by nutrient management and tillage



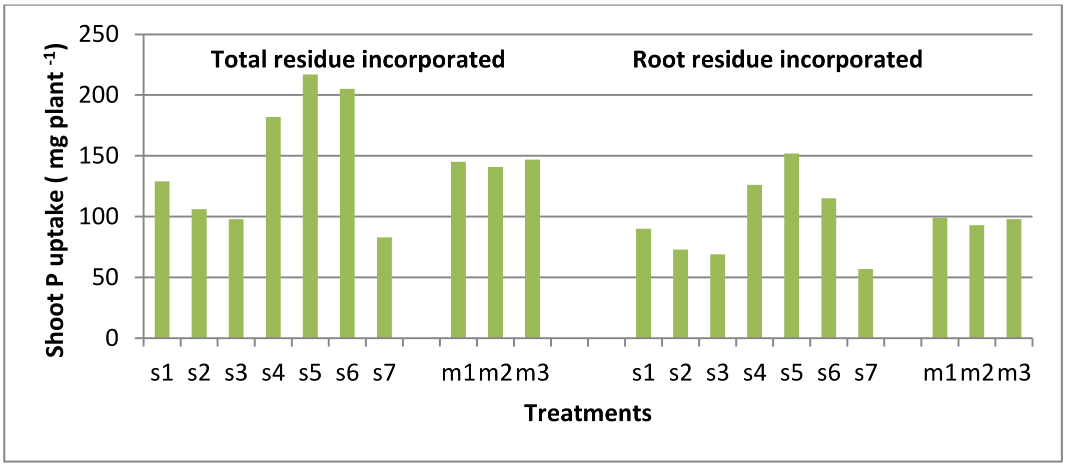
m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 14. Shoot N uptake of fodder maize as affected by nutrient management and tillage



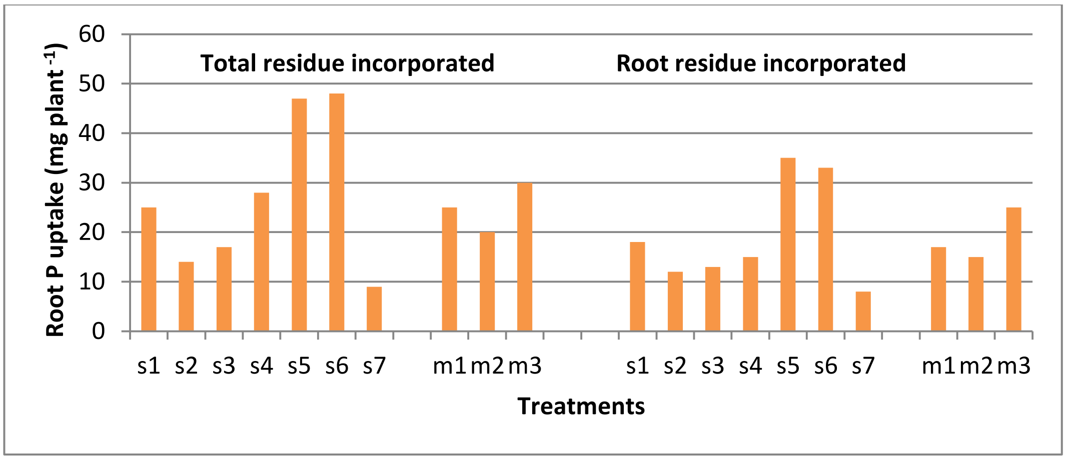
m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 15. Root N uptake of fodder maize as affected by nutrient management and tillage



m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 16. Shoot P uptake of fodder maize as affected by nutrient management and tillage



m_1: Conventional tillage; m_2: Deep tillage; m_3: No till; s_1: POP; s_2: Soil test based POP; s_3: TOF-F; s_4: POP+AMF; s_5: Soil test based POP+AMF; s_6: TOF-F+AMF; s_7: Absolute control

Fig 17. Root P uptake of fodder maize as affected by nutrient management and tillage

On evaluating the temporal influence, it was found that as the cropping sequence advances, soil BD showed a decreased value. Better soil biological activity might have favourably influenced the bulk density. The initial bulk density of the soil had shown a decrease towards the harvest of grain cowpea and to sowing and harvest of succeeding fodder maize. The addition of full crop residue had more favourable influence on soil bulk density compared to the addition of root residue alone. Surely addition of more quantity of biomass leading to more SOM formation resulting in better soil structure development as SOM build up leads to formation of more aggregates and porous structure which might have resulted in much lower BD values (Schjonning *et al.*, 2020; Balume *et al.*, 2022).

The effect of tillage on soil bulk density was also statistically significant and the lowest value was showed by deep till treatment (m_2) due to destruction of clumps of soil. The no till treatment (m_3) maintained the highest bulk density but showed a reduction in BD values as cropping period progresses due to more SOM buildup.

The sub surface layer also behaved in similar manner but the values were slightly higher compared to surface soil. It was reported that the bulk density of soil increased with depth due to more soil compaction, reduced OM levels and microbial activity in deeper soil layers **(**Zou *et al.*, 2016; Thirkell *et al.*, 2017**)**

Tillage and nutrient management had significantly influenced the percentage of water stable aggregates of the soil. The highest WSA per cent was reported by the treatment TOF-F + AMF (s_6) followed by the treatment soil test based POP + AMF (s_5). The positive influence of thermochemical organic fertilizer on improving soil physical properties was reported by several authors (Ramesha, 2019; Ajayan, 2020). The higher TOC, RC and lignin content in TOF-F might have favourably influenced the WSA (%). Addition of AMF together with nutrient sources had remarkably improved the per cent WSA definitely due to better binding of soil particles under the influence of AMF and this is due to their hyphal secretion glomalin which can glue soil particles into aggregates leading to a better stabilized structure **(**Rillig, 2004**)**

On evaluating the temporal influence, it was found that as the cropping sequence advances, there was an increase in WSA per cent. Better soil biological /microbial activity under the influence of crops and the resultant decomposition of sloughed off crop residues, secretions from root, organic compounds produced by microbes etc. have favourably influenced the per cent WSA. The initial WSA per cent of the soil had shown an increase towards the harvest of grain cowpea and to sowing and harvest of succeeding fodder maize. The addition of full crop residue had more favorable effect on WSA per cent compared to the addition of root residue alone. Surely addition of more quantity of biomass was able to increase WSA per cent more and resulted much higher values. Apart from root secretions, the decomposing shoot residues had added more organic matter to soil and had resulted in a higher increase compared to root residue alone.

The effect of tillage on WSA per cent was also statistically significant and the highest value was showed by no till treatment (m_3). The percentage of WSA increased along with the advancement of cropping sequence. No till treatment might have favoured the aggregation of soil particles since the soil clods were not broken by tillage. The decaying crop residues without soil disturbance also favourably influenced the WSA per cent.

5.3.4 Effect of tillage and nutrient management on soil electrochemical properties of grain cowpea - fodder maize cropping sequence

Tillage and nutrient management had significantly influenced the pH of the soil. The highest pH was reported by the treatment TOF-F + AMF (s_6) throughout the cropping sequence. Near neutral pH of TOF-F (Table 2) and the presence of AMF might be responsible for this. All the treatments receiving AMF had shown a higher pH compared to that without AMF. But it was statistically on par with absolute control up to the sowing of maize crop. The positive influence of thermochemical organic fertilizer on improving soil pH was reported by

Sudharmaidevi *et al*. (2017) due to the release of basic cations from TOF-F in contrast to release of acidic cations by mineral fertilizers.

On evaluating the temporal influence, it was found that as the cropping sequence advances, there was an increase in soil pH. Addition of soil amendments and organic manures for each crop might have favourably influenced soil pH. The crop residues of cowpea also might have contributed towards the increase of soil pH being a soil building crop.

The initial pH of the soil had shown an increase towards the harvest of grain cowpea and to sowing and harvest of succeeding fodder maize. The addition of full crop residue had more favourable effect on WSA per cent compared to the addition of root residue alone. Surely addition of more quantity cowpea biomass which is a soil building crop was able to increase pH more and resulted in much higher values.

The effect of tillage on soil pH was also statistically significant and the highest value was showed by deep till treatment (m_2) followed by conventional tillage (m_1). The pH increased along with the advancement of cropping sequence. Deep till and conventional tillage might have promoted the removal of acidity components from soil under the influence rain water. The sub surface layer also behaved in similar manner but the values were slightly lower compared to surface soil. It was reported that the soil pH decreases with depth due to restricted liming effect and by accumulation of acidity contributing factors due to leaching and accumulation of nitrate from nitrogenous fertilizers at subsoil layers (Tang, 2004).

Tillage and nutrient management had significantly influenced the EC of the soil. The highest EC was reported by the treatment POP (s_1) throughout the cropping sequence. POP treatment has received the highest quantity of fertilizers and had resulted highest EC since soil test based treatment received lesser quantity for N, P and K. The presence of AMF might have helped in producing organically bound compound which also favoured the lesser values for EC. All the treatments receiving AMF had shown a lesser EC compared to that without AMF.

On evaluating the temporal influence, it was found that as the cropping sequence advances, there was an increase in soil EC. Addition of soil amendments and organic manures and fertilizers for each crop might have favourably influenced soil EC. The initial EC of the soil had shown an increase towards the harvest of grain cowpea and to sowing and harvest of succeeding fodder maize. The addition of full crop residue resulted more enhancement in EC compared to addition of root residue alone. Surely addition of more quantity cowpea biomass had contributed more soluble salts to soil (Zhahid *et al.,* 2020).

The effect of tillage on soil EC was also statistically significant and the highest value was showed by no till treatment (m_3) except at the time of harvest of cowpea. The EC increased along with the advancement of cropping sequence. Deep till and conventional tillage might have promoted the removal of soluble salts from soil under the influence of rain water. The sub surface layer also behaved in similar manner but the values were slightly lower compared to surface soil as mineralization activities were lower in subsoil due to lesser microbial activity (Glaser *et al.,* 2015). Besides that salt accumulation from fertilizers and irrigation water is mainly a surface phenomenon unless they are leached to subsoil layers by rain water or by irrigation.

5.3.5 Effect of tillage and nutrient management on soil chemical properties of grain cowpea - fodder maize cropping sequence

5.3.5.1 Soil C Fractions

The soil TOC content was significantly influenced by tillage and nutrient management practices and the treatment with organic nutrient management along with AMF (s_6) had highest soil TOC content throughout the cropping period (Fig 18 and Fig 19). Besides that all the treatments with AMF was able to maintain higher soil TOC levels than their respective treatments without AMF clearly indicating the role of AMF in soil C storage. This profound increase in presence

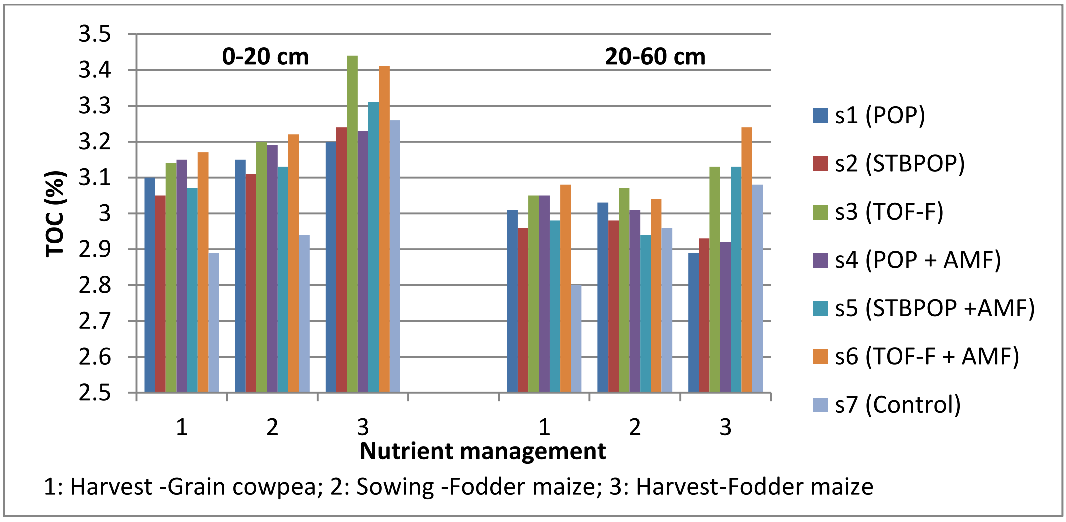


Fig 18. Soil TOC as affected by nutrient management in a grain cowpea – fodder maize cropping sequence that received total residue of cowpea

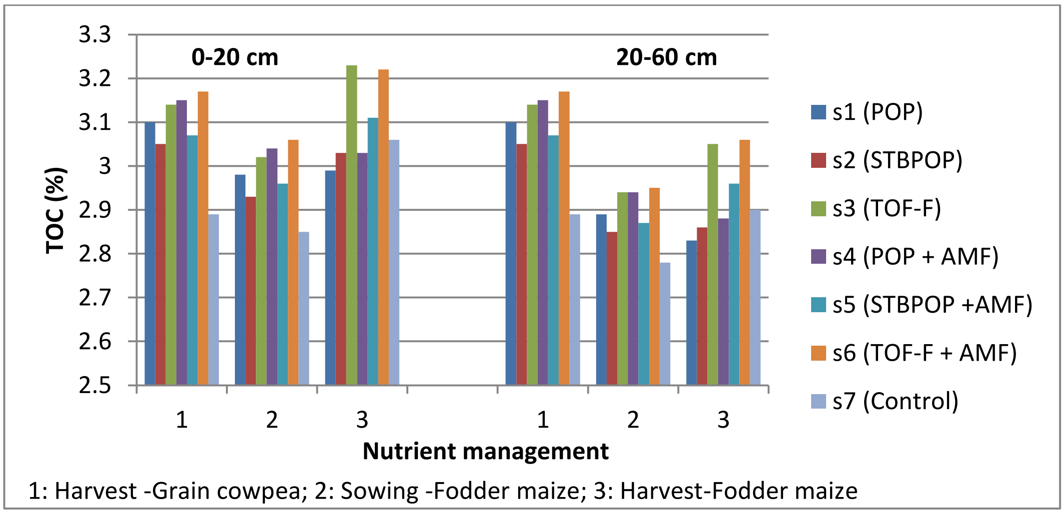


Fig 19. Soil TOC as affected by nutrient management in a grain cowpea – fodder maize cropping sequence that received root residue of cowpea

of AMF is mainly due to more and even allocation of C compounds from plants to soil through their extraradical hyphal structures and more aggregate formation (Ujvari *et al.,* 2021). According to Parihar *et al.* (2020), in exchange of different low diffusive nutrients such as ammonium, phosphorus, zinc and copper, AMF create a sink demand for carbon (C) and facilitate 4–20 per cent C drain from the plants This additional C along with extensive mycelium of AMF have effects on soil C pools.

