EFFECT OF THERMOCHEMICAL ORGANIC FERTILIZER ON SOIL CARBON POOLS, NUTRIENT DYNAMICS AND CROP PRODUCTIVITY IN ULTISOLS

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DECLARATION

I hereby declare that the thesis entitled "**Effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics and crop productivity in Ultisols**" is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that the thesis entitled **"Effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics and crop productivity in Ultisols"** is a bonafide record of research work done independently by Ms. Amrutha S. Ajayan (2017-21-032) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

% - Per cent
@ - At the rate of
B - Boron
Ca - Calcium
Cd - Cadmium
Cu - Copper
CL - Cumulative loss
D - Day
dS m^{-1} - Deci Siemens per meter
Fe - Iron
F-TOF - Fortified thermochemical organic fertilizer
FYM - Farmyard manure
g ha^{-1} - Gram per hectare
kg ha^{-1} - Kilogram per hectare
K - Potassium
LC - Labile carbon
MBC - Microbial biomass carbon
MC - Microbial compost
Mg ha^{-1}- Mega gram per hectare
Mg - Magnesium
Mn - Manganese

N - Nitrogen

OC - Ordinary compost

Org-B - Organically bound boron

Ox-B - Oxide bound boron

Pb - Lead

P - Phosphorus

Ra-B - Readily available boron

RDF - Recommended dose of fertilizers

Res-B - Residual boron

ROC - Recalcitrant organic carbon

S - Sulphur

Spa-B - Specifically adsorbed boron

STBR - Soil test based recommendation

TOC - Total organic carbon

TOF - Unfortified thermochemical organic fertilizer

VC - Vermicompost

W - Week

WSOC - Water soluble organic carbon

Zn - Zinc

INTRODUCTION

1. INTRODUCTION

Soil organic carbon is the prime and primary basis of soil fertility and plays a key role in the enhancement of soil productivity by maintaining soil health and quality in a sustainable manner. Addition of organic matter to enhance soil organic carbon gains is an age old practice aimed at improving the physico-chemical and biological properties of the soil. As the demographic graph is escalating at a tremendous pace, there is an imminent need for enhancing crop productivity from the limited area of cultivable land in order to meet the rising demand for food. Sustainable food production which assures global food security as well as food safety has become the need of the day. Application of organic manures is an integral part of sustainable agriculture and its continuous application results in the build-up of soil organic carbon reserve in the soil (Mariaselvam *et al.,* 2014).

Adherence to intensive cultivation methods of high yielding crop varieties relying solely on inorganic fertilizer inputs with scant regard for recycling of organic residues has aggravated the depletion of soil organic carbon stocks and associated nutrients leading to severe land degradation in the Ultisols. More than 70 per cent of Kerala soils belong to this soil order which is highly weathered, low fertility soils with very low soil organic carbon, low water holding capacity and poor nutrient retention. Application of organic resources has hence become an indispensable necessity for maintaining the sustainability and productivity of these soils. Integrated application of organic manures along with the inorganic fertilizers has multiple benefits such as balanced supply of nutrients, better nutrient availability from the soil due to increased soil microbial activity, degradation of toxic substances and chemicals, improved soil structure and root development, and increased soil water availability (Han *et al.,* 2016). Continuous application of organic fertilizers is essential in the organic carbon depleted tropical soils to improve the soil organic carbon as well as nutrient status.

There exists a huge dearth in the availability of good quality organic fertilizer inputs especially in the tropics. The generation of good quality organic fertilizers from degradable waste, which is available in abundance would be a wise option to tide over this crisis. Proper solid waste management continues to be a matter of great concern in our country. Municipal solid waste (MSW) generation in urban India is about 62 million tonnes (mt) of which only 20 per cent is recycled, about 50 per cent is dumped in landfill sites and 30 percent is left without any treatments, polluting the environment and water bodies. It is anticipated that the urban MSW of India will be about 165 mt in 2030. A study conducted in the metro cities of India revealed that 41 percent of generated MSW is biodegradable in nature (Kumar *et al.*, 2017). Kerala generates about 6000 t of waste per day (Mohan, 2020). Improper management of these wastes has hitherto inflicted severe environmental pollution as well as health hazards to the society. The ecofriendly conversion of biowaste substrate to good quality organic fertilizer resource would provide an apt solution to this problem, at the same time improving agricultural crop productivity.

Different composting methods such as ordinary composting, vermicomposting, microbial composting etc., are some of the prominent techniques for proper disposal of biodegradable waste. Even though composting of biowaste is an ideal option for waste management, there are certain disadvantages associated with different composting methods. Besides the advantages, lot of constraints like space limitation, longer duration for completion of composting, emission of bad odour, microbial contamination, loss of nutrients, presence of pathogens, heavy metals etc. are associated with it. Generally the composting process is quite laborious, tedious and time consuming, requiring larger areas for dumping the waste which predisposes leaching loss of nutrients. Most of these methods require 45 to 60 days for completion. Microbial composting took nearly 50 days to convert organic waste into compost while vermicomposting took 45 days (Jacob, 2018; Ramesha, 2019). Another disadvantage is the emission of greenhouse gases during composting. These problems warranted the quest for a new technology that could rapidly convert degradable biowaste to good quality organic fertilizer in an environmentally safe manner.

Sudharmaidevi *et al.* (2017) developed an innovative technology for instant conversion of biowaste into organic fertilizers without any loss of nutrients and emission of bad odour, employing a converter machine named ‘Suchitha’. Here the organic fertilizer could be produced within a day through the thermochemical decomposition of biowaste followed by drying and fortification. Any biodegradable waste can be processed in ‘Suchitha’ for the production of organic fertilizers. This rapid solid waste management technology with ecofriendly nature was developed at Kerala Agricultural University and patented (Patent No. 321857).

The thermochemical organic fertilizer is comparable to other organic input resources in its manurial value for crop production (Jayakrishna and Thampatti, 2016; Leno *et al.,* 2021) and is gaining much acclaim in the agricultural scenario of Kerala and beyond. However, information on the specificities regarding the pattern of degradation, contribution to soil carbon-nitrogen pools, nutrient dynamics, retention and leaching losses, heavy metal loading, etc. has to be further explored. Hence the present investigation was taken up with the following objectives.

- Production and characterization of thermochemical organic fertilizer as well as other organic fertilizers such as ordinary compost, vermicompost and microbial compost

- To study the effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics, their retention and leaching loss from soil in comparison with other organic fertilizers

- To study the effect of thermochemical organic fertilizer on crop productivity in Ultisols using tomato-amaranthus cropping sequence in comparison with other organic fertilizers

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Sustainable food production which assures food security as well as food safety is the need of the day. For the sustainability, the health and quality of the soil should be maintained. Addition of organic amendments to enhance the soil organic carbon (SOC) is an age-old practice. As the pressure on land for production increased there was a decline in addition of organic manures and crop residues to the soil and an increase in the use of chemical fertilizers and plant protection chemicals in the post green revolution era. This resulted in the sharp decline of SOC content of the cultivated land which has clearly reflected in the crop productivity. At the same time, organic garbage is piling up day by day and becoming a great threat to the environment and organisms. This organic garbage can be easily converted to organic manure and its application to agricultural land will enhance the soil health by increasing SOC content and reduce the environmental pollution.

Patchaye *et al*. (2018) reported microbial management of organic waste as a promising, environment-friendly approach to manage the large quantities of organic waste due to its recycling potential. Composting is a biotechnological process by which different microbial communities convert organic waste into a stabilized form. The microbial compost produced is a bioorganic manure to increase soil fertility and it facilitates sustainable agriculture.

Aalok *et al.* (2008) stated vermicomposting of biowaste using earthworms like *Eisenia foetida* and *Eudrilus eugeniae* as a promising technology for the management of organic solid waste. Role of earthworms in the breakdown of organic debris on soil surface and soil turn over process was first highlighted by Darwin (1881). Vermicompost contains plant growth regulators and other plant growth promoting substances which are produced by microorganisms (Grappelli *et al.,* 1987; Tomati *et al.,* 1987). Kaviraj and Sharma (2003) produced good quality organic fertilizers by vermicomposting the organic part of municipal solid waste using epigeic *Eisenia foetida* within 42 days.

Application of vermicompost improved the tomato yield and its quality parameters such as carbohydrate content, soluble and insoluble solids concentration (Gutiérrez-Miceli *et al.,* 2007). Application of vermicompost increased tomato yield by 74 % and its vitamin C content by 47 % and soluble sugar content by 71 % (Wang *et al.,* 2017).

Different composting methods such as ordinary composting, vermicomposting and microbial composting etc., are some of the prominent techniques for proper disposal of bio-degradable waste to agricultural lands (Leno, 2017). Even though composting of biowaste is an apt option for waste management there are some disadvantages associated with different composting methods (Sikora, 1998; Kokhia, 2015). Besides the advantages, there are some constraints associated with the composting of biowaste such as microbial contamination, loss of nutrients, longer duration, emission of bad odour, presence of pathogen and heavy metals in the final product etc. (Sigmund *et al.,* 2018; Tan *et al.,* 2018; Ayilara *et al.,* 2020)

In vermicomposting, there are restrictions in the nature of bio waste that can be used for composting (Aalok *et al.,* 2008). Food waste with greater pungency and oily nature are not permitted in vermicomposting as they can cause the death of earth worms. Generally composting process is laborious, tedious, and time consuming. Usually it requires a large area for dumping the waste. There are chances for the leaching loss of nutrients during composting. Munroe (2007) reported some of constraints of vermicomposting technology such as laborious requires larger space, vulnerable to environmental stress and requires more start up resources. Das *et al.* (2020) reported the efficiency of composting inoculums in converting leaf litter waste to compost. But composting inoculums took nearly 50 days to convert organic waste into compost while vermicomposting took 45 days (Jacob, 2018; Ramesha, 2019).

One of the major disadvantages associated with composting is the emission of green houses gases and a foul odour (Andersen *et al.*, 2010). So there is a need of a waste management technology as a solution for all these problems and that should be affordable to common man.

Sudharmaidevi *et al.* (2015) introduced an innovative technology of instant conversion of biowaste into organic fertilizers using a machine named ‘Suchitha’ and it is patented (Patent No. 321857). Suchitha produces the organic fertilizer through the thermochemical decomposition of biowaste. This technology produces the organic fertilizer from biowaste within 12-18 hrs and there is no leaching loss of nutrients, emission of green houses gases or foul odour and is free of pathogenic organisms. Almost all types of biodegradable waste can be used in ‘Suchitha’ for the production of organic fertilizers.

Here in this chapter, the effect of different organic fertilizers such as FYM, ordinary compost, vermicompost, microbial compost and thermochemical organic fertilizer on soil organic carbon and nutrient dynamics, their retention and leaching loss from the soil are reviewed below. Long term effect of organic fertilizers on improving soil health, quality and productivity is also critically assessed through the literatures.

2.1 PRODUCTION AND CHARACTERISATION OF CONVENTIONAL AND NON-CONVENTIONAL ORGANIC FERTILIZERS

Organic fertilizers are substances which contain nutrients in bound form and releases slowly by the activity of microorganism. They are derived from animal matters and excreta (manures), human excreta (sludge) and vegetable matters (compost and crop residues) (Lim *et al.,* 2012).

Organic manures are applied as a source of macro and micronutrients and to supply organic carbon in the form of humic substances which help to improve the physical, chemical and biological properties of the soil (Abou El-Magd *et al.,* 2006).

Municipal solid waste generation in urban India is about 62 million tonnes in which only 20 per cent is recycled, 50 per cent dumped in landfill sites and 30 percent is left without any treatments, polluting the environment and water bodies. It is anticipated that the urban MSW of India will be about 165 million tonnes in 2030. The study revealed that 41 % of MSW generated in metro cities of India is biodegradable in nature (Kumar *et al.*, 2017).

The utilization of biowaste as organic fertilizer is a solution for the proper disposal of biodegradable waste and brings economic benefits by enhancing soil productivity. At the same time its improper dumping results in environmental pollution and serious health issues (Sim and Wu, 2010).

Composting is an ideal method for producing organic fertilizer from biowaste as it narrows down the C:N ratio, concentrates the nutrient content, stabilize the heavy metals, transform the phytotoxic biomolecules, kill pathogen microorganism and supress other potential contaminants that cause pollution (Zia *et al.,* 2003; Jimenez and Wang, 2006).

It is essential to check stability or maturity of the compost, before its application to the soil as an organic amendment. Stability of the compost indicates the amount of stabilised carbon compounds and maturity of compost ensures that it is free of phytotoxic compounds and pathogens. Usually phytotoxic compounds are produced by organisms in unstable compost (Chowdhury *et al.,* 2013).

Jacob (2018) studied the phytotoxicity of thermochemical organic fertilizer with (F-TOF) and without fortification (TOF) by conducting germination bioassay with seeds of cucumber, amaranthus and tomato. It was found that F-TOF had germination percentage > 80 and that of TOF >70 and germination index > 70 for F-TOF and 60 for TOF, in all the three crop seeds used for the study. Thus, proved that the thermochemical organic fertilizer free of phytotoxic compound and safe for crop production.

During composting the C:N ratio reduces to 15-20 range due to the evolution of CO_2 during decomposition and the CEC increases due to the production of carboxylic and phenolic functional groups. Humic acid (HA), humification index (HI) and ratio of humic to fulvic acid increased as compost matures, indicating the completion of humification of organic matter (Chowdhury *et al.,* 2013).

The parameters such as C:N ratio, cation exchange capacity, pH, electrical conductivity, mineral nitrogen, organic matter humification and temperature were used to assess the stability and maturity of compost (Cooperband *et al.,* 2003). For matured compost the humification ratio was found to be greater than or equal to 6 and humification index greater than 30 % (Raj and Antil, 2011).

The decrease of EC during composting was mainly due to the production of soluble metabolites such as ammonium (NH_4^+) and the precipitation of dissolved salts and thus EC of final product was within the safe limit of application *i.e.* 4 dS m^{-1} (Lim *et al.,* 2012).

Biodegradable waste can be either utilized as energy source or nutrient source. Several technologies are available to convert biowaste to organic fertilizer, which include conventional composting (aerobic and anaerobic), microbial composting using inoculums and effective microorganism, vermicomposting, biogas-slurry production etc. (Leno, 2017).

Tibu *et al.* (2019) reported that composting of municipal solid waste as a reliable strategy to reduce environmental pollution and to promote vegetable production in urban areas. They have composted market waste, sawdust, rice straw and swine manure in different combination. The pH of compost ranged from 7.12 to 8.20. The total organic carbon and total nitrogen values ranged from 27–31 and 0.77–0.97 per cent, respectively. The total phosphorus and total potassium concentration ranged from 0.2–1.87 and 0.39–2.3 %, respectively. The C:N ratio of the compost varied from 29:1 to 36:1 and the heavy metal content was below the permissible limit.

Rawat *et al.* (2013) conducted a case study on composting of municipal solid waste from three highly populated cities of India, such as Delhi, Ahmedabad and Bangalore. The composted samples were analysed for pH, EC, organic matter, total carbon, nitrogen phosphorus and heavy metal contents. The study revealed that municipal solid waste compost produced from metropolitan cities of India was suitable to be used as green compost. The C:N ratio ranged from 19-25 and metal concentration was within acceptable range as per—Municipal Solid Waste (Management and Handling) Rules, 2000 of India. Proper segregation of metallic components from MSW improves its quality.

Fadhel *et al.* (2016) produced organic manure from liquorice residues using activated effective microorganism and characterized for its pH, EC, C:N ratio and mineral contents. After the fermentation process mediated by microbes, the pH reached to 6.2, C:N ratio reduced to 6:1, EC and mineral elements contents increased. However, proper dilution of the composted liquorice was essential, as its EC was very high, nearly 32 dS m^{-1}.

During the composting, as temperature increases above 55 ^{0}C (thermophilic stage) pathogenic microorganisms in the organic waste gets killed and causes a faster stabilization of organic waste (Bernal *et al.,* 2009). Cruz *et al.* (2007) reported that the leachate collected as a by-product during composting market and house hold waste contained 100 mg kg^{-1} NO_3-N, 770 mg kg^{-1} NH_4-N and 60 mg kg^{-1} K, while the

P content was in trace. This indicates the leaching loss of nutrients during the aerobic composting of organic waste under open condition.

Clark and Cavigelli (2005) produced compost from food remains and horse bedding materials. In laboratory incubation study, it was found that organic fertilizer from food waste resulted in net N mineralization while net N immobilization with horse bedding materials was high due its salinity.

Tiquia *et al.* (2002) produced organic fertilizer by windrow composting of spent pig litters. The compost reached maturity by 56 days with stabilization of total carbon and water extractable metal and elimination of phytotoxic compounds. The NH_4-N content and C:N ratio decreased. The pH, EC, organic matter, nutrient and heavy metal contents were within the safe limit for application.

Bratovcic *et al.* (2018) compared organic fertilizer produced from food waste with goat manure and found that organic fertilizer contain 1.5 times P, equal N and 1.5 times lower K than goat manure.

When rice husk (RH) and straw (RS) were used as substrate for vermicomposting, RS supported healthier growth and reproduction of earthworms and resulted in higher recovery percentage than RH. The mixing of rice straw with cow dung in the ratio of 1:2 found to be the best combination for the production of organic fertilizers out of rice straw (Shak *et al.*, 2014).

Vermicompost produced from rice straw and cow dung contained high concentration of Ca (0.78 %), Mg (0.56 %), P (0.65 %) and K (2.54 %). Increase in the Ca content mainly attributed to the Ca metabolism in earthworm gut (Shak *et al.*, 2014).

Vermicompost is produced from biowaste by the action of red worms *Eisenia foetida* contain micro (Fe, Mn, Cu, Zn and Na) and macro (N, P, K, S, Ca and Mg) nutrients which are essential for the growth and production of crop plants (Theunissen *et al.,* 2010).

The pH of vermicompost was found to be more alkaline than the pH of substrate materials used. The change in the pH was mainly due to the mineralization of proteinaceous materials which result in the production of alkaline ammonia and loss of volatile acids (Li *et al.,* 2011). The rise in pH was also attributed to the degradation of short chain fatty acid and precipitation of $CaCO_3$ (Lim *et al.,* 2011). However, during vermicomposting, pH of final product was determined by the nature of substrate and intermediate compound produced during the composting process (Suthar, 2009).

The chemical characterisation of composted spent pig litters revealed its pH as acidic, EC as less than 4 dS m^{-1} and contains nutrient such as N (1.9 - 3.94 %), P (1.5 - 2.04 %), K (1.42 - 2.01 %) and ash content as 12.4 -14.9 % (Tiquia *et al.,* 2002).

Pressmud is a byproduct from sugar mill and distillery units. It is a rich source of macro and micronutrient and can be utilized as soil amendment for crop production. It contains 2.72 % N, 6.20 % P_2O_5 and 0.79 % K_2O (Mamaril *et al.*, 2000).

The nutrient content of FYM was decided by the nutrient composition of the feeds given to the cattle. Nearly, 70 to 80 % of the N, 60 to 85 % P and 80 to 90 % of K in the feed is excreted through the dung (Herbert, 1998) while for poultry manure is 1.1 to 1.5 % of the N, 0.8 to 1.3 % of the P and 0.5 to 2.7 % of the K in feed is excreted as dung (Gachene and Kimaru, 2003).

Antil and Singh (2007) reported chemical composition of poultry manure as 22.5 % organic C, 2.51 % N, 1.79 % P and 1.13 % K. Shah (2001) stated highest contents of P (1.74 %) in poultry manure and K (2.4 %) content in FYM

Savini *et al*. (2006) reported that addition of organic manure increased the phosphorus availability from rock phosphate. The organic manure on decomposition releases organic acid which decrease the soil pH and increase the chelation of Ca and Mg. thus increased the P availability from rock phosphate.

Preethu *et al.* (2007) produced organic fertilizer by composting the blend of organic waste such as coffee pulp, coffee husk and other additives like forest litter, weeds, coffee effluents, cow dung, rock phosphate, microbial inoculum etc. The characterisation of the final product revealed its pH as 7.41, total N -2.99 %, P- 2.45 %, K- 2.94 % and C:N ratio as 7.25. The micronutrient content was Cu- 14.2 mg kg^{-1}, Fe- 922.11 mg kg^{-1}, Mn- 269 mg kg^{-1} and Zn-14.2 mg kg^{-1}.

Irshad *et al*. (2013) compared the concentrations of total C, total N, extractable P, K, Na and B in fresh and composted manures. It was found that the total C, N, extractable K and Na decreased with composting while, EC, extractable P and B increased with composting.

Qureshi *et al.* (2014) produced rock phosphate enriched composts from farm yardmanure, poultry manure and pressmud using effective microorganism. After composting, there was a decrease in pH, EC and C:N ratio and a gradual increase in the macro and micronutrient contents.

Bouldin and Lawson (2000) reported an organic fertilizer production technology from uncomposted municipal solid waste by destroying the pathogen, removing contaminants and separating the degradable organic components. Busby *et al*. (2007) utilized the organic fertilizer produced by this technology to establish grass in damaged training lands at Georgia, USA.

Rapid organic fertilizer transforming technology is getting more popularized due to its advantages over the ordinary composting method. It includes less time consumption, less labour intensive, reduced emission of CO_2, complete eradication of pathogen and prevent foul odour by thermochemical processing of biowaste (Sudharmaidevi *et al.*, 2017).

Leno (2017) produced a customised organic fertilizer for banana by rapid thermochemical conversion of degradable solid waste and characterized its physical, chemical and biological properties. All the parameters of the customized organic fertilizers were within the safe limit as prescribed by FAI (2018).

Chemical characterization of thermochemical organic fertilizer revealed that it contains more lignin compared to other organic fertilizers, which provide more recalcitrance nature to it (Jacob, 2018).

The fortified thermochemical organic fertilizer contained N-3.27 %, P -0.81 %, K -2.88 %, Ca -1.69 %, Mg -0.25 %, S -42.70 mg kg^{-1}, Fe- 4392 mg kg^{-1}, Mn- 244.36 mg kg^{-1}, Zn- 219.76 mg kg^{-1}, Cu- 4.79 mg kg^{-1} and B -13.88 mg kg^{-1}. (Jacob, 2018).

During composting nearly 30 to 60 % C and 20 % to 50 % N from the raw materials are lost as CO_2 and NH_3, respectively. Chang *et al.* (2019) composted corn stalk by adding fresh cow dung. It was found out that by adding wood peat and biochar @ 10 % of the dry weight of the raw composting materials reduces NH_3 emission by 62.78% and CO_2 loss by 54.13%.

2.2 EFFECT OF ORGANIC FERTILIZERS ON PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF SOIL

2.2.1 Physical properties

Application of organic amendment improves the physical properties of soil like water holding capacity, bulk density and soil structure. It also increases the soil fertility by adding nutrients and makes the soil productive enhancing activities of beneficial microorganisms (Barker, 1997).

Sharma *et al.* (2000) reported that incorporation of crop residue and FYM caused an increase in organic matter content of the soil and improved the soil structure. Application of compost reduced significantly the bulk density of soil from 1.27 to 1.18 Mg m^{-3} when compared to chemical fertilizer alone.

Ranjan *et al.* (2004) reported that continuous application FYM @ 10 t ha^{-1} along with 100 % NPK fertilizer in a soyabean - wheat cropping system for a period of 29 years, had enhanced the oxidizable and non-oxidizable soil OC contents to 1.31 and 10.44 g C kg^{-1} in depth 0–15 cm and 1.87 and 8.44 g C kg^{-1} in depth15–30 cm, respectively. The bulk density of surface soil (0-30 cm) reduced to 1.24 Mg $m^{-3}$from 1.35 Mg m^{-3}. Available water holding capacity increased with treatments such as N + FYM with a net gain of 2.85 cm and treatment NPK+FYM with a net gain of 3.45 cm over the control treatment.

Thakur *et al.* (2010) reported that continuous application of FYM @ 15 t ha^{-1} along with 100 % NPK for period 36 year in a soyabean - wheat cropping system had increased the soil organic carbon content by 3.9 g kg^{-1}, and N, P and S by 126.8, 25.5 and 28.5 kg ha^{-1}, respectively over its initial values.

Kamal *et al.* (2012) conducted a study in sandy loam soil of a mango orchard. It was found that application of poultry manure @ 50 kg per tree along with recommended dose NPK fertilizers had improved the soil physical properties. The bulk density decreased from 1.66 to 1.45 Mg m^{-3}. Aggregate stability increased by 18.10 % and total porosity by 19.27 % than the control.

Hou *et al.* (2012) stated that combined application of FYM at different levels such as 7.5, 15, 22.5 t ha^{-1} along with chemical fertiliser in a continuous maize cropping system resulted in lower soil bulk density and significantly increased the >0.25-mm water-stable aggregate content compared to control and chemical fertilizer alone added plot. It was also found that with higher manure application rates, soil properties improved and crop yield increased.

On decomposition organic matters releases humic molecules and polysaccharides which cause the formation of stable aggregates and thus enhance soil porosity, aeration, and infiltration rate and reduce runoff. The organic molecules bound in the aggregate are physically protected from degradation caused by microorganisms (Tisdale and Oades, 1982).

Application of FYM @ 75 kg per olive tree increased the soil organic matter to 2.28 % while that of control was 0.96 %. The soil porosity increased to 52.5 % while for control it was 38.6 % (Kuzucu, 2019).

Application of compost and manure, continuously for five years had increased available water content (AWC) of soils by 86 and 56 %, respectively (Celik *et al.*, 2004).

Choudhari and Kumar (2013) also recorded an increase in the water holding capacity of soil due to the application cow dung manure (fresh) and FYM at rate of 10 t ha^{-1} compared to control without any organic manures addition.

2.2.2 Chemical properties

Srikanth *et al.* (2000) noticed a reduction in the pH of Alfisol due to application of FYM and vermicompost at the rate to supplement the 50 % of recommended dose of phosphorus to the crop. Similarly, Ghuman and Sur (2006) reported a decrease in the pH of loamy sand from 6.68 to 6.36 due to the application of FYM and the extent of decrease was positively correlated to amount of organic manure incorporated.