The AMF influence on soil C was enhanced to a greater extent in presence of organic manure, TOF-F which might have resulted in highest soil TOC content by s_6 throughout the cropping period. But towards the end of the cropping period ie. after harvest of fodder maize the treatment s_3 (TOF –F) recorded highest TOC content under both conditions, indicating the ability of thermochemical fortified organic manure in increasing SOC levels in a sustained and steady level mainly due to its recalcitrant nature. The subsoil had a decreased TOC content than surface soil due to decrease in OM levels, microbial activity, rhizospheric effect etc for all crops.

On evaluating the temporal influence, it was found that as cropping sequence advances there was an increase in soil TOC content mainly due to addition of organic manures, rhizodeposition activity and crop residue incorporation. But in case of fodder maize with root residue incorporation the condition was not as above, here the increase in soil TOC content was very slow especially at the sowing time of fodder maize, the TOC content was lower than initial TOC content but towards the end of the cropping period the root residue incorporated soils had managed to increase TOC content than initial values. This slow increase in soil TOC was mainly contributed by recalcitrant nature of root residues which might have lead to slower decomposition of root residues and formation of stable humus from roots (Das *et al.*, 2020).

Regarding the tillage effect, conventional tillage recorded highest soil TOC content after harvest of grain cowpea to sowing of fodder maize but towards the end of the cropping sequence no till treatment recorded highest TOC content for both total residue incorporated and root residue alone incorporated soil. The synergestic effect of no till and organic matter addition had resulted in more microaggregate formation and SOM stabilization which might have resulted in this superiority of no tillage condition. In the subsoil, deep tilled plots recorded highest TOC content for the entire cropping period as higher tilling activity might have resulted in better incorporation of crop residues to a greater depth in these plots and got reflected in higher TOC content (Fig 20 and Fig 21).

The interaction effects remained significant throughout the study and during harvest of grain cowpea to sowing of fodder maize of total residue incorporated soil, deep till – s_6 combination remained superior but for the rest of cropping period no till- s6 combination recorded highest TOC content and this shift from deep till to no till occurred mainly due to more OM addition which had resulted in improvement of physical, chemical and biological properties of soil under no till condition.

Dissolved organic carbon (DOC) consists of a wide range of molecules ranging from simple acids and sugars to complex humic substances with large molecular weights. It is largely a product of decomposition of litter and humus but it may also originate directly from exudates from plant roots (Huo *et al.,* 2017). Mainly the DOC in soil serves as the fuel for microbial activity. Throughout the cropping period the treatments with AMF combinations recorded lower values for DOC content than their respective treatments hinting to more microbial activity associated with AMF treatments which lead to more DOC consumption and stabilization of soil organic matter.

Among the nutrient management, s_1 and s_2 recorded highest DOC throughout the cropping period and this was due to lesser microbial activity associated with those treatments. The subsoil had a decreased DOC content than surface soil due to lesser microbial activity and rhizodeposition associated with subsoil layers.

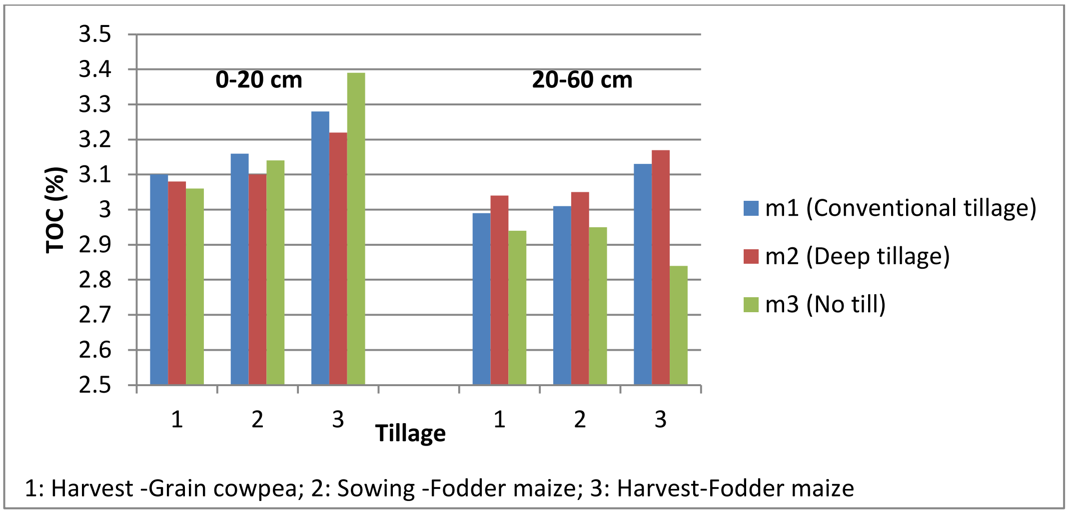


Fig 20. Soil TOC as affected by tillage in a grain cowpea – fodder maize cropping sequence that received total residue of cowpea

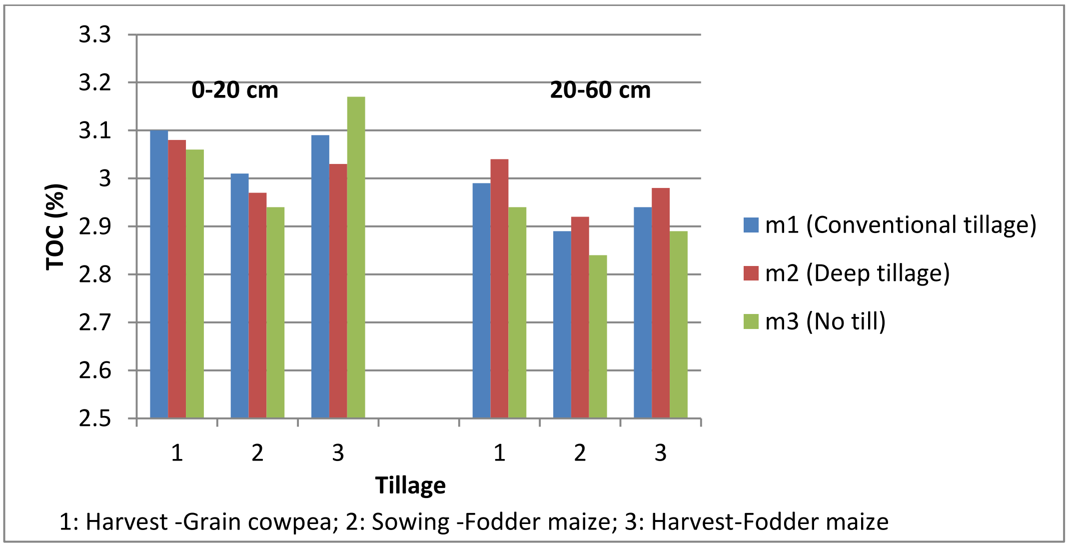


Fig 21. Soil TOC as affected by tillage in a grain cowpea – fodder maize cropping sequence that received root residue of cowpea

Regarding the temporal influence, as cropping sequence advances DOC content in soil exhibited a decreasing trend due to more organic matter addition by residue incorporation and stabilization of soil organic carbon by microbial activity and this decrease was more pronounced in AMF included treatments reflecting the capability of AMF in stabilizing SOC. The lowest DOC content was for s_6 and this decrease in DOC content increases towards the end of cropping period mainly due to recalcitrant nature of TOF-F resulting in more SOC stabilization.

In the case of root residue incorporated soil, a similar trend was noticed but exhibited an increased DOC content than their respective total residue incorporated soils. This increase in DOC content was mainly due to decreased microbial activity associated with these soils as only the recalcitrant root residues which lower decomposition rates were incorporated. This slower and steady decomposition of root residues was due to more condensed tannin and other complex compounds in roots compared to that of shoot residues (Das *et al.,* 2020).

The tillage effects remained significant only for root residue incorporated soils and among them deep tillage recorded highest DOC content indicating lesser stabilization of SOC as SOM protection was not ensured here due to frequent soil disturbances leading to disruption of microaggregates and AMF hyphal structures which had a significant role in SOM stabilization (Ujvari *et al.*, 2021).

The interaction effects of tillage and nutrient management on soil DOC content remained non significant during the cropping period and only after harvest of fodder maize a significant interaction was noticed ie. m_2s_1 recorded highest DOC content. This highest DOC content was mainly due to lesser stabilization of SOC as AMF hyphal structures and microagggregate protection of SOM was lacking here.

Soil LC is the C fraction with more rapid turnover rates and an important indicator of soil health. Labile carbon is only a small proportion of SOC, but critical component as they fuel up the the biogeochemical transformation of nutrients especially N and P (Zhang *et al.,* 2020). The organic manures, crop residues and rhizodepositions were the routes for LC entry to the soil.

Throughout the cropping sequence the AMF included treatments recorded highest LC content than their respective treatments without AMF and among them s_6 which was the combination of organic nutrition - TOF-F with AMF remained superior. The increase in LC content of soil by TOF-F was already reported by several authors (Leno and Sudharmaidevi, 2017; Ramesha, 2019; Ajayan, 2021) and is mainly due to higher TOC content in TOF-F which supports intense microbial activity. The activity of AMF in increasing LC content was mainly due to more C allocation from above ground parts to soil by their extraradical hyphal network (Quin *et al.,* 2019).

As the cropping sequence advances, an increasing trend of soil LC content was noticed as more crop residues as well as rhizodeposits were added to soil. The root residue alone incorporated soils also behaved similarly but exhibited lower LC content than total crop residue incorporated soils reflecting the recalcitrant nature of root residues with slow decomposition and turnover rates (Fig 22 and Fig 23).

Regarding the temporal influence of tillage on soil LC content, no till (m_3) remained superior throughout the study for surface soil while m_2 recorded highest LC content for subsoil. No till treatment supports more microbial activity and surface retention of added residues which might have resulted in higher LC content in surface soils but in case of subsoil deeper tillage was able to provide crop residues to deeper layers which had resulted in more microbial activities and LC content of subsoil. Bongiorno *et al.* (2019) reported that reduced tillage and high organic matter input increase concentrations of labile carbon fractions in soil compared to conventional tillage and low organic matter addition, respectively. The interaction effects for LC content remained non significant for most of the cropping period (Fig 24 and Fig 25).

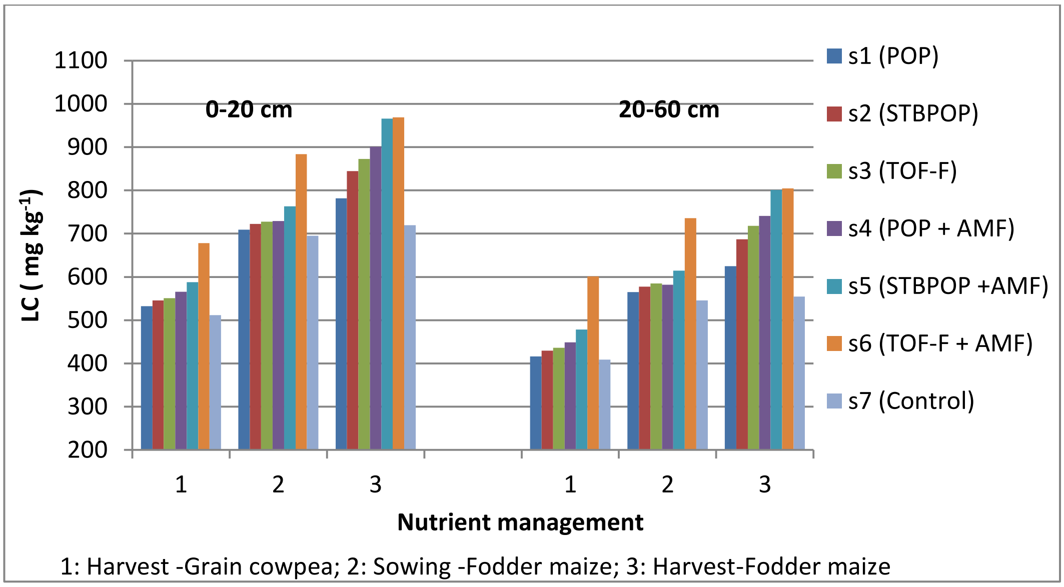


Fig 22. Soil LC content as affected by nutrient management in a grain cowpea – fodder maize sequence that received total crop residue of cowpea