Brar *et al.* (2015) reported that the long experimentation of integrated nutrient management in wheat - maize cropping system for 36 years found out that cumulative infiltration, infiltration rate and aggregate MWD were greater with integrated use of FYM along with 100% NPK compared to control. There was no significant difference between the treatments for bulk density and EC. The SOC pool was lower most in control plot and while was highest with treatment 100 % NPK+FYM.

Long term integrated nutrient management in wheat-maize cropping system resulted in improved soil physical conditions such as increased soil porosity, aeration, water holding capacity etc., and increased SOC content, which resulted in higher maize and wheat yields (Brar *et al.,* 2015).

Continuous application of organic amendments (FYM @ 10 t ha^{-1} and straw incorporation) for 20 years enhanced the soil organic carbon by 49 % than the unfertilized control plot and 29 % 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).

Jacob (2018) revealed that thermochemical organic fertilizer produced from biodegradable waste with and without fortification had a higher EC of 0.657 and 0.610, dS m^{-1}, respectively and TOC content of 40 and 48 %, respectively than FYM and other organic fertilizers (aerobic compost, vermicompost, microbial compost) produced from similar type of biowaste.

Thermochemically produced organic fertilizer from biodegradable waste had slightly acidic to neutral pH. Fortified thermochemical organic fertilizer had a lower pH (6.38) than unfortified (6.98) and this may due to the nature of materials used for fortification (Jacob, 2018)

2.2.3. Biological properties

Continuous application of organic amendments such as FYM @ 10 t ha^{-1}, poultry manure 5 t ha^{-1} and sugarcane filter 7.5 t ha^{-1} alone or along with inorganic fertilizers in pearl millet-wheat cropping system for a period of seven years, enhances the soil organic carbon, microbial biomass and increase the total NPK content of the soil (Kaur *et al.* 2005).

Application of FYM @ 20 t ha^{-1} significantly increased the microbial biomass carbon, water soluble carbon and water soluble carbohydrates content of the soil, whereas maximum amount of soil microbial biomass nitrogen and dehydrogenase activity was found in 100% NPK + 10 t FYM ha^{-1} treatment and maximum soil microbial biomass phosphorus (SMB-P) was observed in 150% NPK treatment compared to sole use of chemical fertilizers (Verma and Mathur, 2009).

Nakhro and Dkhar (2010) conducted an experiment on upland paddy with and without organic fertilizer application. It was found that organic fertilizer application enhanced the microbial count and microbial biomass carbon to a depth of 0-30 cm of soil compared to sole inorganic fertilizer and control plots.

Application of organic manures alone or in combination with inorganic fertilizer significantly increased the microbial biomass C and N when compared to application of inorganic fertilizer alone (Kumari *et al.,* 2011).

Long term fertilization with organic and inorganic fertilizer increased the microbial biomass carbon up to a depth of 60 cm from surface. There was a depth wise decrease in microbial biomass carbon from the surface due to the depletion of labile carbon. The application inorganic fertilizer along with FYM showed the maximum increase followed by inorganic fertilizer + straw residue and FYM alone (Liu *et al.,* 2013).

Martin and Marinissen (1993) reported that application of vermicompost increased activity of dehydrogenase to 210 µg TPF hydrolysed 24 hr^{-1}. Continuous application of FYM either alone or along with inorganic fertilizers significantly increased dehydrogenase, phosphatase and urease activities in soil (Jagadeesh, 2000).

Rajeshwari (2005) observed highest dehydrogenase activity (16.40 µg TPF g^{-1} soil day^{-1}) in the treatment receiving 100 per cent recommended dose of nitrogen

(RDN) through FYM and the lowest dehydrogenase activity (12.18 µg TPF g^{-1} soil day^{-1}) in the treatment received 100 per cent RDN through chemical fertilizer alone.

Application of FYM @ 11.2 t ha^{-1} on N equivalent basis to maize crop increased biological dehydrogenase enzyme activity in the soil (116.8 µ g TPF g^{-1} soil 24 hr^{-1}) compared to application RDN through chemical fertilizers (83.2 µ g TPF g^{-1} soil 24 hr^{-1}) (Ramesh *et al.,* 2008).

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

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

Ramesha (2019) reported that in a field experiment with amaranthus the treatment received thermochemical organic fertilizer @ 16.5 t ha^{-1} recorded a 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}).

2.3 EFFECT OF ORGANIC FERTILIZERS ON CARBON AND NITROGEN DYNAMICS IN SOIL

Kwabiah *et al*. (2003) reported that the dynamics of different nutrients and the microbial activity in the soil are directly affected by the composition of different organic amendments added to the soil.

Roy and Kashem (2014) conducted an incubation study by adding organic manures such as cow dung, chicken manure and a combination of both at a rate of 10 t ha^{-1} for a period of 60 days. It was observed that pH of soil slightly increased upto 30 days and then declined. EC had exhibited an increase throughout the incubation period. Organic carbon content of manure treated soils reached its peak at 15 days of incubation and thereafter decreased with time. The content of NH_4-N increased significantly in organic manure added soil and maximum release was recorded in combination treatment of cow dung and chicken manure.

Maltas *et al.* (2018) studied the effects of organic amendments on carbon sequestration in a 37 year field experiment. It was found that SOC content tends to increase with 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 cause a noticeable increase in SOC content in the long term trial.

Sanger *et al.* (2010) studied the effects of different rainfall patterns on C and N dynamics in soil amended with biogas slurry (BS) and composted cattle manure (CM) @ 100 kg N ha^{-1}. Cumulative emissions of CO_2 and N_2O from soils amended with BS were 92.8 g CO_2-C m^{-2} and 162.4 mg N_2O-N m^{-2}, respectively, whereas emissions from soils amended with CM were 87.8 g CO_2-C m^{-2} and 38.9 mg N_2O-N m^{-2}. Cumulative NO_3 leaching was highest in the BS-amended soils (9.2 g NO_3 -N m^{-2}) followed by the CM-amended soil (6.1 g NO_3 -N m^{-2}) and lowest in the control (4.7 g NO_3 -N m^{-2}).

Li *et al.* (2018) revealed that continuous application of organic amendments for 33 years that combined along with mineral fertilizers has increased OC by 26 % and N by 23 % than sole mineral fertilizer application. It was due to the C and N storage in the recalcitrant mineral-associated and coarse mineral-associated fractions.

Nitrogen fertilization enhances SOC accumulation by increasing microbial activity and crop use efficiency (Manzoni *et al.,* 2010). Nitrogen fertilization can increase SOC by increasing crop residue input, and it can also decrease SOC by increasing mineralization. N fertilization, stabilizes SOC by lowering the C:N ratio of crop residue. Crop residue incorporation followed by N- fertilization increases the quality of coarse particulate organic matter and shift the aggregate dynamics, allowing SOC to a more stable form, such as fine intra aggregate particulate organic matter (Brown, 2013).

As the decomposition of organic matter proceeds, the amount of labile carbon increases and when it exceeds a certain limit, it will be converted to stable pools like mineral-associated or occluded within microaggregates and thus prevent from mineralization (Gale *et al.,* 2000). Soils have a limited capacity to store soil organic C called as C - saturation (Stewart *et al.,* 2007) and after that no more stable SOC pools are formed from labile fractions (McLaren and Peterson, 1965; Burchill *et al.,* 1981).

Long term application of N-fertilizers for 10 years @ 134 kg ha yr^{-1} along with organic manure @ 5 t ha^{-1} under continuous winter wheat cropping system enhanced the total N and SOC content of soil (Aula *et al.,* 2016).

The increase in SOC with increased N rates may be attributed to increased C sequestered in plant biomass which returned to the soil as crop residue (Dolan *et al.,* 2006). Zhang *et al.*, (2009) reported sole application of mineral fertilizers without organic manure did not increase the soil organic carbon content.

SOC concentration and its storage to depth of 60 cm increased during long term fertilization with FYM @ 7.5 t ha^{-1} and inorganic fertilizers N: P @ 90: 30 kg ha^{-1}. It caused an increase in SOC concentration at profile depth 0-60 cm by 41.3 %, 32.9 %, 28.1 % and 17.9 %, 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 upto 60 cm depth.

The concentration of particulate organic carbon, dissolved organic carbon and microbial biomass carbon upto 60 cm depth increased 64.9 to 91.9 %, 42.5–56.9 %, and 74.7–99.4 % respectively, compared to the control treatment (Liu *et al.*, 2013).

Balanced application of mineral fertilizers along with organic fertilizers increases the SOC and it can enhance and maintain sustainable soil productivity (Purakayastha *et al.,* 2008).

Labile soil organic carbon pools like dissolved organic carbon, microbial biomass carbon and particulate organic matter carbon can directly influence the microbial activity and nutrient transformations in the soil. The labile fractions of carbon in the soil can be increased by the application of organic manure and by proper management of crop and soil (Xu *et al.,* 2011).

Nayak *et al.* (2012) reported that application of inorganic fertilizers alone and along with organic manures increased the total organic carbon content in the soil upto a profile depth of 60 cm at the Indian sub-Himalayas. In a 19 years puddle rice-wheat system, NPK @ 100:60:60 kg ha^{-1}+ FYM @ 5 t ha^{-1} treated plots there was an increase in labile carbon by 14 % upto 60 cm depth compared to the control plot (Majumder *et al.,* 2008)

In long term fertilization trial conducted under greenhouse condition revealed that cultivation without addition of organic manure caused a decline in SOC pools due to the decomposition of stable recalcitrant form of organic carbon. While addition of organic manure did not cause any increment in SOC pool, but prevented its decline. By changing the type of organic manure from low C:N ratio to higher C:N ratio manure, it was found to be more effective in stabilizing the SOC pool due to their recalcitrance nature. N-fertilizer optimization in accordance with the crop plants did not show any influence in the SOC content or total N in the soil, but reduced the apparent N-loss through fertilization (Ren *et al.*, 2014).

The long-term application of organic manures such as rice straw biochar and compost with C:N ratio greater than pig manure, enhanced SOC pool of soil by reducing carbon mineralization rate due to their recalcitrance nature (Liu *et al*., 2012).

Higher crop production in response to mineral N fertilizer application resulted in greater root exudates and more crop residues, thereby enhancing SOC sequestration in agricultural soils (Swanston *et al*., 2004). Also, the application of N fertilizer stabilized the organic matter and retarded the mineralization (Hagedorn *et al*., 2003). N-fertilization also attributed to the decline in SOC by increasing the decomposition rate of fresh organic residues (Fonte *et al*., 2009).

Nitrogen turnover in the soil is greatly influenced by soil organic carbon (SOC) content. As SOC increases, mineralization rate of N decreased and reduced its losses (Schimel, 1986).

Organic manures with C:N ratio more than 15, decreased availability of nitrogen for a very short term and thus have a negative correlation between C:N ratio of organic manure and N-mineralization (Qian and Schoenau, 2002).

Application of inorganic fertilizers has a direct impact on the decomposition of organic matter. Application of nitrogen fertilizers increased the mineralization of recalcitrant organic N and mineralization rate of SOM was 2.7 times more (0.67 μg N g^{-1} day^{-1}) than the control treatment. The application of organic fertilizers enhanced the mineralization of labile organic N (Zhanga *et al*., 2012).

Han *et al*. (2004) studied the effects of combined application of urea and compost on the urea-N transformation and net mineralization of compost-N in three soils with different contents of organic-C and inorganic-N. The study revealed that addition of urea along with compost caused increased N immobilization and decreased nitrification of urea-derived N in soils with high organic-C and inorganic-

N contents. At the same time, the reverse pattern was observed in the soils with relatively low organic-C and low nutrient contents. The blending of urea with compost caused a net mineralization of compost-N irrespective of the soil characteristics. Thus, the study inferred that addition of inorganic N fertilizer along with compost increase N-use efficiency of compost by increasing the N mineralization from compost. At the same time, it would increase nitrification of fertilizer-N in soils with low nutrients contents, thus resulting in increased NO_3 leaching.

N mineralization rate was highly correlated to C:N ratio of organic materials and material with high C:N ratio caused a nutrient imbalance in the soil for a short term due to immobilization. But such materials were required for improving the SOM content of the soil. So along with inorganic fertilizers organic materials of different C:N ratio (high and low) can be combined to improve soil fertility (Morvan *et al.,* 2005).

Application of organic materials of wide C:N ratio like wood shavings and rice straw mixed along with cattle manure did not hinder plant growth, but maintain soil organic carbon pools and nutrient status of soil (Mariaselvam *et al.,* 2014).

Jacob (2018) studied the rhizosphere priming effects of different organic fertilizers such as aerobic compost, vermicompost, microbial compost, unfortified and fortified thermochemical organic fertilizers. It was found that application of microbial compost and fortified thermochemical organic fertilizers had enhanced nutrients availability and improved physical and chemical properties of soil than other organic fertilizers. But the positive rhizosphere priming effect observed with C and N dynamics was almost similar for all the organic fertilizers irrespective of its method of preparation.

2.4 EFFECT OF ORGANIC FERTILIZER ON NUTRIENT RETENTION IN SOIL

There is a complex interaction between the organic amendments and chemical fertilizers added to the soil. Addition of organic manure interacts positively with applied nutrients and thus reduces its loss and enhances the fertilizer use efficiency. It improves the charge characteristics of the soil by maintaining an optimum soil pH and provides a good soil structure and aggregate stability. It activates the short-term microorganism mediated immobilization of nutrients and thus lowers their loss through leaching, nitrification and denitrification. Application of compost, biochar, crop residue and FYM found to have a potential to reduces nutrient loss from inorganic fertilizers applied to the soil (Vanlauwe *et al.,* 2011)

Application of inorganic fertilizer along with organic fertilizer caused an increase in the nitrate content in surface layer and reduced the leaching loss of nitrate to lower layers under tomato cultivation (Xiao-yu *et al*., 2012)

The leaching loss of nutrients especially N from the organic manure amended soil can be reduced by considering the manure characteristics. Application of cattle and pig slurry to the sandy soil caused very high leaching loss of N from the soil. While application FYM caused comparatively less N loss due to its lower proportion of available N (Beckwith *et al*., 1998). Due to the improper fertilization, leaching of N is more from organic fertilizers and inorganic fertilizers (Duynisveld *et al.,* 1988).

A soil column study conducted in a 15 cm column by mixing the soil with fresh and composted broiler litter on their N equivalent basis. These columns were leached at weekly interval with 500 mL distilled water. Leachate analysis revealed that nitrate, phosphorous and dissolved organic carbon content in leachate from composted broiler litter was 30%, 40 % and 53 % respectively less than from fresh broiler litter. Thus, showed that composting of organic residue stabilizes the nutrients and cause their slow release and thus reducing the leaching losses (Adeli *et al.,* 2017).

Kostyanovsky *et al.* (2011) conducted a mine reclamation study using biosolids and found out that P leaching from the reclaimed soil was negligible compared to the quantity of P added to the soil.

The composting process accelerates microbial transformation of labile organic compounds into more stable, humus-like molecules that are less susceptible to immediate mineralization and leaching. Also, the humus substances formed have more CEC which improves its nutrient retention capacity (Preusch *et al.,* 2002). Composting is an ideal approach to stabilize soil nutrients and reduce potential loss of nutrients from manure (Dere *et al.,* 2012).

A leaching study conducted with maize- alfalfa rotation after adding dairy manure, composted dairy manure and inorganic N respectively at N equivalent basis. It was found that there was leaching loss of NO_3-N at the rate of 55, 30 and 25 kg ha^{-1} from raw dairy manure, composted dairy manure and inorganic N added soil, respectively (Basso and Ritchie, 2005).

Brauer *et al.* (2005) reported that application of soil amendments such as lime and gypsum reduced leaching loss of P from soil by stabilising soil aggregates from dispersion and formation of insoluble Ca phosphate in the soil. Application of Ca compounds stabilizes soil aggregates and increases the infiltration rate in the soil which promotes the leaching loss of NO_3-N (Adeli *et al.,* 2017).

Singh and Taneja (1977) reported that application of gypsum stimulated microorganisms responsible for N mineralization and causes release of NH_4–N and NO_3–N at a higher rate.

Le and Marschner (2018) reported that addition of cow manure to soil did not cause high leaching of N even though its C:N ratio was low. Incorporation of FYM along with wheat straw reduced N leaching but increased P leaching as addition of wheat straw increased the P mineralization rate of FYM.

Application of organic materials with high C:N ratio along with organic materials of a low C:N ratio reduced the N-mineralization rate and thus reduced the leaching loss of N (Vityakon *et al.*, 2000)

Dissolved organic N (DON) losses from agricultural lands accounted for 26 % of the total soluble N. DON losses across agricultural systems varied widely with minimum losses of 0.3 kg DON $ha^{-1}yr^{-1}$ in a pasture to a maximum loss of 127 kg DON $ha^{-1}yr^{-1}$ in a grassland (Kessel *et al.*, 2009).

Drainage water collected from agricultural lands at 150 cm depth contained total N of 21.03 mg l^{-1}, of which 20.40 mg l^{-1} was in NO_3 form, 0.08 mg l^{-1} as NH_4 and 0.55 mg l^{-1}as organic N. The dissolved organic matter had a C:N ratio of 3.1 and this ratio was shown to increase with increasing depth of drainage water collection (Murphy *et al.,* 2000).

Loss of nitrogen in the form of organic N is comparatively very low as nitrate is the predominant form in the agricultural lands. The organic N added to soil as organic amendment was converted to nitrate form with a short span under aerobic condition. While in the undisturbed forest soil, loss of N as of dissolved organic nitrogen has greater significance in N-cycle (Kessel *et al.*, 2009).

Dissolved organic N is composed of hydrophobic and hydrophilic compounds, in which hydrophilic part form the dominant (78%) portion (Moller *et al.,* 2005).

Jones *et al.* (2004) reported that dissolved organic nitrogen (DON) was composed of two pool such as low molecular weight (LMW) and high molecular weight (HMW) pools. LWM pool mainly composed of free amino acids and proteins and has a high turn-over rate. It acts as an active substrate for ammonification and nitrification. While, HMW pool is rich in humic substances, has a slower turn-over rate, and is the predominant source of DON in groundwater and streams.

Average loss of N as nitrate from agricultural land was nearly 60.0 kg N ha^{-1} $yr^{-1}$and that of dissolved organic N was comparatively very less (Barton *et al.,* 2006).

DON leaching losses from agricultural fields can be a significant component of total N losses. Therefore, it should be considered in the total N budgeting. When biogeochemical models are updated to predict N losses, it was suggested to take account of DON loss component (Korsaeth *et al.,* 2003).

Decrease in the DON concentration as it moves through the soil profile is through the uptake of DON by plants (Streeter *et al*., 2000).

Concentration of DOC and DON in the leachate collected from lower depths (>1.5 m) were low. This was due to the dilution from other sources of water and by utilization of these organic components by microorganism. High denitrification potential has detected in subsoil. Denitrification decreases the DOC and DON concentration in soil solution (Van Groenigen *et al.,* 2005).

Total DON leaching losses increased from a maximum of 4.7 kg N $ha^{-1}yr^{-1}$ under fallow to 9.2 kg N $ha^{-1}yr^{-1}$ when cropped with ryegrass (*Lolium* spp.) and maize (Siemens and Kaupenjohann, 2002).

Application of organic manure to agricultural land causes increased DON leaching losses (Murphy *et al.,* 2000).

The microbial biomass is highly prone to seasonal fluctuations and contributes to the release of labile organic N through the cell lysis (Lipson and Nasholm, 2001).

Dissolved organic N is used as a substrate by soil microbes. As DON is composed of different labile and more stable fractions which are utilized by the microorganisms as it moves through the soil profile (Lajtha *et al.,* 2005).

DON leaching losses were highly correlated to soil texture. Light textured soils such as sandy and sandy loam soil were more prone to DON leaching than clayey soils (Kessel *et al.*, 2009).

Application of urine to pastures and high rates of organic and inorganic N to turf grass caused significant loss of DON. It was found that the average loss of DON is nearly 1/3 rd losses of nitrate-N. In United States, the DON content in the leachate of agricultural land exceeded permissible level of drinking water and thus posse a potential health hazard (Kessel *et al.*, 2009).

Cultivation of maize crop in a continuous paddy-rice cropping system causes an initial increase of drainage and leaching losses of N and DOC. It was due to the decomposition of soil organic matter that accumulated during long-term paddy-rice cultivation (He *et al.,* 2017).

Li *et al.* (1997) conducted a leaching study in soil column amended with different composts such as sugarcane filter cake, biosolids, and mixtures of municipal solid wastes and biosolids at rate of 100 Mg ha^{-1} in sandy soil and leached with 300 ml of distilled water for five days. The concentration of NO_3-N, NH_4-N and PO_4-P in the leachate was 246, 29 and 7 mg L^{-1}. Through leaching 3.3-15.8 % of total N and 0.2-2.8 % total P were removed from different compost.

Jing *et al.* (2017) reported that addition of organic manure along with mineral fertilizers enhanced soil productivity and reduced leaching loss of nitrogen, but there was higher loss N as NH_3 volatilization. Therefore, suitable application method like deeper placement and incorporation strategy should be adopted in N fertilization management of upland red soil.

2.5 EFFECT OF ORGANIC FERTILIZERS ON DYNAMICS OF NUTRIENTS IN THE SOIL

During the mineralization process, soil micro-organisms convert organic N to inorganic forms (NO_3-N and NH_4-N). The microbial population increases under the sufficient supply of C source from the organic amendments and immobilization of mineralized N takes place by synthesis of proteins by micro-organisms (Brady 1990). Immobilization of mineralized N was observed when the C:N ratio of applied amendments was more than 20 (Sims, 1990). However, application of matured organic manure within the C:N ratio of 20 can increase the microbial biomass and cause a net N-mineralization in the soil (Madejon *et al*., 2001).

Sims (1995) reported that mineralization of nitrogen from organic manure depends on manure characteristics, soil properties and environmental factors. The high clay content of soil physically protects the organic matter and reduces their decomposition rate (Stenger *et al.,* 1995). Decomposition of water-soluble carbon such as sugar and aminoacid molecules in the organic waste occur at a faster rate and it was followed by protein molecules. Cellulose and lignin degrade very slowly only (Smith *et al.,* 1992).

Under optimum moisture and aerated condition, mineralization occurs at a faster rate. The optimum temperature for N-mineralization was found to be 30-35 ºC. Some factors such as water stress, poor aeration and low and very high temperature hinders microbial activities and decrease N-mineralization rate (Stott *et al*., 1990).

In soils amended with organic materials there was an increase in the NO_3-N content and a decline NH_4-N content of the soil as their decomposition proceeds. It was due the nitrification of NH_4-N mineralized from organic compounds (He *et al.,* 2000).

A study on the N- mineralization of different organic amendments such as municipal solid waste compost, non-composted paper mill sludge and agroforest compost was carried out in sandy soil. The composts prepared from agroforest waste materials and municipal waste had exhibited a short period of N- immobilization followed by a continuous mineralization. While, the non-composted industrial paper sludge waste had exhibited a long N-immobilization due to its high C:N ratio. (Burgos *et al.,* 2006)

Application of undecomposed or unstabilized organic material with very high C:N ratio can cause immobilization of nutrients by microorganisms and thus make nutrients available for crop plants (Busby *et al*., 2007).

Before the application of organic substrate to crop plants as a nutrient source, its reliability can be confirmed by conducting C evolution and N mineralization tests. Microbial respiration along with NH_4-N and NO_3-N concentration in the organic fertilizer confirms its maturity and check chances of nutrient immobilization or phytotoxicity (Busby *et al*., 2007).

The organic P from the organic manure or compost is less susceptible for soil adsorption. So, the chances of leaching loss of P from organic fertilizer amended soil are more (Eghball, 2003). But leaching loss of inorganic P through percolating water is very less due to the adsorption of P on to soil particles and their precipitation with soil minerals (Yoo *et al.,* 2006). Leaching loss of P from the soil was influenced by the type of soil. Andisols which exhibit a high P-sorption capacity prevent the leaching loss of organic P from added organic fertilizers (Kim *et al.,* 2011).

Organic manures or compost can either increase or decrease the P adsorption of a soil depending on their nature and complexity of the organic molecule present in it (Singh and Jones, 1976). Application of organic materials caused a net mineralization of P from the soil (Mariaselvam *et al.,* 2014).

Bihari *et al.* (2018) conducted an incubation study for 120 days to study the nutrient release pattern from FYM and pressmud compost. It was found that NH_4-N decreased and NO_3-N increased during the incubation period. Available P and K increased from 0 to 30 DAI and then decreased gradually up to 120 DAI. Application of FYM increased available K and P by 122% and 86 %, respectively and that of pressmud by 282 % and 101% respectively, than control.

Kumar *et al.* (2015) reported that application of organic amendments can increase the P availability in the soil. It acts as a source of P and also causes the release of phosphate anion by substituting the soil site with organic anions. Also, the organic compounds mask the P-adsorption site of sesquioxide present in the soil and thus reduce the P-fixation capacity of soil.

Singh and Patel (2016) reported the mineralization of P from organic manures during first few weeks after the application which was followed by an immobilization in the subsequent weeks.

Lal *et al.* (2000) reported that as soil incubated with FYM and aerobic compost, the availability of K increased due to the mineralization of organically bound K and the K released from the native soil K pools which were caused by the organic acid released during the decomposition of organic manure.

The low NH_4-N concentration and increased NO_3-N concentration during incubation of soil organic manure mixture indicate that nitrification of NH_4-N proceeds at a faster rate than mineralization of organic nitrogen to NH_4-N. (Kolahchi and Jalali, 2012).

Datt *et al.* (2003) recommended that incorporation of FYM @ 10 t ha^{-1} along with chemical fertilizers recorded increased the availability N, P and K compared to the application of chemical fertilizer alone.

Jacob (2018) reported that soil application of thermochemical organic fertilizer @ 20 t ha^{-1} maintained a higher TOC content in the soil compared to the other organic fertilizers due their higher C:N ratio and recalcitrance nature. The N-mineralization rate was found to increase gradually and peak mineralization was observed at 30 days after application.

2.6 EFFECT OF ORGANIC FERTILIZERS ON CROP GROWTH AND PRODUCTIVITY

Tolanur and Badanur (2003) reported an increase in soil organic carbon and a higher grain yield in pearl millet (1767 kg ha^{-1}) - pigeonpea (801 kg ha^{-1}) cropping system, when 50 % of N was supplement with organic manure (FYM or green manure like subabul) and the remaining 50 % through chemical fertilizers.