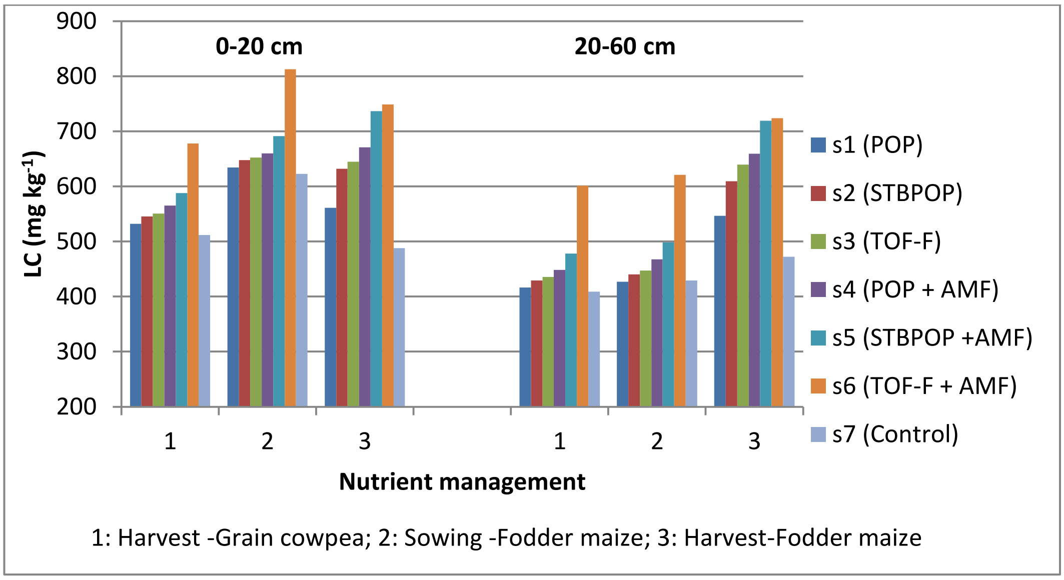


Fig 23. Soil LC content as affected by nutrient management in a grain cowpea – fodder maize sequence that received root residue of cowpea

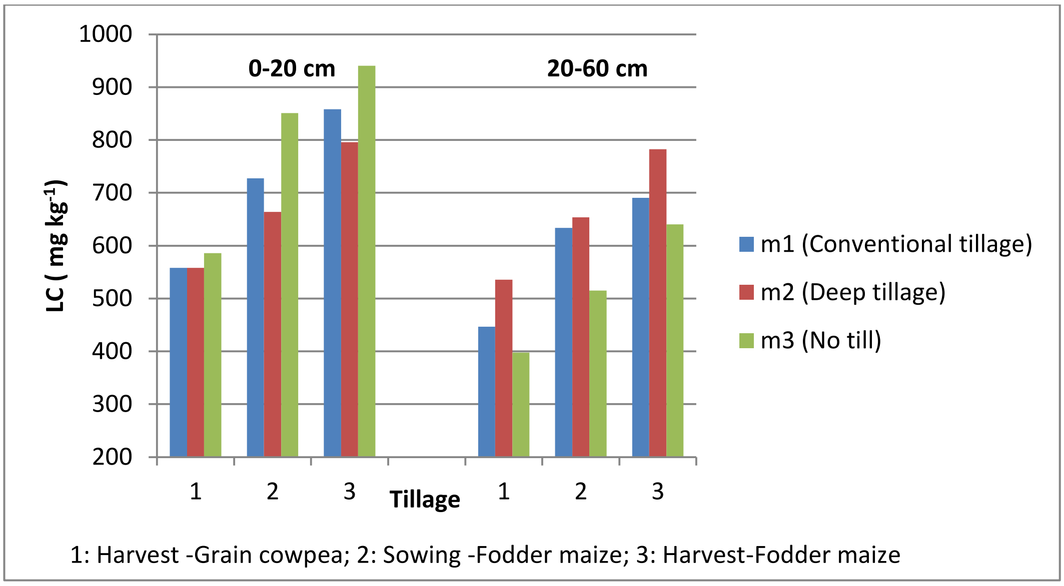


Fig 24. Soil LC content as affected by tillage in a grain cowpea – fodder maize sequence that received total crop residue of cowpea

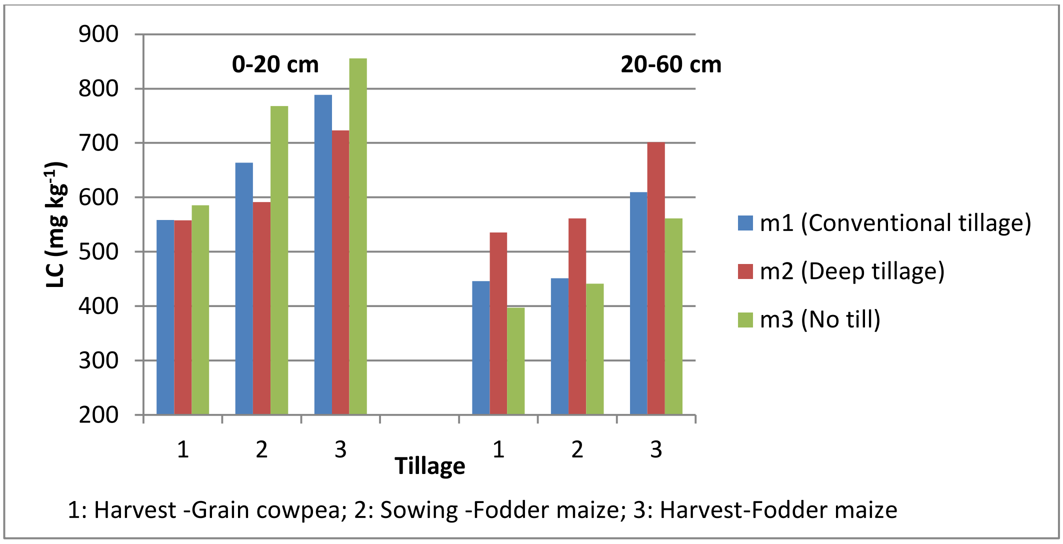


Fig 25. Soil LC content as affected by tillage in a grain cowpea – fodder maize sequence that received root residue of cowpea

Labile carbon mainly consists of soil microbial biomass carbon, dissolved organic matter, and easily oxidative organic matter, whereas the recalcitrant carbon usually refers to the component of SOM that is resistant to microbial decomposition or protected by mineral soil particles and is the main contributor to C sequestration (von Lützow *et al*. 2007; Zhang and Zhou, 2018).

The recalcitrant carbon content in soil was significantly influenced by nutrient management and tillage practices. In case of different nutrient managements, AMF included treatments recorded highest RC content than their respective without AMF treatments and among them s_6 (TOF-F + AMF) was superior and towards the end of cropping season ie. at the time of harvest of fodder maize under both conditions, the treatment of organic nutrition - TOF-F alone (s_3) outcasted the effect of s_4 which is an AMF included treatment reflecting the recalcitrant nature of TOF-F. The subsoil had a decreased RC content throughout the cropping period as less rhizodeposists and organic matter addditions occurred in subsoil than surface soils.

Regarding the temporal influence, an increased RC content was observed as cropping period advances and this was mainly attributed to more C stabilization due to combined activity of microbes especially AMF, more OM additions and rhizodepositions etc. The AMF role in contributing towards recalcitrant C fraction through their hyphal exudates in particular glomalin and storage of C in microagggregated soils were already reported by Holatko *et al*. (2021). The root residue incorporated soils exhibited soil RC which was only slightly less than their respective total residue incorporated soils hinting to the fact that roots were the most significant source for recalcitrant C entry to soils.

The tillage effects remained significant and no till (m_3) remained superior for all crops. Due to minimum soil disturbance, SOM remained protected with more RC fraction in no tilled plots as here disruption of aggregates and hyphal structures were nil. The interaction effects on soil RC content remained non significant for most of the cropping period and wherever significant the combination of m_3s_6 recorded highest value which is due to the synergistic effect of AMF, OM additions, better physical soil conditions by no till treatment and the recalcitrant nature of organic manure, TOF-F.

5.3.5.2 Soil N fractions

Nitrogen (N) is the most abundant element in the atmosphere and is usually the most limiting crop nutrient. Nitrogen cycles through soil mediated by microbial load are necessary to convert N into plant asssimilable forms. Nitrogen is mainly added to soil naturally from N fixation by soil bacteria and legumes and through atmospheric deposition in rainfall. Additional N is typically supplied to the crop by fertilizers, manure, or other organic materials like crop residues green manures etc.

All soil N fractions were significantly influenced by different tillage levels and nutrient management. Among the nutrient management s_5 (STBPOP + AMF) remained superior in terms of soil TN content followed by s_6 (TOF-F + AMF) throughout the cropping period. All the AMF included treatments recorded highest TN than their respective treatments without AMF clearly indicating the role of AMF in acquisition of nitrogen from soil (Fig 26 and Fig 27).

As reported by Meng *et al.* (2020), hyphae of an AM fungus could accelerate the decomposition of organic matter and can also acquire N directly from organic matter. In addition, AMF also accelerated N release and transformation in soil organic matter by other microbes. (Bukovska *et al*., 2018). The subsoil had a decreased TN compared to surface soil due to less OM addition, rhizodeposition and microbial activity which were the main drivers of soil N cycle.

Regarding the temporal influence on soil TN content, an increasing trend in soil TN was noticed with the advancement of cropping period reflecting the beneficial role of crop residue addition in maintaining soil TN content. Besides that more microbial activity in response to crop residue incorporation also adds to TN content of soil ie greater mineralization of OM releasing macro and

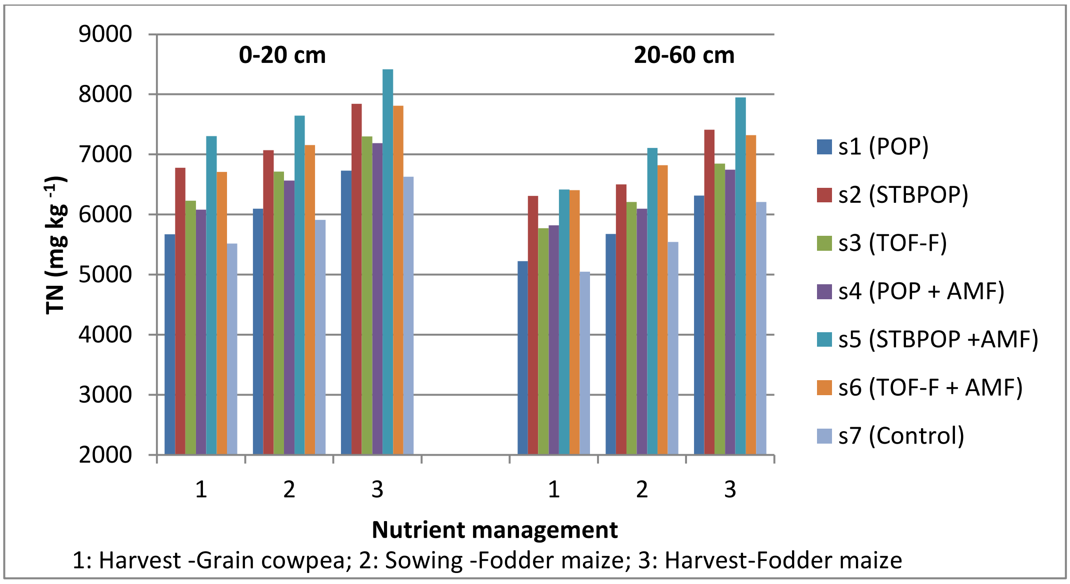


Fig 26. Soil TN as affected by nutrient management in a grain cowpea – fodder maize cropping sequence that received total residue of cowpea

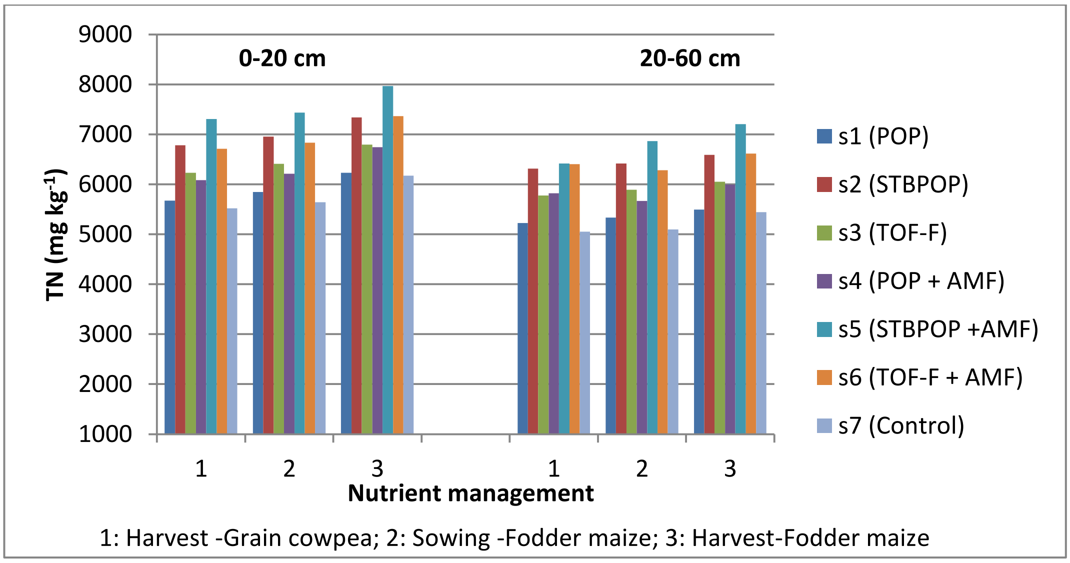


Fig 27. Soil TN as affected by nutrient management in a grain cowpea – fodder maize cropping sequence that received root residue of cowpea