Kamal *et al.* (2012) evaluated effect of poultry manure on the yield and quality of mango. They found out an increase in mango yield (53 %) and quality over the control due to the addition of organic materials.

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 (compost @ 10 t ha^{-1} + vermicompost 12 t ha^{-1} and 1/3rd RDF resulted in higher yield of 21.7 % over control than the solo organic manure application (7.1 % over control). Integrated nutrient management system sustains soil fertility and productivity.

Abera *et al.* (2018) suggested an integrated use of conventional compost and vermicompost based on N equivalency with recommended dose of NP fertilizer for the sustainable production of barley in Chelia district of Ethiopia.

Application of green waste compost @ 62.5 t ha^{-1} and 125 t ha^{-1} along with inorganic fertilizers to the crop lands for a period one year significantly increased the SOC content of peri urban soil and enhanced vegetable production (Eldridge *et al.,* 2018).

Choudhary *et al.* (2008) reported that application of FYM @ 5 t ha^{-1} along with *Rhizobium* and PSB recorded higher N and P uptake in chickpea. Similarly, Subbarayappa *et al.* (2009) noticed higher total uptake of N, P and K when 100 % RDF supplemented along with FYM in chickpea.

Choudhary *et al.* (2008) reported that plant growth parameters and dry matter accumulation in chick pea was higher due to application of FYM @ 2.5 t ha^{-1} along with 50 % RDF and it was on par with vermicompost application @ 3 t ha^{-1} along with *Rhizobium* plus PSB.

Similarly, application of FYM @ 10 t ha^{-1} along with N @ 20 kg ha^{-1} and 15 kg $ZnSO_4$ ha^{-1} increased seed yield in black gram (Sharma and Abraham, 2010).

Crude protein content in black gram seed increased from 14.7 to 18.7 per cent due to the application of FYM @ 2.5 t ha^{-1} along with 75% RDF (Vasanthi and Subramanian, 2004).

Chivenge *et al.* (2011) through meta-analysis had shown that the yield can be increased up to 60 % by the application of organic amendment and upto 114 % by the combined application of organic amendments and nitrogen fertilizers.

Leno and Sudharmaidevi (2017) studied the suitability of rapidly produced organic fertilizer by the thermo-chemical decomposition method as substitute for FYM under banana cultivation. It was found that rapid organic fertilizer was able to provide a better buffering action to the soil and an optimum supply of essential nutrient at the active growing stage of the crop plant and resulted in higher yield in banana.

Jacob (2018) studied the phytotoxicity of thermochemical organic fertilizer with (F-TOF) and without fortification (TOF) by conducting germination bioassay with seeds of cucumber, amaranthus and tomato. It was found that F-TOF had germination percentage > 80 and that of TOF >70 and germination index > 70 for F-TOF and 60 for TOF, in all the three crop seeds used for the study. Thus proved that the thermochemical organic fertilizer free of phytotoxic compound and safe for crop production.

Leno and Sudharmaidevi (2018) found out that application of rapid organic fertilizer fortified with soil test-based micronutrients, enhanced total dry matter production in banana and it was par bunch yield obtained with the application of FYM.

Vanilarasu and Balakrishnamurthy (2014) reported that organic fertilizer enhances the microbial population in rhizosphere and result in better uptake and utilisation of nutrients.

Continuous application of organic fertilizer improved soil quality parameters such as soil organic carbon content, bulk density etc., and maintained a good N, P and K status in the soil. On cultivation of vegetable crops such as pechay, lettuce, tomato and brinjal in the soil, resulted in higher yield (Cruz *et al.*, 2007).

Adediran *et al.* (2003) reported that productivity of amaranthus found to increase by application compost. The most effective was the compost from soybean, followed by leaf litter, weed, maize and urban waste composts in the order. But for tomato composts from maize and soybean residues were more effective than other composts

Vijaya Sankar *et al.* (2007) reported that application organic manures such as, FYM, pressmud and poultry manure resulted in higher cane yield in sugarcane, while application of pressmud followed by poultry manure caused higher sugar yield.

Continuous cropping and integrated use of organic and inorganic fertilizers increased soil C sequestration and crop yields. Balanced application of NPK fertilizers with FYM was best option for higher crop yields in maize–wheat rotation (Brar *et al.,* 2015).

Application of enriched vermicompost with rock phosphate resulted in increased plant height, number of branches, nodules number and yield in cowpea. It also improved the available NPK status of the soil (Sailajakumari, 1999).

Bhalerao *et al.* (2009) observed that combined application of 100% recommended dose of NPK along with organic manures increased the pseudostem height and girth, minimize the days for flowering and total crop duration and increased yield attributes in banana. Similar results were reported by Hazarika and Ansari (2010).

The application of fortified manure based on thermochemical digest of waste to the crop showed a significant increase in fruit yield of chilli, tomato and brinjal (Sudharmaidevi *et al.,* 2015).

The plants which received the fortified manure produced from degradable waste by rapid conversion technology exhibited significant difference in crop biometric characters and vine length of melon over the poultry manure and FYM applied plant (Leno *et al.,* 2016).

Jayakrishna (2017) proved that the custom blended thermochemical digest of biodegradable waste had manorial value and can be used as organic fertilizer in crop production. In a trial conducted with polybag grown chilli, it was found that thermochemical digest (25 g per plant) blended with coco peat and soil at the ratio 1:2:1 used as potting mixture and with full dose of recommended NPK, resulted in highest yield in chilli.

Ramesha (2019) reported that application of thermochemical organic fertilizer @ 25 t ha^{-1} facilitated efficient root phenomic characters in amaranthus coupled with proliferation of rhizospheric microorganisms, which favoured enhanced mineralisation of soil available nutrients and root nutrient acquisition compared to other organic fertilizers such microbial compost, aerobic compost, vermicompost, poultry manure and FYM. It also stated that thermochemical organic fertilizer as an effective and efficient substitute for conventional organic manures and its fortification with nutrients helped for realising higher productivity and profitability in crop plants.

2.7 EFFECT OF ORGANIC FERTILIZER ON NUTRIENT UPTAKE

The available N and Ca increased by 38.2 % and 24.4 %, respectively, with the application of FYM, while application poultry manure increased the availability of P, K and Mg by 122.2 %, 23.6 % and 47.4 %, respectively (Vijay Sankar *et al.*, 2007).

The concentration of Mg, Fe, K, Ca, and Mn of the edible part of vegetables *Solanum lycopersicum* and *Lactuca sativa* were greater when grown in organic farms compared with conventional farms (Hattab *et al.,* 2019)

The uptake of P and K in rice was found to be greater with application of chicken manure than compost while, uptake of N, Ca, and Mg was found greater with compost (Steiner *et al.,* 2007).

Leno and Sudharmaidevi (2018) reported that application of rapid organic fertilizer produced by thermochemical decomposition of biowaste enhanced nutrient uptake in banana and resulted in good pseudostem growth and higher bunch yield.

Higher uptake of N and P was recorded in seed and stover of green gram due to the application of vermicompost either alone or in combination with chemical fertilizers (Rajkhowa *et al.* 2003). Similarly, higher uptake of N, P and K in grain and haulm of chickpea was reported due to integrated application of vermicompost and chemical fertilizers at rate each to supply 50 per cent level of recommended nutrients (Tolanur, 2009).

Application of 75 % recommended chemical fertilizer (75:100:50 N, P and K kg ha^{-1}) along with biofertilizer like *Azospirillum*, phosphobacteria, potash mobilizer (1 litre $acre^{-1}$) + VAM (5 kg $acre^{-1}$) along with humic acid (3 litre $acre^{-1}$) as soil application recorded higher yield and capsaicin content in chilli compared to control which received 100 % recommended dose NPK fertilizer and resulted in yield of 22 t ha^{-1} and capsaicin content 0.42 % (Janaki *et al.,* 2019).

Gao *et al.,* (2020) combined application of the biofertilizer mixture (*Azotobacter chrocoocum,* AMF, and *Bacillus circulans*) through seed treatment followed by the field application of biogas slurry @ 500 litre per ha and 50 % recommended dose of NPK resulted in higher growth, yield and nutrient uptake in maize plants. The bio-organic fertilization also improved the quality parameters of maize seeds such as soluble sugars, starch, carbohydrates, protein, and amino acid contents etc. it had also increased the microbial enzymatic activity (acid phosphatase and dehydrogenase enzymes), bacterial count, and mycorrhizal colonization levels in maize rhizosphere as compared with the chemical fertilization.

2.8 EFFECT OF ORGANIC FERTILIZERS ON SOIL HEALTH AND SUSTAINING PRODUCTIVITY

Li *et al*. (2018) conducted a long-term organic fertilization experiment in winter wheat to check its yield and sustainable production. Along with the NPK fertilizers the pig manure, straw residues and combination of pig manure and straw residue were given as different treatments in which the average yield increased by 9.9, 13.2 and 17.4 %, respectively for each treatment than control after the nine years of continuous trail. In the control treatment, average yield reduced by 6.5 %. The study revealed that long term application of chemical fertilizers along the organic manures stabilize crop yield and make the production sustainable by improving the properties of the soil.

Chen *et al.* (2014) reported that continuous cultivation of cropland with the application of excessive amounts of chemical fertilizers can lead to nutrient imbalance and a degradation of soil quality and health.

Harris (2003) indexed soil microbial biomass carbon, soil microbial biomass nitrogen, microbial quotient, and soil enzyme activity and soil respiration as indicators to asses' soil quality and health.

Ma *et al.* (2010) found out that application of organic fertilizers can significantly increased microbial biomass carbon and enzyme activity in the soil.

Long-term organic fertilization with pig manure @ 7500 kg ha^{-1}enhances the soil fertility and sustains soil productivity by improving soil organic carbon content and microbial activity. There was an increase in soil microbial biomass carbon and nitrogen content in the soil which was positively correlated to the yield and productivity winter wheat (Chun-xi *et al.*, 2018).

Application of organic manures to crop plants have many benefits such as balanced supply and availability of nutrients, enhanced soil microbial activity which promote plant growth, degradation of toxic substances and chemicals, improved soil structure and root development (Han *et al.,* 2016).

Chand *et al.* (2006) have reported that combined application of chemical fertilizer and livestock organic manure increased the average growth of mint (*Mentha arvensis*) and mustard (*Brassica juncea*) by 46% and increased uptake of N, P and K by 36 %, 129 %, and 65 %, respectively.

There is need on continuous application of organic manure in tropical soil as they are poor in organic matter to improve its SOC and NPK content (Kaur *et al.,* 2005). Jacob (2018) reported a positive rhizospheric priming effect on total organic carbon content of soil applied with fortified thermochemical organic fertilizer at 15 days after the application and for unfortified the highest priming effect was observed 60 days after application to the soil.

Kahu *et al*. (2019) reported that application of poultry manure @ 10 t ha^{-1} resulted in higher leaf area and shoot yield in amaranthus than control treatment and the treatment received compound NPK fertilizer @ 70 kg ha^{-1}.

Cruz *et al.* (2007) produced organic fertilizer by composting house hold and market waste using buffalo, chicken or goat manure as microbial activators and carbonized rice hull as stabilizer. The organic fertilizer produced had a pH around 7.4 and the chemical composition was 2.0 % N, 2.60 % P, 1.75 % K and 196 mg kg^{-1} Zn. Heavy metal content was below detectable limit.

Application of organic fertilizer is the main source of trace metals to the soil and can also become a potential source of environmental pollution. Presence of heavy metal limits the use of organic fertilizers in the soil (Ding *et al.,* 2017). Application of organic manures and sewage sludges to agricultural land can cause heavy metal contamination in the soil (Mortvedt, 1996). Municipal solid waste from different sources mostly contains heavy metal and contaminates the soil with its application (Hamdi *et al.,* 2003). So it is important to understand the status and extent of soil contamination of trace metals from organic fertilizers to develop sustainable management strategies for agricultural soils (Gong *et al*., 2019). At the same time potential of organic fertilizers in bioremediation of heavy metal contaminated soil was reported by Park *et al.* (2011) and Hu *et al.* (2021).

2.9 ORGANIC FERTILIZERS AND ECONOMIC BENEFITS

Application of FYM along with 100 % RDF resulted in a higher B:C ratio of 2.2 in cowpea (Subbarayappa *et al.,* 2009). Similarly, application of vermicompost @

1 t ha^{-1} along with 30 % RDF resulted in a higher a BC ratio 1.73 in green gram (Sutaria *et al.,* 2010).

Kumar *et al.* (2013) conducted an integrated nutrient management study in okra and reported that the treatment received 75 kg N +40 kg P_2O5 + 40 kg K_2O + 5 tones VC + 20 kg $ZnSO_4$ ha^{-1} recorded the highest net return of Rs. 25677and B:C ratio of 1.29.

Application of 75% RDF along with 40 % *Wellgro* organic manures (blend of neem and non-timber forest produce) recorded highest yield and gross income from banana with the highest B:C ratio 2.63 (Kuttimani, *et al.,* 2013).