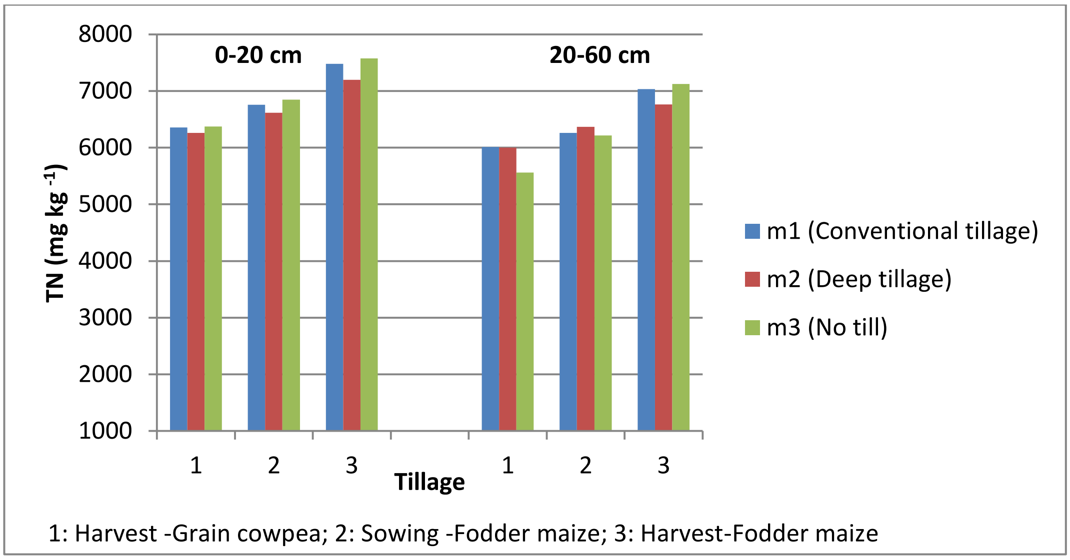


Fig 28. Soil TN as affected by tillage in a grain cowpea – fodder maize cropping sequence that received total residue of cowpea

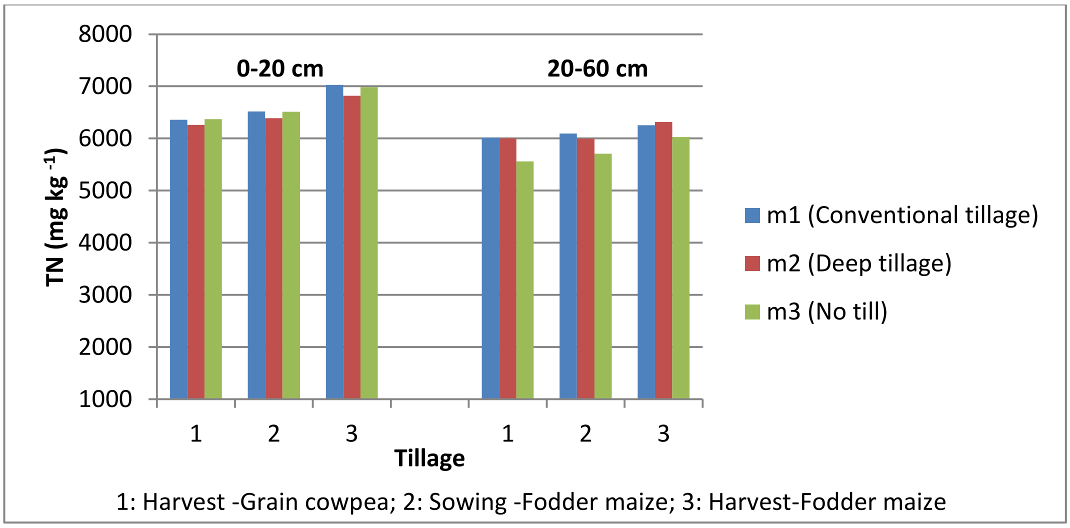


Fig 29. Soil TN as affected by tillage in a grain cowpea – fodder maize cropping sequence that received root residue of cowpea

micronutrients. Rhizodeposition can also contribute to soil TN content and inclusion of grain legume in the cropping sequence have resulted in an increase of soil TN content as the roots and rhizodeposits and nodules from legumes are much richer in N_2 than other crops (Stagnari *et al.,* 2017; Wang *et al.,* 2021). Therefore the role of legumes in increasing soil TN content was not only limited to its N_2 fixation from atmosphere.

The root residue incorporated soils also behaved in a way similar to that of total residue incorporated soils but with lower soil TN content due to slow decomposition of root residues to add to SOM pool which is attributed by more recalcitrant nature of root residues.

Regarding the effects of tillage, no till (m_3) remained superior for surface soil TN content but in case of subsoil m_2 (deep tillage) recorded higher values due to more organic matter addition to deeper soil layers but towards the end of cropping period m_3 (no till) managed to attain superiority as more OM additions might have improved the physical, chemical and biological properties of no tilled plots. More residue retention and microbial load under no tilled condition might have resulted in increased soil TN (Fig 28 and Fig 29).

The interactions effects on soil TN content remained non significant for most of the cropping period and wherever significant m_3s_6 remained superior and the synergestic effect of TOF-F, AMF, and no tilled condition had resulted in this.

The soil organic N content also exhibited a similar pattern to that of soil TN content throughout the cropping period. Besides green manuring and crop residue incorporation, the rhizodeposition of amino acids like glycine, serine, cell lysates, sloughed roots, root hairs and root-derived debris were also the entry points for nitrogenous compounds to soil OM pool (Navreet *et al.,* 2019; Pinto *et al.,* 2021).

Among the nutrient managements, s_5 remained superior in terms of soil ON content followed by s_6 throughout the cropping period. All the AMF included treatments recorded highest ON than their respective treatments without AMF clearly indicating the role of AMF in acquisition of nitrogen from soil. The subsoil had a decreased ON compared to surface soil due to less OM addition, rhizodeposition and microbial activity which were the main drivers of soil N cycle.

Regarding the temporal influence on soil ON content, an increasing trend was noticed with the advancement of cropping period reflecting the beneficial role of crop residues in particular legume residues in maintaining soil ON content. Rhizodeposition can also contribute to soil ON content and inclusion of grain legume in the cropping sequence have resulted in an increase of soil ON content as the roots and rhizodeposits and nodules from legumes are much richer in N_2 than other crops (Stagnari *et al.,* 2017; Wang *et al.,* 2021). Therefore the role of legumes in increasing soil ON content was not only limited to its N_2 fixation from atmosphere into amino acids and proteins inside the plants.

The root residue incorporated soils also behaved in a way similar to that of total residue incorporated soils but with lower soil ON content due to slow decomposition of root residues to add to SOM pool which is attributed by more recalcitrant nature of root residues.

Regarding the effects of tillage, no tilled (m_3) and conventionally tilled (m_1) soils were on par for surface soil ON content but in case of subsoil m_2 recorded higher values due to more organic matter addition to deeper soil layers in deep tilled plots. More residue retention and protection of soil OM under no tilled condition might have resulted in increased soil ON under no tilled conditions.

In natural soils, roughly 95 per cent of the nitrogen is found in soil organic material. Organisms, including plants, animals, and microorganisms contain nitrogen rich compounds, including amino acids, nucleic acids, and proteins in their tissues. When wastes or dead bodies of these organisms are deposited in the soil, this material and its breakdown products form soil organic matter.

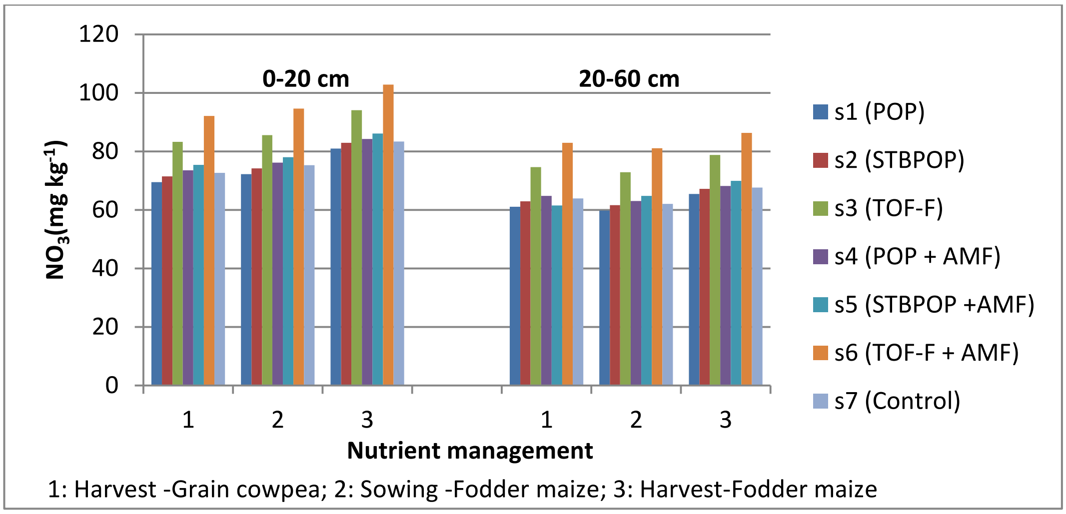


Fig 30. Soil NO_3 - N content as affected by nutrient management in a grain cowpea – fodder maize sequence that received total crop residue of cowpea

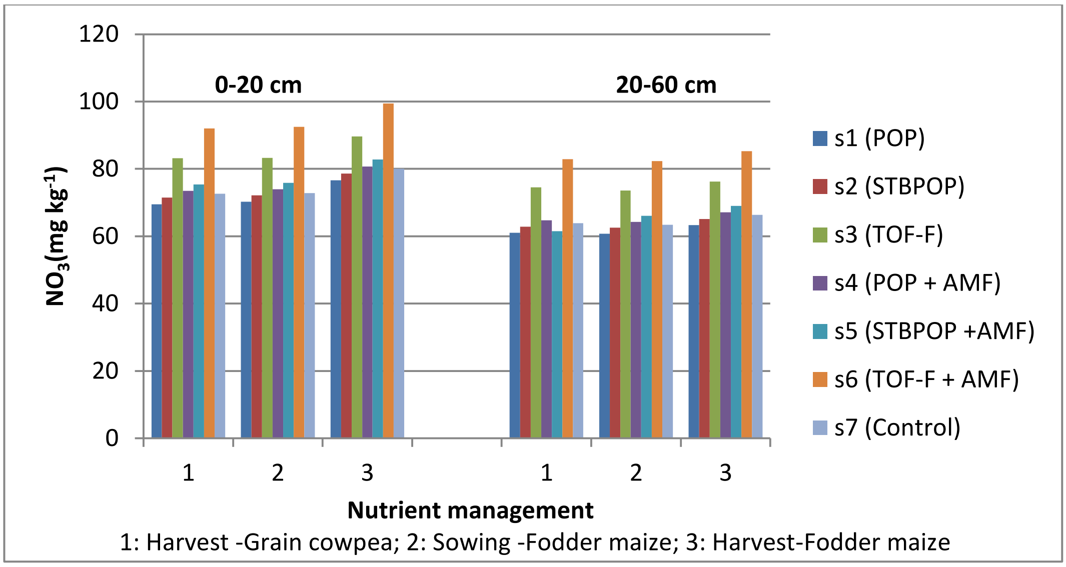


Fig 31. Soil NO_3 - N content as affected by nutrient management in a grain cowpea – fodder maize sequence that received root residue of cowpea

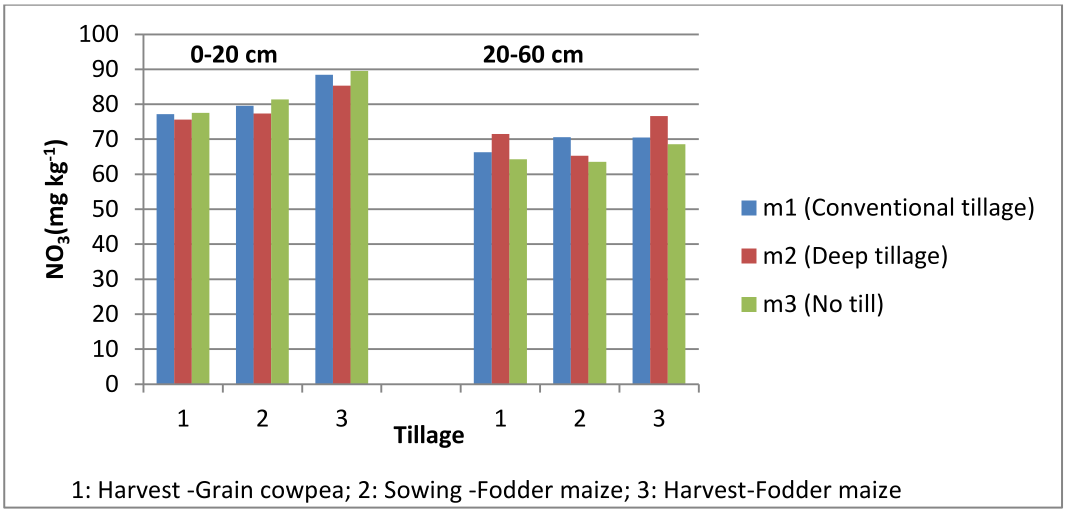


Fig 32. Soil NO_3 - N content as affected by tillage in a grain cowpea – fodder maize sequence that received total crop residue of cowpea