Ghosh *et al.* (2014) cultivated rice cv Nerica 10 under integrated nutrient management system, applying RDF and cow dung @ 5 t ha^{-1}. There obtained a B:C ratio of 10.69 during the cultivation

Basnet and Shakya (2016) conducted a study to check suitability different organic manure to get optimum yield from cauliflower. In the trail B:C ratio was obtained highest with vermicompost (4.31) and lowest with FYM (1.8).

INM increased the fruit yield of tomato up to 33.94 % and 38.51 % during rabi and kharif season with a B:C ratio of 4.39 and 4.29, respectively. It also reduced the yield loss due to incidence of pest and diseases by improving the plant health and fruit quality. Thus in INM expenses on inputs such as chemical fertilizers and pesticides were reduced (Singh *et al.,* 2016).

Sudharmaidevi *et al.* (2017) reported production of organic fertilizer from biowaste through thermo-chemical process. It was stated that through the production and sale a net profit of US $229 per month (US $0.101 per kg waste) is generated from the pilot plant taken for trial study.

Nargave and Mandloi (2018) showed that in the integrated nutrient management of maize, application of recommended dose of NPK (150:75:40 kg ha^{-1}) + FYM @ 10 t ha^{-1} recorded higher grain yield (65.8 q ha^{-1}) with gross returns of Rs. 44,378 per hectare and B:C ratio of 2.62. The integrated nutrient management of maize, application of 100% RDF + vermicompost at 5 t ha^{-1} recorded higher gross returns net return Rs. 56840 per ha with a B:C ratio of 2.84 (Maruthupandi and Jayanthi, 2018).

Kumar *et al.* (2019) reported that application of 100 per cent RDF+ Vermicompost @ 6 t ha^{-1} + S @ 45 kg ha^{-1} to garlic produced the highest net returns of Rs. 185629.90 with B:C of 1.80 over all other treatments.

Ramesha (2019) reported a B:C ratio of 1.75 in amaranthus cultivation with thermochemical organic fertilizer which was on par with application of poultry manure. These two was followed by TOF which had given a B:C ratio of 1.62, which was superior to the application of microbial compost, vermicompost, FYM and conventional compost.

Mondal *et al*. (2019) reported that cultivation of red amaranthus with NPK + cowdung @ 8 t ha^{-1} was more economic with a marginal rate of returns 11.45 %, while, application NPK + poultry manure @ 8 t ha^{-1} resulted in higher yield but the marginal rate of returns was 7.75 % only.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A study entitled “Effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics and crop productivity in Ultisols” was conducted from April 2018 to January 2020 at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. The objective was to study the effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics, their retention and leaching, and crop productivity in comparison with other organic fertilizers in Ultisols with tomato-amaranthus cropping sequence. The methodologies followed for the study are detailed in this chapter.

The study was carried out in three parts:

Part 1- Production and characterization of organic fertilizers

Part 2- Leaching study in soil columns and incubation study

Part 3- Field experiment

3.1 PRODUCTION OF ORGANIC FERTILIZERS

Ordinary compost, vermicompost, microbial compost, unfortified thermochemical organic fertilizer and fortified thermochemical organic fertilizer were prepared from biodegradable waste which includes vegetable waste from market, food waste from college hostels and agricultural waste from Instructional Farm, Vellayani.

Ordinary compost (OC) was prepared by mixing the biowaste with fresh cow dung and piling it on a flat hard surface (Plate 1a). The mixture was turned over at weekly intervals for better aeration and faster and complete decomposition. It was ready for use within 65 days. Vermicompost (VC) was prepared by introducing earth worms (*Eudrillus eugineae*) into the biowaste-cow dung mixture after a decomposition period of 25 days (Plate 1b). Vermicompost was ready to use within 45 days after composting. For microbial compost (MC) preparation, composting inoculum was purchased from the Department of Agricultural Microbiology, College of Agriculture, Vellayani. The bio-waste - cowdung mixture was supplemented with microbial composting inoculum @ 5 g per kg of waste for faster decomposition and turned over at weekly intervals for better aeration. The MC was ready to use within 50 days (Plate1c).

Thermochemical organic fertilizer was produced as per patented KAU rapid thermochemical processing technology developed by Sudharmaidevi *et al.,* (2017). Fresh biodegradable waste was ground to uniform consistency in the grinder unit of KAU Suchitha waste processing machine (Plate 1d) and boiled at 100°C in the reactor unit after adding the reagent 1 *viz*., very dilute hydrochloric acid @ 50 ml kg^{-1} waste for 30 minutes followed by addition of reagent 2 *viz.*, dilute potassium hydroxide @ 100 ml kg^{-1} waste for 30 min under ambient pressure. Processing was completed within one hour and TOF was produced. Coir pith @ 40 g kg^{-1} waste and charcoal powder @ 30 g kg^{-1} waste were added and sun dried or electrically dried to reduce the moisture content. Under sun drying, it had taken two days drying under intense sunlight to reduce the moisture content within permissible limits. The dried product was fortified with mineral nutrients to produce fortified thermochemical organic fertilizer (F-TOF) which is being marketed in the trade name of "Suchitha". One kilogram of F-TOF contained 80 g FYM, 20 g groundnut cake, 15 g Rajphos, 5 g MOP, 10 g lime, 7.5 g $MgSO_4$, 50 mg $ZnSO_4$ and 5 mg borax. Thermochemical organic fertilizer without fortification (TOF) was also used in the study though it was not marketed. It was used only for research purpose.

3.2 CHARACTERIZATION OF ORGANIC FERTILIZERS

The prepared organic fertilizers and FYM were characterized for their physical, chemical and biological properties as per the standard analytical method.

Plate 1a: Ordinary composting

Plate 1b: Vermicomposting

Plate 1c: Microbial composting

Plate 1d: Suchitha- Rapid waste converter

Plate 1: PRODUCTION OF ORGANIC FERTILIZERS

The Fertilizing index and clean index of the composts were computed using the formula described by (Saha *et al*., 2010)

1. Fertilizing index $$\mathrm{FI} = \frac{\sum_{j=i}^{n} \mathrm{Sj} * \mathrm{Wj}}{\sum_{j=1}^{n} \mathrm{Wj}}$$

Sj is score value of analytical data and Wj is weighing factor of the jth fertility parameters are presented in table mentioned in Appendix I A.

2. Clean index $$\mathrm{CI} = \frac{\sum_{j=i}^{n} \mathrm{Sj} * \mathrm{Wj}}{\sum_{j=1}^{n} \mathrm{Wj}}$$

The clean index was calculated using heavy metal concentrations (Zn, Cu, Cd, Pb, Ni, Cr). Score values were given to each analytical value of the heavy metals as per table mentioned in Appendix I B

3.3 LEACHING STUDY WITH SOIL COLUMNS

3.3.1 Setting up of the soil columns

A leaching study was conducted in the laboratory, using soil columns amended with organic fertilizers to determine the leaching loss and to account the mobility of nutrients within the soil column. Poly vinyl tubes of 100 cm length and 11 cm diameter fitted with perforated caps at the bottom lined with filter paper were filled with 2 mm sieved red loam soil in such a manner to attain the same bulk density as that of field. Each soil column contained 11 kg of air-dried soil. The soil columns were mounted on a stand (Plate 2)

3.3.2 Treatments

The organic fertilizers were added as per treatments to the surface soil of the columns and mixed thoroughly within the top 15 cm of soil. The soil columns were maintained at field capacity. The experiment details are furnished below

Design: CRD
Replication: 4
Treatments: 7
T_1- Control (soil without manure)
T_2- Soil + 50 g FYM
T_3- Soil + 50 g Ordinary compost (OC)
T_4- Soil + 50 g Vermicompost (VC)
T_5- Soil + 50 g Microbial compost (MC)
T_6- Soil + 50 g Unfortified TOF (TOF)
T_7- Soil + 50 g Fortified TOF (F-TOF)

3.3.3 Leaching and sampling

Soil columns maintained at field capacity were leached with double the pore volume of water (Bundy and Meisinger, 1994) at 1st (1W), 4th (4W), 8th (8W), 12th (12 W), 16th (16 W), 20th (20 W) and 24th week (24 W) after the application of the specified treatments. From the leachate collected, 500 ml was kept for chemical analysis.

After the completion of leaching at 24th week, the columns were cut into vertical sections of 0-15, 15-30, 30-60 and 60-90 cm and soil samples from corresponding depths were drawn and dried. These soil samples and initial soil samples (before leaching) were subjected to chemical analysis as per the standard analytical procedures (Table 3).

Plate 2: LEACHING STUDY

Plate 3: INCUBATION STUDY

3.3.4 Statistical analysis

The data generated from the leaching study were analyzed statistically by applying the analysis of variance technique for Completely Randomized Design and Randomized Block Design (Cochran and Cox, 1965). The F values for treatments were compared with the table values. The level of significance used in ‘F’ test was P = 0.05. Critical difference values were calculated between various treatments wherever the ‘F’ test was found significant. The treatment means were compared by Duncan’s multiple range test (DMRT).

3.4 INCUBATION STUDY

3.4.1 Setting up of the incubation experiment

An incubation study was carried out to investigate the pattern of nutrient release from organic fertilizers added to the red loam soil (Plate 3). Two kg air dried 2 mm sieved soil was taken in 3 kg containers. Treatments were applied and the soil was incubated for 24 weeks at field capacity

3.4.2 Sampling

Soil samples were drawn at 1W, 4 W, 8 W, 12 W 16 W, 20 W and 24 W of incubation and subjected to chemical analysis as per the standard analytical procedures.

3.4.3 Treatments

Design: CRD
Replication: 4
Treatments: 7

T_1- Control (soil without manure)
T_2- Soil + 50 g FYM
T_3- Soil + 50 g Ordinary compost (OC)
T_4- Soil + 50 g Vermicompost (VC)
T_5- Soil + 50 g Microbial compost (MC)
T_6- Soil + 50 g Unfortified TOF (TOF)
T_7- Soil + 50 g Fortified TOF (F-TOF)

3.3.4 Statistical analysis

The data generated from the incubation study were analyzed statistically by applying the analysis of variance technique for Completely Randomized Design and Randomized Block Design (Cochran and Cox, 1965). The F values for treatments were compared with the table values. The level of significance used in 'F' test was P = 0.05. Critical difference values were calculated between various treatments wherever the 'F' test was found significant. The treatment means were compared by Duncan's multiple range test (DMRT).

3.5 FIELD EXPERIMENTS

3.5.1 Location

Field experiments were carried out at the Instructional Farm, College of Agriculture, Vellayani from November 2018 up to November 2019. The experimental site was situated at $8^{\circ} 25' 46''$ North latitude and $76^{\circ} 59' 24''$ East longitude, at an altitude of 29 m above MSL.

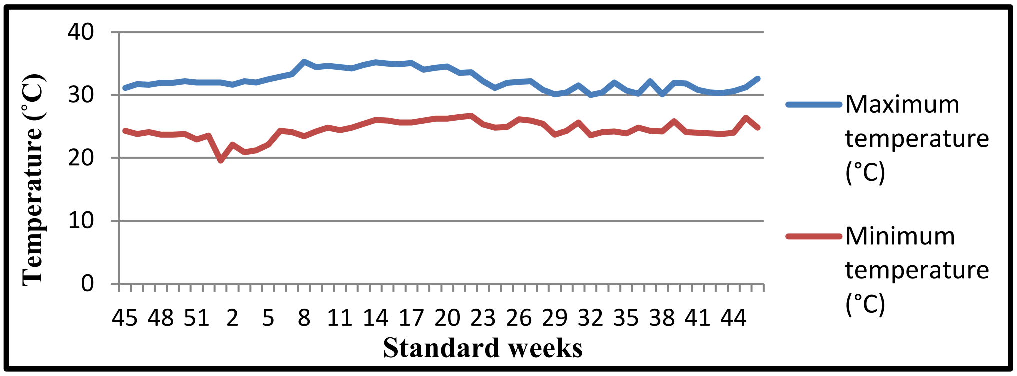


Fig 1a: Temperature

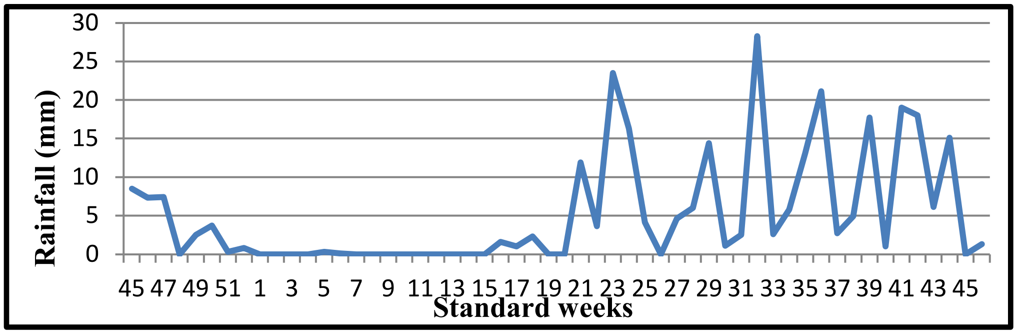


Fig 1b: Rainfall

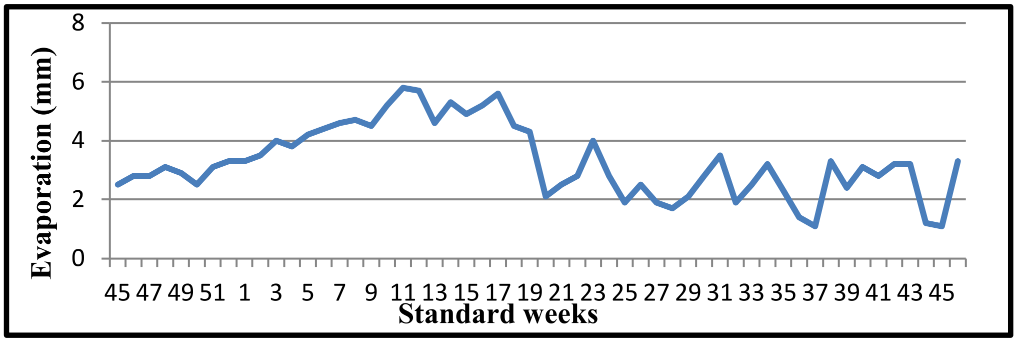


Fig 1c: Evaporation

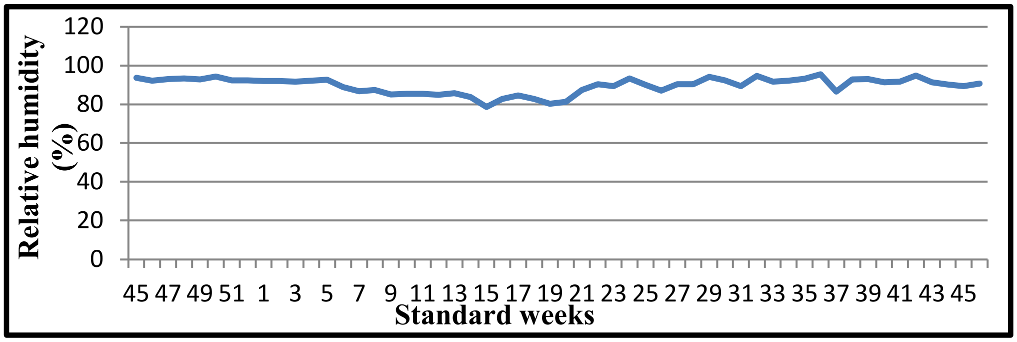


Fig 1d: Relative humidity

Fig 1: Weather parameters during the field experiments (from November 2018 to November 2019)

3.5.2 Weather parameters

The weather parameters during the cropping period were collected from the Department of Agricultural Meteorology, College of Agriculture, Vellayani and are presented below (Fig. 1 and Table 1).

Table 1: Weather parameters during the cropping period (from November 2018 to November 2019)

Crop No.	Mean air temperature (° C)		Mean relative humidity (%)	Total rainfall (mm)
	Minimum	Maximum		
Tomato I	24.81	32.17	83.80	30.90
Amaranthus I	24.15	31.22	86.44	105.2
Tomato II	24.15	30.86	89.83	585.5
Amaranthus II	24.36	32.19	87.13	135.3

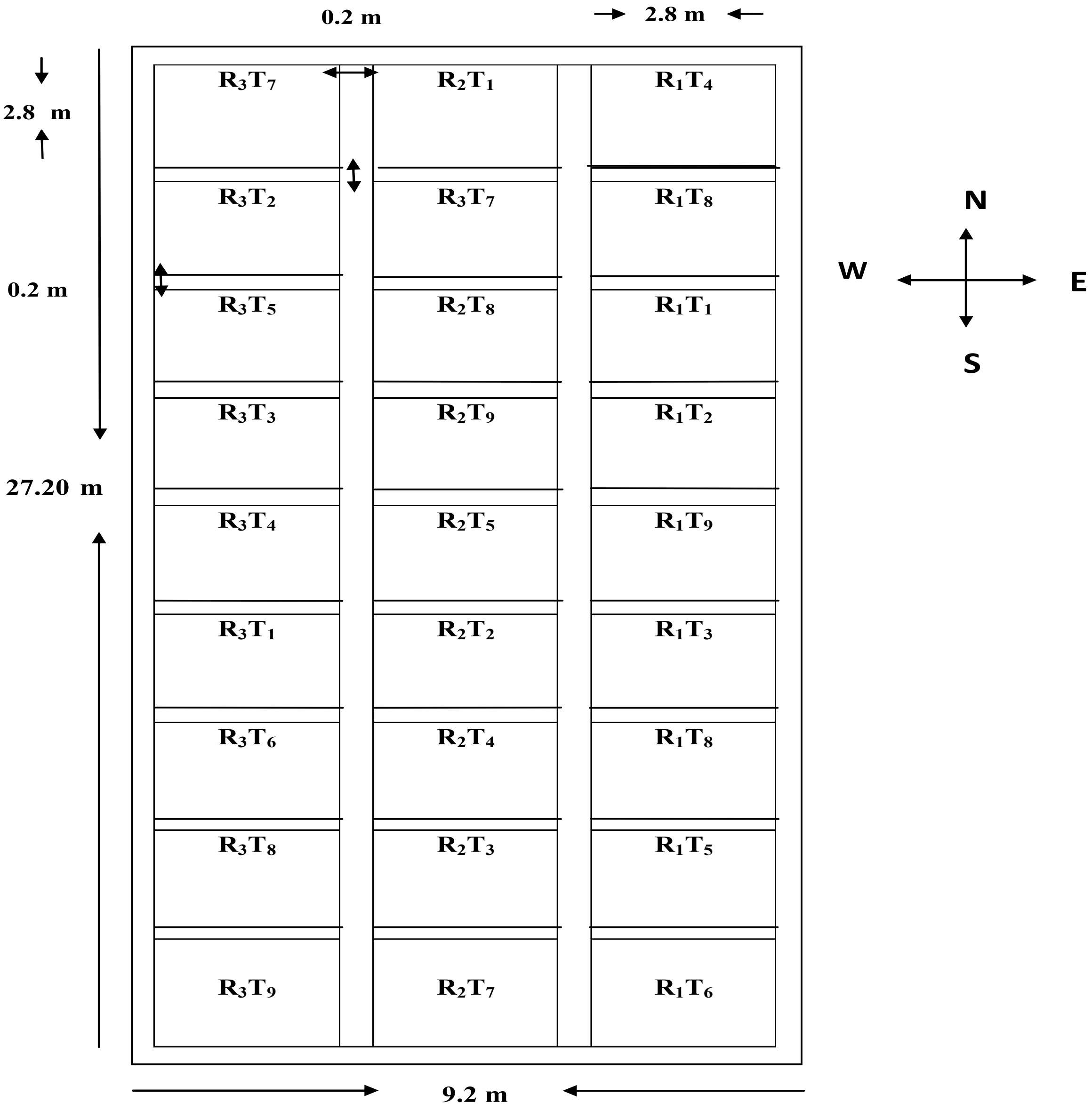
3.5.3 Soil

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

3.5.4 Layout

Field experiments were carried out with tomato-amaranthus cropping sequence for two seasons (Plate 5). The field experiment was laid out as shown in Fig.2.

Cropping sequence: I	: November 2018 to April 2019
Tomato	: November 2018 to January 2019
Amaranthus	: February 2019 to April 2019
Cropping sequence: II	: June 2019 to November 2019
Tomato	: June 2019- August 2019
Amaranthus	: September 2019-November 2019



R_3T_7	R_2T_1	R_1T_4
R_3T_2	R_3T_7	R_1T_8
R_3T_5	R_2T_8	R_1T_1
R_3T_3	R_2T_9	R_1T_2
R_3T_4	R_2T_5	R_1T_9
R_3T_1	R_2T_2	R_1T_3
R_3T_6	R_2T_4	R_1T_8
R_3T_8	R_2T_3	R_1T_5
R_3T_9	R_2T_7	R_1T_6

Fig. 2: Layout of field experiment

3.5.4.1 Design and treatments

Design	: RBD
Replication	: 3
Treatments	: 9
Plot size	: 2.4 m x 2.4 m
Crop Varieties	:

Tomato variety	: Vellayani Vijay
Amaranthus variety	: Arun

Treatments

T_1	FYM + NPK as per *POP
T_2	FYM +Soil test-based recommendation (STBR)
T_3	Ordinary compost + STBR
T_4	Vermicompost + STBR
T_5	Microbial compost + STBR
T_6	Unfortified TOF + STBR
T_7	Fortified TOF + STBR
T_8	Fortified TOF alone
T_9	Absolute control

(***POP** recommendation**:** Tomato- 75:40:25 N: P_2O_5: K_2O + FYM @ 20 t ha^{-1}
Amaranthus- 100: 50: 50 N: P_2O_5: K_2O + FYM @ 25 t ha^{-1} FYM)

For each crop, organic fertilizers will be applied as per POP recommendation (KAU, 2016) in terms of nitrogen equivalence of FYM @ 20 t ha^{-1} for tomato and 25 t ha^{-1} for amaranthus.

Plate 4a: Layout of field experiment

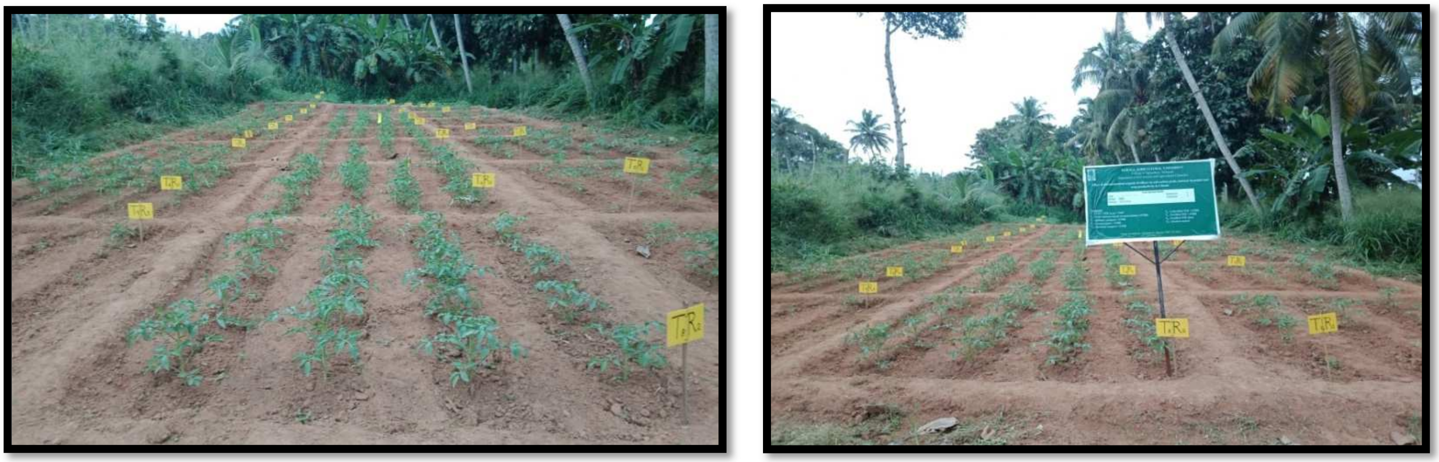


Plate 4b: Tomato crop of first and second cropping sequences

Plate 4c: Amaranthus crop of first and second cropping sequences

Plate 4: FIELD EXPERIMENT

3.5.5 TOMATO

3.5.5.1 Raising of seedlings

Tomato seeds were sown in protrays filled with mixture of coir pith and vermicompost in the ratio 2:1. They were kept in netted insect proof tray stands and irrigated at two days intervals. On 12 days after sowing (DAS), *Pseudomonas* was drenched at 2 % concentration. The seedlings of 21 days old were transplanted to the main field.

3.5.5.2 Land preparation and transplanting

The field was prepared to fine tilth by ploughing, harrowing, clod crushing and levelling. The plots of size 2.4 m × 2.4 m were taken as per the experimental design and layout. Lime was incorporated @ 500 kg ha^{-1}. Channels were taken in North-South direction at 60 cm apart and organic fertilizers were added after two weeks of lime application. The organic fertilizers were applied as per the POP recommendation for tomato (KAU, 2016) in terms of nitrogen equivalence of FYM @ 20 t ha^{-1} and incorporated into the channels. Later the channels were drenched with 2 % copper oxy chloride for disinfection. One week after the application of organic fertilizers, tomato seedlings were planted in the channels at 60 cm apart. The crop was irrigated at two days interval and basal dose of chemical fertilizers were applied one week after transplanting.

3.5.5.3 Fertilizer application

Fertilizer recommendation for tomato was 75: 40: 25 kg ha^{-1} NPK (KAU, 2016). Half dose of N, full dose of P and half dose of K were given as basal dose. The 1/4th dose of N and half dose of K were applied at 30 days after planting and the remaining 1/4th dose of N was applied two months after planting. The fertilizers used were urea, factamphos and muriate of potash. For treatments except T_1, T_8 and T_9, fertilizers were applied as per soil test-based recommendations (KAU, 2016).

3.5.5.4 Irrigation

Plants were irrigated daily during the summer season and as and when needed during the rainy season.