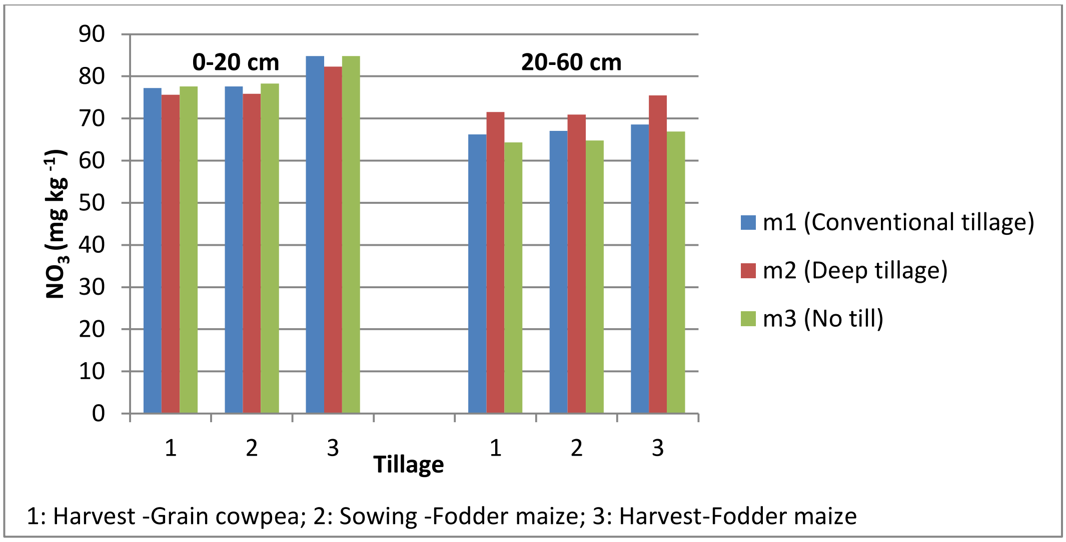


Fig 33. Soil NO_3 - N content as affected by tillage in a grain cowpea – fodder maize sequence that received root residue of cowpea

Organic nitrogen is largely unavailable to growing plants and microbial SOM mineralization releases ammoniacal and nitrate forms of N_2 which can be easily absorbed by plants. The mineralizable forms of N ie. both NH_4 – N and NO_3 – N exhibited a similar pattern throughout the cropping period. Among the nutrient management s_6 (TOF-F + AMF) recorded highest NH_4 – N and NO_3 – N followed by s_5 and s_3 for NH_4 – N and NO_3 – N respectively. Organic manures ability to supply plant available N forms were well known and ability of TOF-F to increase soil NO_3-N was already reported (Sudharmaidevi *et al.,* 2017; Jacob, 2018; Ajayan, 2021) mainly due to its higher N content and ability to support higher microbial load which were the drivers of N mineralization.

The mineral fertilized soils recorded lowest soil NH_4 – N and NO_3 – N content mainly due to preferential substrate utilization by microbes ie. microbes utilizes easily available N from fertilizers for their growth without procuring N_2 by SOM mineralization (Kuzyakov, 2002; Jones *et al.,* 2009; Huo *et al.,* 2017). The root residue incorporated soils also exhibited a similar pattern for soil mineralizable N forms but with lower values due to more recalcitrant nature of root residues (Fig 30 and Fig 31).

On evaluating the temporal influence, an increasing trend on soil mineralizable N forms was observed as cropping sequence advances and this increase is mainly due to more OM additions in soil particularly legume crop residues, more rhizodeposition and microbial activities. The subsurface soil had lower values for NH_4 – N and NO_3 – N content due to lesser OM, rhizodeposition and microbial activities associated with subsoil.

Regarding the tillage effects, no tilled plots recorded higher values for soil mineralizable N forms in surface soil but for subsoil deep tilled plots remained superior mainly due to better crop residue incorporation to deeper layers which lead to more microbial activity in subsoil of deep tilled plots. Mbuthia *et al.* (2016) reported that the key enzymes associated with C, N and P cycling (b-glucosidase, b-glucosaminidase, and phosphodiesterase) were significantly higher under no-till relative to tilled condition. Better soil physical conditions, more residue retention on surface soil and more microbial load favoured by undisturbed soil conditions etc. might have contributed to more mineralizable N forms in no tilled soils (Fig 32 and Fig 33).

The interaction effects remained significant and m_3s_6 combination remained superior in surface soil mineralizable N_2 content due to synergistic effect of no tilled condition, organic manure- TOF-F, rhizodeposition and crop residue incorporations.

5.3.5.3 Soil P fractions

The soil P fractions were influenced by tillage and nutrient management practices and the interactions effects remained non significant for all P fractions for most of the sampling periods for both crops. The TP and NLP fractions behaved similarly throughout the cropping period. The subsoil had higher values for all P fractions than surface soils due to leaching of phosphorus from surface soil to deeper soil layers by heavy rains. Among nutrient management all AMF included treatments had higher values for soil TP and NLP content than their respective without AMF treatments and among them s_5 (soil test based POP+ AMF) remained superior throughout the cropping period. The AMF role in P absorption from deeper soil layers to surface layers through its extensive hyphal structures were reported by many (Kayama and Yamanaka, 2014; Begum *et al.,* 2019; Mitra *et al.,* 2019; Wang *et al.,* 2021). The root residue incorporated soils recorded lesser values for TP and NLP than total residue incorporated soils (Fig 34 and Fig 35).

On evaluating the temporal influence on soil TP and NLP content, an increasing trend was observed as cropping sequence advances due to more organic matter addition, rhizodeposition and microbial activity. Regarding the tillage effects on soil TP and NLP content, the conventionally tilled soils recorded higher values for grain cowpea and fodder maize that received total cowpea residues but for fodder maize grown in only root residue incorporated soils, no till was found to be superior. In such soils the better physical conditions for microbial

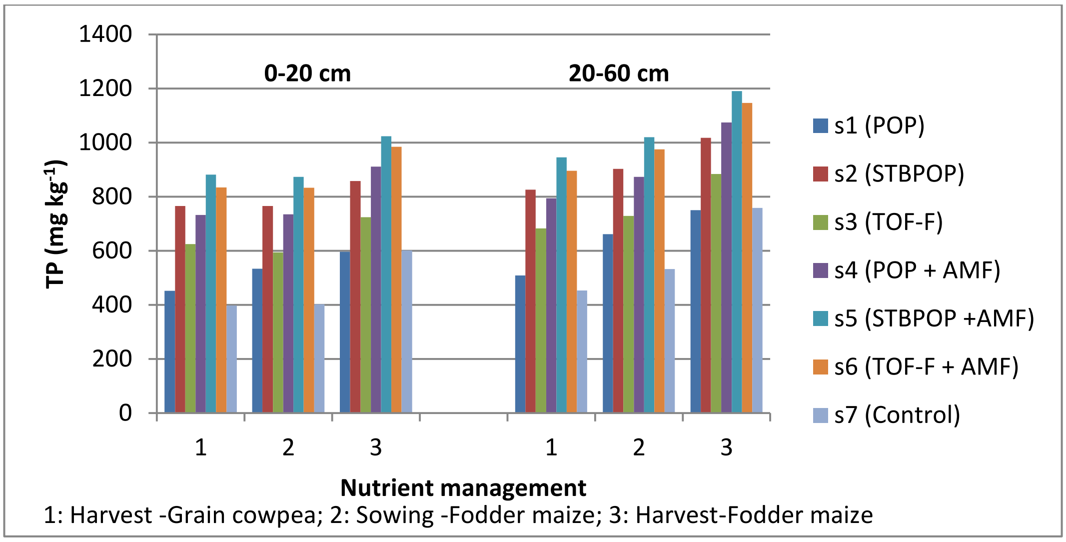


Fig 34. Soil TP as affected by nutrient management in a grain cowpea – fodder maize cropping sequence that received total residue of cowpea

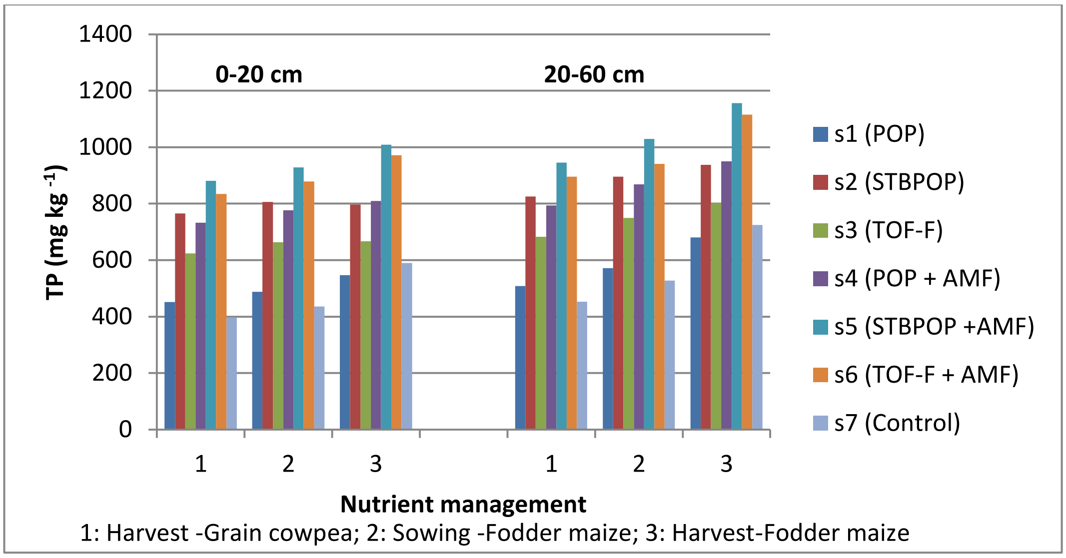


Fig 35. Soil TP as affected by nutrient management in a grain cowpea – fodder maize cropping sequence that received root residue of cowpea

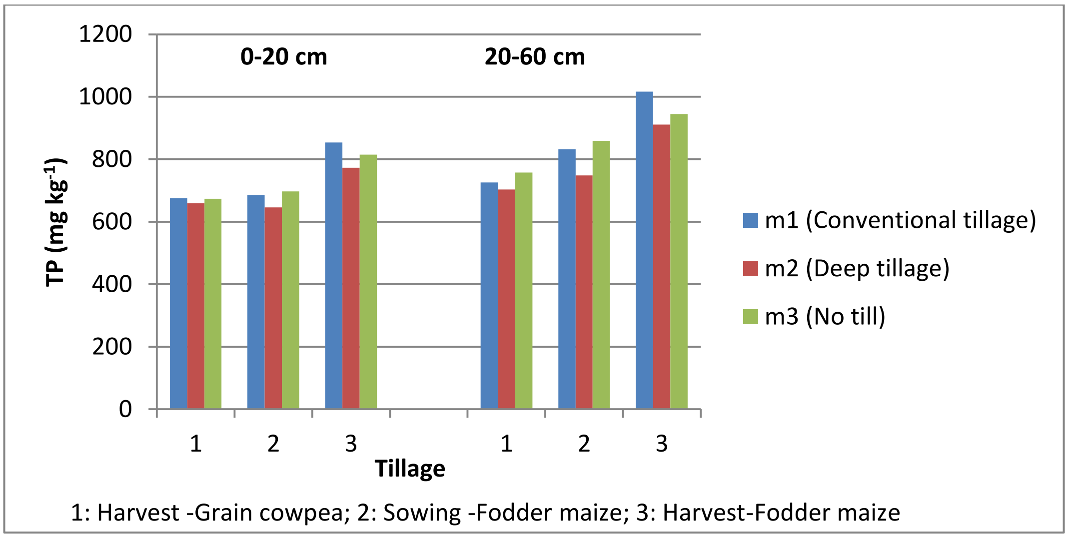


Fig 36. Soil TP as affected by tillage in a grain cowpea – fodder maize cropping sequence that received total residue of cowpea

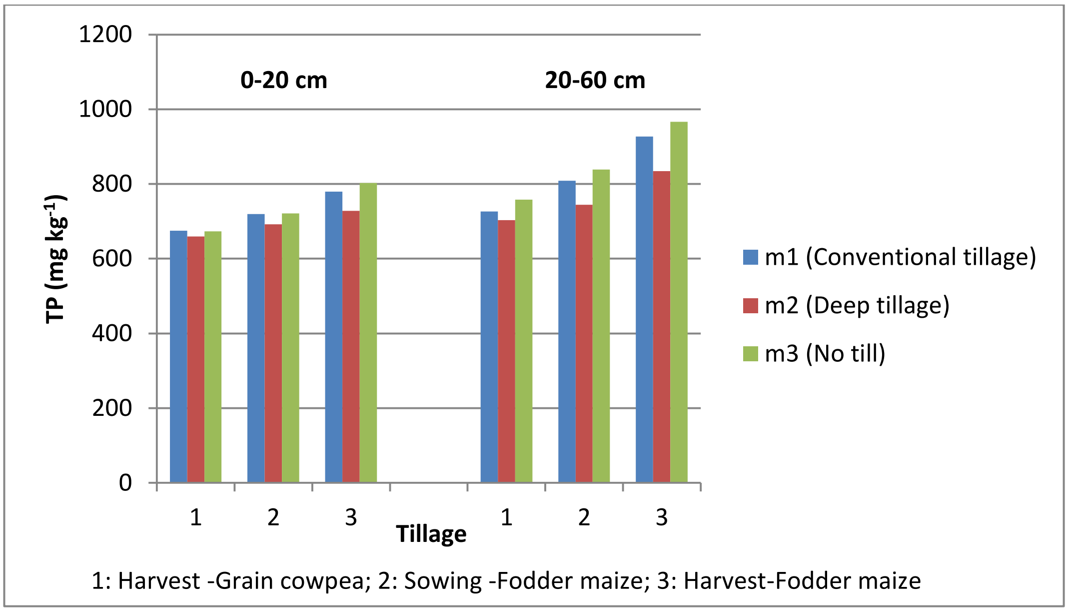


Fig 37. Soil TP as affected by tillage in a grain cowpea – fodder maize cropping sequence that received root residue of cowpea

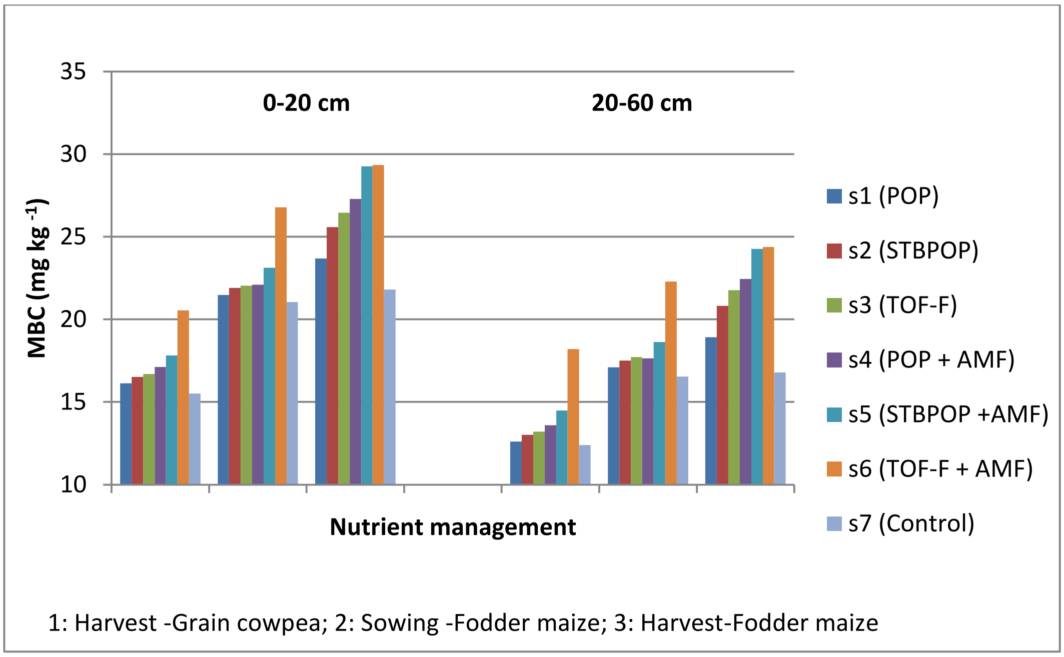


Fig 38. Soil MBC content as affected by nutrient management in a grain cowpea – fodder maize sequence that received total crop residue of cowpea

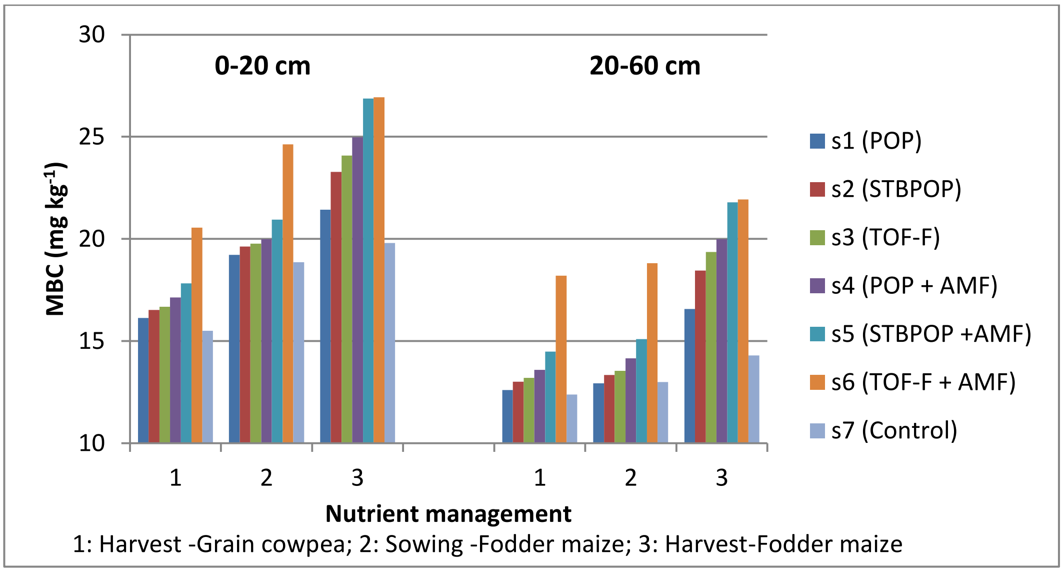


Fig 39. Soil MBC content as affected by nutrient management in a grain cowpea – fodder maize sequence that received root residue of cowpea

activity were primarily provided by no tilled condition as less OM levels by root residue incorporation was not able to create better conditions (Fig 36 and Fig 37).

The soil LP fraction was significantly influenced by tillage and nutrient management and AMF included treatments remained superior throughout the cropping period. Among nutrient management s_6 recorded highest soil LP content throughout the cropping period and it showed an abrupt increase towards the end of cropping sequence ie. at the harvest of fodder maize grown under both conditions. Such an abrupt increase was shown by s_5 also and this increase might be due to enormous microbial activity especially AMF activity in presence of organic manures and controlled fertilizer application. Besides that soil organic matter increase by residue incorporation also might have contributed to this effect.

On evaluating the temporal influence, an increasing trend was observed for soil LP content as cropping sequence advances and this increase is mainly due to more organic matter levels and rhizodeposition which supports more microbial activity. Regarding the tillage effects the no till treatment recorded highest LP content except at the harvest of fodder maize grown in total cowpea residue incorporated soils. The increased microbial activity in no tilled soils might have contributed to this increase. Mbuthia *et al.* (2015) reported that the key enzymes associated with C, N and P cycling (b-glucosidase, b-glucosaminidase, and phosphodiesterase) were significantly higher under no-till relative to tilled condition.

5.3.6 Effect of tillage and nutrient management on soil biological properties of grain cowpea - fodder maize cropping sequence

5.3.6.1 Soil MBC and dehydrogenase activity

Soil microorganisms perform a major function in the soil carbon cycle of soil and regulating the ecosystem cycling. For the formation of the organic pool, soil microbial biomass carbon acts as a key indicator of soil organic carbon by decomposing organic matter and controlling nutrient dynamics which affect the primary productivity of the terrestrial ecosystem (Kara and Bolat 2008; Lepcha *et al.,* 2020).

The soil microbial biomass acts as a labile reservoir of plant available nutrients and constitutes a significant part of the potentially mineralizable-N and plays an important role in nutrient cycling due to rapid turnover rate. Dehydrogenase enzyme are active in cells, and their relative activity levels are taken as an indicator of microbial activity (Philip *et al.,* 2018). Therefore, the study of soil microbial biomass and their dehydrogenase activity is important for understanding early changes in biological quality of soil following changes in the management practices (Palma *et al.*, 2000).

The soil MBC content and dehydrogenase activity exhibited a similar trend throughout the cropping sequence. Among nutrient management s_6 – TOF-F + AMF treatment recorded highest MBC and dehydrogenase activity followed by s_5. Organic manures have strong effects on the soil microbiome and are fundamental to support soil health by increasing microbial activity, microbial interactions and nutrient cycling (Lazcano *et al*., 2013; Ling *et al*., 2016; Su *et al*., 2021). The TOF-F application significantly increased the microbial biomass C and microbial load in many studies due to its abundant supply of easily soluble nutrients along with higher OC content (Sudharmaidevi *et al.,* 2017; Jacob, 2018; Ramesha 2019; Ajayan, 2021). The subsoil recorded lower MBC and dehydrogenase activity than surface soils for all crops due to decreased organic matter content and rhizodeposition in these layers as compared to surface soils (Fig 38 and Fig 39).

On evaluating the temporal influence, both soil MBC and dehydrogenase activity increased as cropping period advances mainly due to crop residue incorporation and more rhizodeposition and root residue incorporated soils exhibited lower values than total residue incorporated soils. The increased SOM due to total residue incorporation might have resulted in higher values.

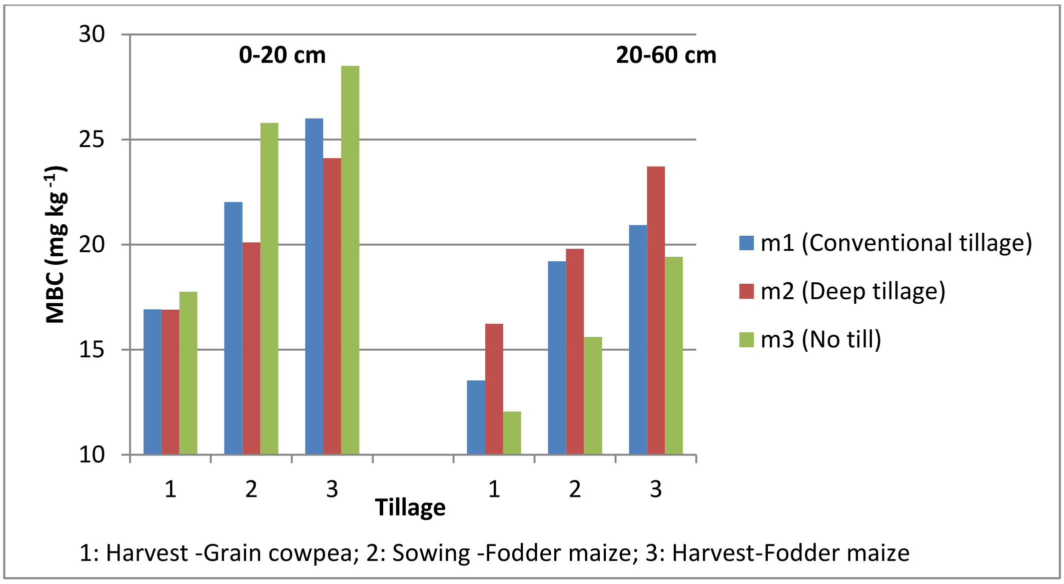


Fig 40. Soil MBC content as affected by tillage in a grain cowpea – fodder maize sequence that received total crop residue of cowpea

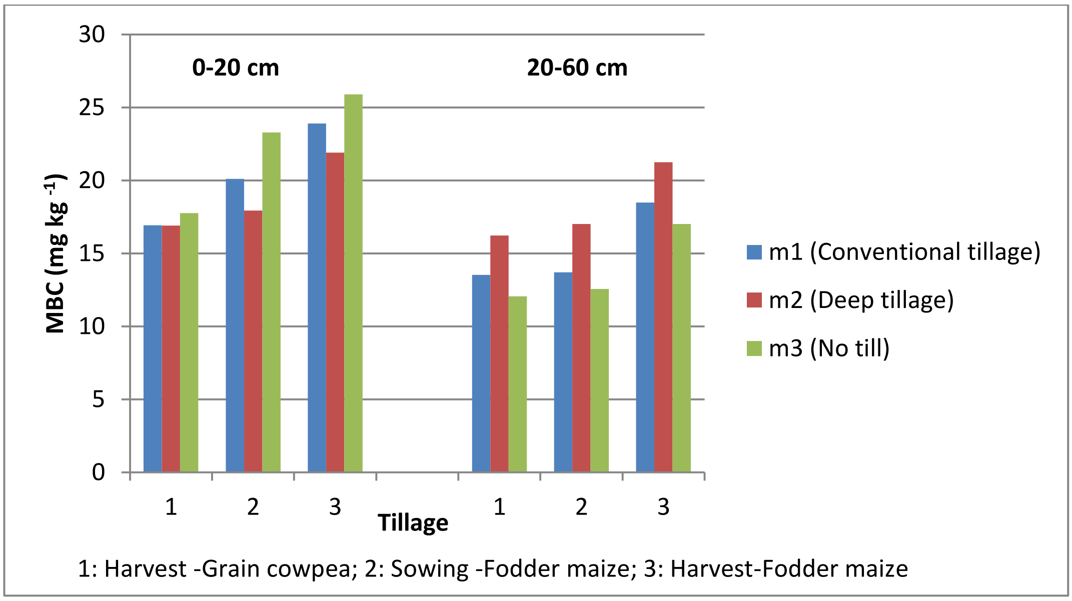


Fig 41. Soil MBC content as affected by tillage in a grain cowpea – fodder maize sequence that received root residue of cowpea

Regarding the tillage effects, the no till treatment exhibited higher values for soil MBC and dehydrogenase activity. The no-till treatments were characterized by a significantly greater abundance of Gram positive bacteria, actinomycetes and mycorrhizae fungi fatty acid methyl ester (FAME) biomarkers compared to tilled conditions (Mbuthiya *et al.*, 2016; Castillo *et al.*, 2018) (Fig 40 and Fig 41).

The different nutrient management and tillage practices significantly influenced soil physical, chemical and biological properties. The treatments with AMF remained superior in various soil properties and yield and growth attributes emphasizing the role of AMF in C storage and nutrient cycling in soils. The no tilled condition with total residue incorporation responded better than only root residue incorporated condition hinting to the fact that more organic matter contributing practices can improve the physicochemical and biological conditions of no tilled soils favourably.

6. SUMMARY

The study entitled "Exploration on the links between soil carbon storage and root biomass and elucidation of drivers of carbon stabilization" was conducted at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during November 2019 to September 2021 with the objective to study the links between soil carbon storage and root biomass in soils of different agro ecological units and to identify the key drivers of C stabilization and NP fluxes under different management practices. A summary of salient results of the study are presented in this chapter.

Exploration on the links between soil organic C and NP pools with root biomass in soils of different AEUs

- The physical properties like BD and gravel per cent of all the AEUs showed an increase towards depth while the electrochemical properties showed a decrease.
- Among the different AEUs, AEU 16 recorded lowest BD (1.22 Mg m^{-3}) and gravel per cent (30.53 %) and had a subsoil increase of 12 per cent and 17 per cent for BD and gravel per cent respectively.
- The different fractions of soil C, and N showed a decrease with depth for all AEUs.
- The soil TOC (5.94 %) and RC (1.64 %) content were highest for AEU 14 with a decrease of 26 per cent and 31 per cent respectively for subsoil.
- The highest DOC (54.63 mg kg^{-1}) and LC (877.50 mg kg^{-1}) content were for AEU 16 with a subsoil decrease of 45 per cent and 27 per cent respectively. AEU 12 recorded lower values for C fractions which may be due to decreased root biomass by 38 per cent and 25 per cent in surface soil and 55 per cent and 70 per cent in subsoil than that of AEU 14 and AEU 16 respectively.
- The root biomass and soil C fractions were positively and significantly correlated at both sampling depths.

- The highest correlation coefficients between root biomass and soil C fractions were recorded by DOC (0.976) followed by RC (0.931) and LC (0.975) followed by DOC (0.953) for surface and subsoil respectively.
- From the regression analysis perfect fit towards linear regression model, expressed as R^2 value, was highest for DOC (0.95) and LC (0.94) at sampling depths of 0-20 cm and 20-60 cm respectively.
- The different fractions of N were highest for AEU 12 and surface soil showed an increase in total nitrogen by 6 per cent and NH_4-N by 20 per cent, NO_3 – N by 18 per cent and organic N (ON) by 5 per cent than subsoil.
- For soil P fractions an increase was observed with depth and AEU 12 recorded highest values for P fractions.
- Among soil N and P fractions, ON and labile P were found to be more correlated to root biomass and with higher R^2 values at both sampling depths.
- The MBC (26.89 mg kg^{-1}) and DHA (34.94 µg TPF g^{-1} 24 hr^{-1}) were highest for AEU 16 and surface soil showed an increase in MBC by 28 per cent and DHA by 30 per cent, than subsoil.

Assessment of carbon storage under different land use system and identifying the drivers of C stabilization

- The most prominent land use system of each AEU were identified as rubber plantations for AEU 12 and AEU 14 and cardamom plantations for AEU 16.
- The rubber plantations of AEU 14 recorded the highest C storage (434.0 t ha^{-1}) and lowest value was observed for cardamom plantations of AEU 16 (329.9 t ha^{-1}).
- The soil physical properties and electrochemical properties behaved similar to that of Part I.
- Cardamom plantations of AEU 16 recorded lowest BD (0.97 Mg m^{-3}) and gravel content (28.02 %) while AEU 12 had highest pH (5.61) and lowest EC (0.39 dS m^{-1}).

- Among the different land use systems, rubber plantations of AEU 14 recorded highest values for soil TOC (6.72 %) and DOC (55.16 mg kg $^{-1}$) content while cardamom plantations had highest soil LC (910.91 mg kg $^{-1}$) and surface soil RC (1.92 %) content but subsoil RC (1.26 %) content was more for rubber plantations of AEU 14.
- In rubber plantations the root biomass were correlated to all C fractions and more correlated to RC and TOC and in cardamom plantations root biomass were significantly correlated to TOC (0.98) and DOC (0.95) fractions only.
- A significant and positive correlation between root lignin and soil C fractions (RC and TOC) was also observed.
- The different fractions of N and P were highest for cardamom plantations of AEU 16 and surface soil showed an increase in TN by 5 per cent, NH_4-N by 14 per cent, NO_3– N by 22 per cent and ON by 4 per cent than subsoil and a subsoil increase of TP by 12 per cent, LP by 29 per cent and NLP by 11 per cent were also observed.
- The shoot biomass were more correlated to soil N and P fractions than root biomass and were more correlated to ON and TN and to TP and NLP among soil N and P fractions respectively.
- A significant positive correlation between N and P removal and soil NP pools were also obtained.
- The MBC (28.28 mg kg^{-1}) and DHA (35.51 µg TPF g^{-1} 24 hr^{-1}) were highest for cardamom plantations of AEU 16 and surface soil showed an increase in MBC by 25 per cent and DHA by 23 per cent than subsoil.

Field experiments to study the effect of tillage and nutrient management on the link between root and shoot biomass C, and SOC and NP pools

- Among various nutrient management treatments, soil test based POP + AMF (s_5) recorded the highest plant height, shoot biomass and grain yield plant^{-1} (107.70 g) and TOF-F + AMF (s_6) showed highest values for root characteristics and quality parameters for grain cowpea.

- Similarly for fodder maize grown under both conditions, the treatment soil test based POP + AMF (s_5) gave highest shoot biomass, fodder yield and quality parameters while highest root biomass were recorded by the treatment, TOF-F + AMF (s_6).
- Among the tillage levels, the no till treatment (m_3) performed best in connection with growth, yield and quality characteristics throughout the cropping period.
- Tillage and nutrient management had significantly influenced various soil properties. The lowest soil BD and higher WSA per cent and soil pH was reported by the treatment TOF-F + AMF (s_6) throughout the cropping sequence.
- Among tillage levels, deep tillage (m_2) remained superior for soil BD and pH and no till treatment (m_3) for WSA per cent respectively.
- The treatment, TOF-F + AMF (s_6) remained superior for soil C fractions viz., TOC, LC and RC content, mineralizable N fractions (NH_4-N and NO_3-N), labile P and MBC content and dehydrogenase activity throughout the cropping sequence.
- The treatment, soil test based POP +AMF (s_5) recorded higher values for NP fractions like TN, ON, TP and non labile P (NLP).
- Among the tillage levels, the no till treatment (m_3) remained superior in connection with soil chemical and biological properties especially towards the end of cropping period.
- As the cropping sequence advances an improvement in soil physical, chemical and biological properties were observed and this is mainly attributed to the crop residue addition of grain cowpea and more improvement was observed for total residue incorporation than root residue alone addition.

To conclude it was found that the soil C pools were highly linked to root biomass and NP pools to shoot biomass. The root biomass and root lignin were the main drivers of C stabilization. The treatments with AMF remained superior in various soil properties and yield and growth attributes emphasizing the favorable role of AMF in C storage and nutrient cycling in soils. With regard to nutrient management, soil test based POP + AMF recorded the highest yield in cropping sequence while organic nutrition (TOF-F) + AMF contributed more to soil properties indicating the need for further research on nutrient translocation and assimilation under organic nutrition. The no tilled condition with total residue incorporation responded better than root residue alone incorporation, hinting to the fact that more organic matter contributing practices improved the physicochemical and biological conditions of soils favorably.

Future line of work

- Studies on translocation and assimilation of nutrient under organic source of nutrition
- Yield limiting factors under organic nutrition
- Role of AMF on uptake of nutrient apart from N and P and then utilization for yield enhancement
- Long term tillage experiments to study C sequestration and effects on soil properties

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EXPLORATION ON THE LINKS BETWEEN SOIL CARBON STORAGE AND ROOT BIOMASS AND ELUCIDATION OF DRIVERS OF CARBON STABILIZATION

by

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ABSTRACT

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ABSTRACT

The study entitled “Exploration on the links between soil carbon storage and root biomass and elucidation of drivers of carbon stabilization” was conducted at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during November 2019 to September 2021 with the objective to study the links between soil carbon storage and root biomass in soils of different agro ecological units and to identify the key drivers of C stabilization and NP fluxes under different management practices.

The study area comprised of three Agro ecological units (AEUs) of Southern Kerala viz. Southern and Central Foot Hills (AEU 12), Southern High Hills (AEU 14) and Kumily High Hills (AEU 16). The study was carried out in three parts namely exploration on the links between soil organic C and NP pools with root biomass in soils of different AEUs, assessment of carbon storage under different land use system and identifying the drivers of C stabilization and field experiments to study the effect of management practices on the link between root and shoot biomass C and SOC and NP pools.

For the study exploration on the links between soil organic C and NP pools with root biomass in soils of different AEUs, the study area was surveyed and geocoded soil samples from 0-20 cm and 20-60 cm depth were collected using core samplers. The root biomass from the soil samples were separated out and weighed. The soil samples were analyzed for its various physical, chemical and biological properties. For assessment of carbon storage under different land use system and identifying the drivers of C stabilization, the most prominent land use system of each AEU was identified and five samples were collected from each system. The sampling size was one sq.m to a depth of 60 cm. The plants of the same area were uprooted and their shoot and root biomass were recorded. Both the soil and plant samples were collected and analysed for various parameters.

The field experiment in split plot design on grain cowpea – fodder maize cropping sequence was laid out with the main plot treatments as m_1: conventional

tillage, m_2: deep tillage (30 cm depth) and m_3: no till and sub plot treatments as s_1: POP recommendation, s_2: soil test based POP, s_3: organic nutrient management (TOF-F), s_4: POP + AMF, s_5: soil test based POP + AMF, s_6: TOF-F + AMF and s_7: absolute control. After the harvest of grain cowpea, shoot biomass were removed and roots were retained in three replications and in the other three replications total biomass of grain cowpea were added into the soil and left for decomposition. After that fodder maize was raised in the field and the crop and soil samples were collected and analysed for various parameters.

The results of the Part I revealed that the physical properties like bulk density (BD) and gravel per cent of all the AEUs showed an increase towards depth while the electrochemical properties showed a decrease. Among the different AEUs, AEU 16 recorded lowest BD (1.22 Mg m^{-3}) and gravel per cent (30.53 %) and had a subsoil increase of 12 per cent and 17 per cent for BD and gravel per cent respectively. The different fractions of soil C and N showed a decrease with depth for all AEUs. The soil total organic carbon (TOC-5.94 %) and recalcitrant C (RC-1.64 %) content were highest for AEU 14 with a decrease of 26 per cent and 31 per cent respectively for subsoil. The highest dissolved organic C (DOC-54.63 mg kg^{-1}) and labile C (LC- 877.50 mg kg^{-1}) content were for AEU 16 with a subsoil decrease of 45 per cent and 27 per cent respectively. AEU 12 recorded lower values for C fractions which may be due to decreased root biomass by 38 per cent and 25 per cent in surface soil and 55 per cent and 70 per cent in subsoil than that of AEU 14 and AEU 16 respectively. The root biomass and soil C fractions were positively and significantly correlated at both sampling depths. The highest correlation coefficients between root biomass and soil C fractions were recorded by DOC (0.976) followed by RC (0.931) and LC (0.975) followed by DOC (0.953) for surface and subsoil respectively. From the regression analysis perfect fit towards linear regression model, expressed as R^2 value, was highest for DOC (0.95) and LC (0.94) at sampling depths of 0-20 cm and 20-60 cm respectively.

The different fractions of N were highest for AEU 12 and surface soil showed an increase in total nitrogen (TN) by 6 per cent and NH_4-N by 20 per cent, NO_3 – N by 18 per cent and organic N (ON) by 5 per cent than subsoil. For soil P fractions an increase was observed with depth and AEU 12 recorded highest values for P fractions. Among soil N and P fractions, ON and labile P (LP) were found to be more correlated to root biomass and with higher R^2 values at both sampling depths. The MBC (26.89 mg kg $^{-1}$) and DHA (34.94 µg TPF g^{-1} 24 hr^{-1}) were highest for AEU 16 and surface soil showed an increase in MBC by 28 per cent and DHA by 30 per cent, than subsoil.

For part II, the most prominent land use system of each AEU were identified as rubber plantations for AEU 12 and AEU 14 and cardamom plantations for AEU 16. The rubber plantations of AEU 14 recorded highest C storage (434.0 t ha^{-1}) and lowest value was observed for cardamom plantations of AEU 16 (329.9 t ha^{-1}). The soil physical properties and electrochemical properties behaved similar to that of Part I. Cardamom plantations of AEU 16 recorded lowest BD (0.97 Mg m^{-3}) and gravel content (28 %) while AEU 12 had highest pH (5.61) and lowest EC (0.39 dS m^{-1}). Among the different land use systems, rubber plantations of AEU 14 recorded highest values for soil TOC (6.72 %) and DOC (55.16 mg kg^{-1}) content while cardamom plantations had highest soil LC (910.91 mg kg^{-1}) and surface soil RC (1.92 %) content but subsoil RC content was more for rubber plantations of AEU 14. In rubber plantations the root biomass were correlated to all C fractions and more correlated to RC and TOC and in cardamom plantations root biomass were significantly correlated to TOC (0.98) and DOC (0.95) fractions only. A significant and positive correlation between root lignin and soil C fractions (RC and TOC) was also observed.

The different fractions of N and P were highest for cardamom plantations of AEU 16 and surface soil showed an increase in TN by 5 per cent, NH_4-N by 14 per cent, NO_3– N by 22 per cent and ON by 4 per cent than subsoil and a subsoil increase of TP by 12 per cent, LP by 29 per cent and NLP by 11 per cent were also observed. The shoot biomass were more correlated to soil N and P fractions than root biomass and were more correlated to ON and TN and to TP and NLP among soil N and P fractions respectively. A significant positive correlation between N and P removal and soil NP pools were also obtained. The MBC and DHA were highest for cardamom plantations of AEU 16 and surface soil showed an increase in MBC by 25 per cent and DHA by 23 per cent than subsoil.

In the field experiment, among the various nutrient management treatments, soil test based POP + AMF (s_5) recorded the highest plant height, shoot biomass and grain yield plant^{-1} (107.70 g) and TOF-F + AMF (s_6) showed highest values for root characteristics and quality parameters for grain cowpea. Similarly for fodder maize grown under both conditions, the treatment soil test based POP + AMF (s_5) gave highest shoot biomass, fodder yield and quality parameters while highest root biomass were recorded by the treatment, TOF-F + AMF (s_6). Among the tillage levels, the no till treatment (m_3) performed best in connection with growth, yield and quality characteristics throughout the cropping period.

Tillage and nutrient management had significantly influenced various soil properties. The lowest soil BD and higher WSA per cent and soil pH were reported by the treatment TOF-F + AMF (s_6) throughout the cropping sequence. Among tillage levels, deep tillage (m_2) remained superior for soil BD and pH and no till treatment (m_3) for WSA per cent respectively. The treatment, TOF-F + AMF (s_6) remained superior for soil C fractions viz., TOC, LC and RC content, mineralizable N fractions (NH_4-N and NO_3-N), labile P and MBC content and dehydrogenase activity throughout the cropping sequence. The treatment, soil test based POP +AMF (s_5) recorded higher values for NP fractions like TN, ON, TP and non labile P (NLP). Among the tillage levels, the no till treatment (m_3) remained superior in connection with soil chemical and biological properties especially towards the end of cropping period.

As the cropping sequence advances an improvement in soil physical, chemical and biological properties were observed and this is mainly attributed to the crop residue addition of grain cowpea and more improvement was observed for total residue incorporation than root residue alone addition.

The soil C pools were highly linked to root biomass and NP pools to shoot biomass. The root biomass and root lignin were the main drivers of C stabilization. The treatments with AMF remained superior in various soil properties and yield and growth attributes emphasizing the favourable role of AMF in C storage and nutrient cycling in soils. With regard to nutrient management, soil test based POP + AMF recorded the highest yield in cropping sequence while organic nutrition (TOF-F) + AMF contributed more to soil properties indicating the need for further research on nutrient translocation and assimilation under organic nutrition. The no tilled condition with total residue incorporation responded better than root residue alone incorporation, hinting to the fact that more organic matter contributing practices improved the physicochemical and biological conditions of soils favourably.

സംഗ്രഹം

"മണ്ണിലെ കാർബൺ സംഭരണവും റൂട്ട് ബയോമാസും തമ്മിലുള്ള ബന്ധത്തെക്കുറിച്ചുള്ള പര്യവേക്ഷണവും കാർബൺ സ്ഥിരത ഡ്രൈവറുകളുടെ വിശദീകരണവും" എന്ന തലക്കെട്ടിലുള്ള പഠനം വെള്ളായണിയിലെ സോയിൽ സയൻസ് ആൻഡ് അഗ്രികൾച്ചറൽ കെമിസ്ട്രി വകുപ്പിൽ, വിവിധ കാർഷിക പാരിസ്ഥിതിക യൂണിറ്റുകളുടെ മണ്ണിലെ കാർബൺ സംഭരണവും റൂട്ട് ബയോമാസും തമ്മിലുള്ള ബന്ധം പഠിക്കാനും, വ്യത്യസ്ത മാനേജ്മെന്റ് രീതികൾക്ക് കീഴിൽ കാർബൺ സ്ഥിരതയുടെ (C stabilization) പ്രധാന ഡ്രൈവറുകൾ, എൻപി പ്രവാഹങ്ങൾ (NP fluxes) എന്നിവ തിരിച്ചറിയാനുമുള്ള ലക്ഷ്യത്തോടെ, 2019 നവംബർ മുതൽ 2021 സെപ്റ്റംബർ വരെ നടത്തി.

ദക്ഷിണ കേരളത്തിലെ മൂന്ന് കാർഷിക പാരിസ്ഥിതിക യൂണിറ്റുകൾ (എ.ഇ.യു) അതായത് തെക്ക് - മധ്യമേഖല മലയടിവാരങ്ങൾ (എ.ഇ.യു 12), ദക്ഷിണമലനിരകൾ (എ.ഇ.യു 14), കുമിളി മലനിരകൾ (എ.ഇ.യു 16) എന്നിവ ഉൾപ്പെടുന്നതാണ് പഠനമേഖല. വിവിധ കാർഷിക പാരിസ്ഥിതിക യൂണിറ്റുകളിലെ റൂട്ട് ബയോമാസ്സും, മണ്ണിലെ ജൈവ കാർബൺ, നൈട്രജൻ, ഫോസ്ഫറസ് പൂളുകൾ തുടങ്ങിയവ തമ്മിലുള്ള ബന്ധത്തെക്കുറിച്ചുള്ള പര്യവേക്ഷണം, വിവിധ ഭൂവിനിയോഗ സംവിധാനത്തിന് കീഴിലുള്ള കാർബൺ സംഭരണത്തിന്റെയും വിലയിരുത്തൽ ഒപ്പം കാർബൺ സ്ഥിരതയുടെ ഡ്രൈവറുകൾ തിരിച്ചറിയുക, നിലം പരീക്ഷണത്തിലൂടെ വിവിധ കൃഷിരീതികൾക്ക് മണ്ണിലെ ജൈവ കാർബൺ, നൈട്രജൻ, ഫോസ്ഫറസ് പൂളുകൾ, റൂട്ട് ആൻഡ് ഷൂട്ട് ബയോമാസ് തുടങ്ങിയവ തമ്മിലുള്ള ബന്ധം, എന്നിങ്ങനെ മൂന്ന് ഭാഗങ്ങളായാണ് പഠനം നടത്തിയത്.

വ്യത്യസ്ത കാർഷിക പാരിസ്ഥിതിക യൂണിറ്റുകളിലെ റൂട്ട് ബയോമാസ്സും, മണ്ണിലെ ജൈവ കാർബൺ, നൈട്രജൻ, ഫോസ്ഫറസ് പൂളുകൾ തുടങ്ങിയവ തമ്മിലുള്ള ബന്ധത്തെക്കുറിച്ചുള്ള പഠന പര്യവേക്ഷണത്തിന്, പഠന പ്രദേശം സർവേ ചെയ്യുകയും 0-20 സെന്റീമീറ്റർ മുതൽ 20-60 സെന്റീമീറ്റർ വരെ ആഴത്തിലുള്ള മണ്ണ് സാമ്പിളുകൾ കോർ സാമ്പിളറുകൾ ഉപയോഗിച്ച് ശേഖരിക്കുകയും ചെയ്തു. മണ്ണിന്റെ സാമ്പിളുകളിൽ നിന്നുള്ള റൂട്ട് ബയോമാസ് വേർതിരിച്ച് തൂക്കിനോക്കി. മണ്ണ് സാമ്പിളുകൾ വിവിധ ഭൗതിക, രാസ, ജൈവ ഗുണങ്ങൾക്കായി വിശകലനം ചെയ്തു. വ്യത്യസ്ത ഭൂവിനിയോഗ സംവിധാനത്തിന് കീഴിലുള്ള കാർബൺ സംഭരണം വിലയിരുത്തുന്നതിനും സ്ഥിരതയുടെ ഡ്രൈവറുകൾ തിരിച്ചറിയുന്നതിനും, ഓരോ എ.ഇ.യു.-യിലേയും ഏറ്റവും പ്രധാനപ്പെട്ട ഭൂവിനിയോഗ സംവിധാനം തിരിച്ചറിയുകയും ഓരോ സിസ്റ്റത്തിൽ നിന്നും അഞ്ച് സാമ്പിളുകൾ ശേഖരിക്കുകയും ചെയ്തു. സാമ്പിൾ വലുപ്പം ഒരു ചതുരശ്ര മീറ്റർ മുതൽ 60 സെന്റിമീറ്റർ വരെ ആഴത്തിലായിരുന്നു. അതേ പ്രദേശത്തെ സസ്യങ്ങൾ പിഴുതുമാറ്റുകയും അവയുടെ ഷൂട്ട്, റൂട്ട് ബയോമാസ്

എന്നിവ രേഖപ്പെടുത്തുകയും ചെയ്തു. മണ്ണിന്റെയും സസ്യങ്ങളുടെയും സാമ്പിളുകൾ ശേഖരിക്കുകയും വിശകലനം ചെയ്യുകയും ചെയ്തു.

സ്പ്ലിറ്റ് പ്ലോട്ട് ഡിസൈനിലെ ഫീൽഡ് പരീക്ഷണം - പയർ - ചോളം വിളക്രമം അടിസ്ഥാനം ആക്കിയതായിരുന്നു. പ്രധാന പ്ലോട്ട് പരിചരണം; m_1: പരമ്പരാഗത കാർഷികവൃത്തി, m_2: ആഴത്തിലുള്ള കാർഷികവൃത്തി (30 സെന്റീമീറ്റർ ആഴം), m_3: നിലം ഉഴുകാതെയും, ഉപപ്ലോട്ട് പരിചരണം s_1: കേരള കാർഷിക സർവ്വകലാശാല വിള പരിപാലന ശുപാർശകൾ (പി.ഒ.പി), s_2: മണ്ണ് പരിശോധന അടിസ്ഥാനമാക്കിയുള്ള പി.ഒ.പി, s_3: ജൈവ പോഷക മാനേജ്മെന്റ് (ശുചിത-TOF-F), s_4: പി.ഒ.പി + AMF, s_5: മണ്ണ് പരിശോധന അടിസ്ഥാനമാക്കിയുള്ള പി.ഒ.പി + AMF, s_6: TOF-F + AMF, s_7: കേവല നിയന്ത്രണം. പയർ വിളവെടുപ്പിനു ശേഷം, ഷൂട്ട് ബയോമാസ് നീക്കം ചെയ്യുകയും വേരുകൾ മൂന്ന് പകർപ്പുകളിൽ നിലനിർത്തുകയും ചെയ്തു, കൂടാതെ മറ്റ് മൂന്ന് പകർപ്പുകളിൽ പയറിന്റെ മൊത്തം ജൈവാംശം മണ്ണിൽ ചേർത്ത് വിഘടിക്കാൻ അനുവദിച്ചു. അതിനുശേഷം, വയലിൽ ചോളം വളർത്തുകയും വിളയുടെയും മണ്ണിന്റെയും സാമ്പിളുകൾ ശേഖരിക്കുകയും വിവിധ മാനദണ്ഡങ്ങൾക്കായി വിശകലനം ചെയ്യുകയും ചെയ്തു.

മണ്ണിലെ കാർബൺ പൂൾസ് റൂട്ട് ബയോമാസുമായും നൈട്രജൻ, ഫോസ്ഫറസ് പൂളുകൾ ഷൂട്ട് ബയോമാസുമായും വളരെയധികം ബന്ധപ്പെട്ടിരിക്കുന്നു. റൂട്ട് ബയോമാസും, റൂട്ട് ലിഗ്നിനും കാർബൺ സ്ഥിരതയുടെ പ്രധാന ഡ്രൈവറുകൾ ആണെന്ന് തിരിച്ചറിഞ്ഞു. AMF -നൊപ്പമുള്ള പരിചരണങ്ങൾ വിവിധ മണ്ണിന്റെ ഗുണങ്ങളിലും വിളവ്, വളർച്ചാ ഗുണങ്ങളിലും മികച്ചതായി തുടർന്നു, കാർബൺ സംഭരണത്തിലും മണ്ണിലെ പോഷക വർധനവിനും AMF ന്റെ അനുകൂലമായ പങ്ക് ഈ പരീക്ഷണത്തിന് തെളിയിക്കാനായി. പോഷക പരിപാലനവുമായി ബന്ധപ്പെട്ട്, മണ്ണ് പരിശോധന അടിസ്ഥാനമാക്കിയുള്ള POP + AMF വിളവെടുപ്പ് ക്രമത്തിൽ ഏറ്റവും ഉയർന്ന വിളവ് രേഖപ്പെടുത്തി, ജൈവ പോഷണത്തിന് കീഴിൽ പോഷകങ്ങളുടെ വേരുകളിൽ നിന്ന് ഇലകളിലേക്ക് ഉള്ള പ്രയാണവും സ്വാംശീകരണവും സംബന്ധിച്ച കൂടുതൽ ഗവേഷണത്തിന്റെ ആവശ്യകത ഈ പരീക്ഷണം സൂചിപ്പിക്കുന്നു. ജൈവ പോഷണം (TOF-F)+AMF മണ്ണിന്റെ ഗുണങ്ങൾക്ക് കൂടുതൽ സംഭാവന നൽകി. മൊത്തം അവശിഷ്ട സംയോജനത്തോടുകൂടിയ ഉഴുകാതെയുള്ള അവസ്ഥ റൂട്ട് അവശിഷ്ടം മാത്രം സംയോജിപ്പിക്കുന്നതിനേക്കാൾ മികച്ച രീതിയിൽ പ്രതികരിച്ചു, കൂടുതൽ ജൈവവസ്തുക്കൾ സംഭാവന ചെയ്യുന്ന രീതികൾ മണ്ണിന്റെ ഭൗതിക രാസ, ജൈവ അവസ്ഥകളെ അനുകൂലമായി മെച്ചപ്പെടുത്തി.