3.5.5.5 Plant protection

The soil was drenched with 2 % copper oxychloride after the application of organic fertilizers to disinfect the soil. Fusarium wilt of tomato was observed which was managed by the application of 2 % concentrated Saaf @ 250 ml per plant at 20 DAT. White fly was managed by keeping yellow sticky trap (1 @ six plots) and by spraying of Actara (Dimethoate) @ 0.3 g per litre. Attack of fruit borer was managed by the application of Fame @ 2 ml per 10 litres at the time of fruiting.

3.5.5.6 Weeding

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

3.5.5.7 Staking

Wooden stakes of fine thickness were placed near the plants and they were tied using threads. Plants grown on stakes were checked daily and were tied as they grow.

3.5.5.8 Harvesting

At each harvest, tomatoes harvested from the observational plants were labelled separately (treatment and replication wise) to calculate the average tomato yield from each plot. Tomatoes other than from the observation plants were harvested randomly as and when they got ripened. After the final harvest, observational plants were pulled out and dried to record the dry matter content. The plant samples were oven dried at 70 ºC and powdered for chemical analysis. Shoot, root and fruits were dried and powdered separately. Fresh samples of tomato fruits were stored under refrigerated condition for analysis of their quality parameters (Table 6).

3.5.5.9 Collection of soil samples

Before and after the crop, soil samples were collected from the treatment plots at two depth *viz.,* 0-15 cm and 15-30 cm for estimation of carbon stock. The surface soil (0-15 cm depth) was subjected for detailed chemical analysis as per the standard procedures (Table 4). The sub-surface soil (15-30 cm) was analyzed only for determining the carbon stock in the soil.

3.5.5.10 Estimation of soil organic carbon stock

Soil organic carbon stock was calculated by the equation given by Batjes (1996) and expressed in Mg ha^{-1}.

SOC stock = soil organic carbon (%) x bulk density (Mg m^{-3}) x soil depth (m) x 100

3.5.5.11 Growth parameters

For the precision in the observation of growth and yield attributes, border plants were avoided and four central plants were tagged as observation plants.

3.5.5.11.1 Height of plant

Height of plants was measured from base of the plant to the terminal leaf bud at final harvest and expressed in centimeters (cm).

3.5.5.11.2 No. of primary branches per plant

The branches formed from the main stem of the crop were counted from the four tagged plants. The mean was worked out and expressed as number.

3.5.5.11.3 Dry matter production

Four observation plants tagged were taken for estimation of dry matter production. They were shade dried initially and then dried in hot air oven at 70°C until a constant weight was attained. Shoots, roots and fruits of samples plants were dried separately to determine individual dry matter production (DMP) and expressed in g plant^{-1}.

3.5.5.12 Yield attributes

3.5.5.12.1 Days to first flowering

Number of days to reach first flowering from the date of sowing was noted.

3.5.5.12.2 Days to 50 % flowering

Number of days taken by the plants in each plot to reach 50 % flowering was noted.

3.5.5.12.3 Number of fruits per plant

Number of fruits harvested from observational plants was counted and the average was worked out.

3.5.5.12.4 Fruit yield per plant

Weight of fruits from observational plants was recorded and the mean was worked out and expressed in grams.

3.5.5.12.5 Fruit yield

Fruit yield per plant was computed by adding the weight of fruits of each harvest of the observational plants and the mean values were worked out and expressed in t ha^{-1}.

3.5.5.13 Nutrient concentration and total nutrient uptake

Nutrient concentration in the shoot, root and fruit of the tomato plants were estimated with the standard analytical procedures (Table 5). The nutrients estimated were N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B. Heavy metals Cd and Pb were also tested.

Nutrient uptake was calculated based on the average nutrient concentration in the plant parts and their dry matter content. Nutrient uptake by shoot, root and fruit were calculated separately and added together to get the total uptake of nutrients. The uptake values were expressed in kg ha^{-1} for macronutrients and in g ha^{-1} for micronutrients.

3.5.6 AMARANTHUS

3.5.6.1 Raising of seedlings

The land was ploughed two times to attain a fine tilth and then mixed with FYM. Raised beds were taken and seeds were broadcasted in these beds after moistening. The shade was provided with coconut fronds for about 3 days. After three days, seeds were germinated and fronds were removed.

3.5.6.2 Land preparation and transplanting

After the harvest of tomato crop, the same plots were used for raising amaranthus since the experiment was planned in tomato-amaranthus cropping sequence. The treatments applied to the plots were same as that of tomato, but the dosage was based on the POP recommendation for amaranthus. The existing channels were ploughed; deepened and organic fertilizers were incorporated as per the treatments. One week after the incorporation of organic fertilizers, amaranthus seedlings of 15 DAS were transplanted in to the main field.

3.5.6.3 Fertilizer application

The fertilizer recommendation for amaranthus is 100: 50: 50 NPK kg ha^{-1}. Five days after transplanting, half dose of N and K and full dose P were given as basal. The remaining half dose of N and K were given at 20 days after transplanting (DAT). For treatments except T_1, T_8 and T_9 fertilizers were applied as per soil test-based recommendations. The fertilizers used were urea, factamphos and muriate of potash.

3.5.6.4 Irrigation

Plants were irrigated as and when needed.

3.5.6.5 Plant protection

Bavistin was sprayed @ 20 g per 10 litres for managing the incidence of leaf spot in the amaranthus nursery (10 DAS) as well as in field (10 DAT). Leaf webber was managed by the application of Fame @ 2 ml per 10 litres at the nursery stage (12 DAS) and in the field (15 DAT).

3.5.6.6 Weeding

Hand weeding was done as and when needed for the proper growth of amaranthus and to avoid weed competition.

3.5.6.7 Harvest

Amaranthus was harvested at 30 DAT. Five observational plants from the centre of the plot were uprooted and taken as the samples to record biometric observations and for chemical analysis. Shoots and roots were separated and oven dried at 70 ºC and powdered separately for chemical analysis. Fresh samples of amaranthus shoot were stored under refrigerated condition for analysis of quality parameters (Table 6).

3.5.6.8 Collection of soil samples

Before and after the crop, soil samples were collected from the treatment plots at two depths *viz*., 0-15 cm and 15-30 cm for estimation of carbon stock as mentioned in the section 3.5.5.10. The surface soil (0-15 cm depth) was subjected to detailed chemical analysis as per the standard procedures mentioned in Table 4 to investigate the effect of application of organic fertilizers in the physical, chemical and biological properties of soil. But sub-surface soil was analyzed only for determining the carbon stock in the soil.

3.5.6.9 Growth parameters and shoot yield in Amaranthus

For the precision in the observation of growth and yield attributes, border plants were avoided and five plants tagged at the centre of the plot were taken as observational plants.

3.5.6.9.1 Plant height

Plant height was recorded from each observational plant by measuring the length of main stem from ground level to the top leaf bud of plants. Mean length was measured and expressed in centimeters.

3.5.6.9.2 Number of branches

The total branches of each observational plant were counted and average was worked out.

3.5.6.9.3 Dry matter production

The fresh samples of shoots and roots were initially shade dried and then oven dried at 70 °C till it attained a constant dry weight and was expressed in g plant^{-1}.

3.5.6.9.4 Shoot yield

Yield from the observational plants were recorded and average yield from the plots were calculated. It was expressed as t ha^{-1}.

3.5.6.10 Nutrient concentration and total nutrient uptake

Nutrient concentration of the shoot and root was estimated by standard analytical procedures as given in the Table 5. The nutrients estimated were N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B. Heavy metals Cd and Pb were also tested.

Total nutrient uptake in amaranthus plant was calculated based on the average 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. The uptake values were expressed in kg ha^{-1} for macronutrients and g ha^{-1} for micronutrients.

3.6 ECONOMICS OF CULTIVATION

Economics of cultivation was worked out for the field experiments after considering the cost of cultivation and prevailing market price of tomato and amaranthus. The B:C ratio was calculated as follows for each crop separately.

B:C ratio = Gross income / Total expenditure

3.7 DERIVED INDICES

1. Agronomic use efficiency (AUE) =

$$\frac{\text{Yield from fertilized plot in kg ha}^{-1} - \text{Yield from unfertilized plot in kg ha}^{-1}}{\text{Nutrient applied (kg ha}^{-1})}$$

2. Percentage of nutrient mineralized from organic fertilizer = $\frac{OF_i - C_i}{TN} \times 100$

OF_i = Available nutrient from organic fertilizer amended soil at i^{th} day (mg kg^{-1})

C_i = Available nutrient from control (unamended soil) at i^{th} day (mg kg^{-1})

TN = Total quantity of nutrient added to per kg of soil through organic fertilizer (mg)

3. Tomato equivalent yield of amaranthus (t ha^{-1}) =

$$\frac{\text{Yield of amaranthus (t ha}^{-1}) \times \text{Price of amaranthus}}{\text{Price of tomato}}$$

4. Production efficiency ($kg\ ha^{-1}\ day^{-1}$) $= \frac{\text{Total tomato equivalent yield (kg ha}^{-1})}{360}$

5. Equivalent energy ($MJ\ ha^{-1}$) =

$$\text{Economic yield (kg ha}^{-1}) \times \text{energy equivalent (MJ kg}^{-1})$$

3.8 STATISTICAL ANALYSIS

The data generated from the field experiment were analyzed statistically by applying the analysis of variance technique for Completely Randomized Design and Randomized Block Design (Cochran and Cox, 1965). The F values for treatments were compared with the table values. The level of significance used in 'F' test was $P = 0.05$. Critical difference values were calculated between various treatments wherever the 'F' test was found significant. The treatment means were compared by Duncan's multiple range test (DMRT). The correlation between crop growth and yield with soil properties as well as nutrient uptake by crop plants and soil properties were also determined.

Table 2: Standard analytical methods followed for organic fertilizer analysis

Parameter	Method	Reference
Physical		
Colour	Munsell chart	Munsell (1905)
Odour	Sensory perception	FAI (2018)
Moisture	Gravimetric method	FAI (2018)
Bulk density	Tap volume	Saha *et al.* (2010)
Chemical		
pH (1:5)	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	FAI (2018)
EC (1:5)	Conductometry EC-TDS Analyzer (CM 183, Elico India)	FAI (2018)
Total organic carbon (TOC)	Weight loss on ignition CHNS Analyzer (Vario EI cube, Elementar, Germany)	FAI (2018)
Water soluble organic carbon	Extraction with water and 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)
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 Van Soest (1970)
Lignin	Extraction with neutral and acid detergent solution followed by gravimetry	
Total P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdo yellow colour method (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Greenberg *et al.* (1992)
Total K	Nitric-perchloric (9:4) acid digestion and flame photometry (Digital Flame Photometer 130, Systronics, India)	FAI (2018)

Total Ca, Mg	Nitric-perchloric (9:4) acid digestion and versanate titration method	FAI (2018)
Total S	Nitric-perchloric (9:4) acid digestion and spectrophotometry using turbidity method	FAI (2018)
Total Fe, Cu, Mn, Zn	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrometry (A Analyst 400, Perkin Elmer Inc., USA)	FAI (2018)
Total B	Nitric-perchloric (9:4) acid digestion and spectrophotometry - azomethine-H method (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Roig *et al.* (1996)
Total Pb, Cd	Nitric-perchloric (9:4) acid digestion and emission spectroscopy (ICP OES Optima 8000, Perkin Elmer Inc., USA)	Wei and Yang (2010)
Biological		
Microbial count (Bacteria, fungi, actinomycetes),	Serial dilution method	Goldman and Green (2008)
Dehydrogenase activity	Colorimetric determination of 2,3,5-triphenyl formazan (TPF)	Casida *et al.* (1964)

Table 3: Standard analytical methods followed for leachates analysis

Parameter	Method	Reference
Chemical analysis of leachates		
pH	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	Singh *et al.* (2005)
EC	Conductometry EC-TDS Analyzer (CM 183, Elico India)	Singh *et al.* (2005)
DOC	Modified Walkley and Black titration method	Jones and Willet (2006)
NH_3-N	Macro kjeldahl distillation and titrimetry	Hesse (1971)
NO_3-N	Macro kjeldahl distillation and titrimetry	Hesse (1971)
Organic N	Total N – (NH_3-N + NO_3-N)	Hesse (1971)
Total N	Micro kjeldahl distillation and titrimetry	Jackson (1973)
Total P	Spectrophotometry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Jackson (1973)
Total K	Flame photometry (Digital Flame Photometer 130, Systronics, India)	Jackson (1973)
Total Ca, Mg	Versanate titration method	Hesse (1971)

Total S	Turbidimetry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Massoumi and Cornfield (1963)
Total Fe, Mn, Zn, Cu	Atomic absorption spectrophotometry (A Analyst 400, Perkin Elmer Inc., USA)	Osiname *et al.* (1973)
Total B	Spectrophotometry (azomethine – H method) (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Gupta (1967)
Heavy metals-Pb, Cd	Emission spectroscopy (ICP OES Optima 8000, PerkinElmer Inc., USA)	Wei and Yang (2010)

Table 4: Standard analytical procedures followed for soil analysis

Parameter	Method	Reference
Physical		
Bulk density	Core method	Gupta.and Dakshinamoorthy (1980)
Water holding capacity	Core method	Gupta.and Dakshinamoorthy (1980)
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 (TOC)	Weight loss on ignition CHNS Analyzer (Vario EI cube, Elementar, Germany)	Nelson and Sommers (1996)
Organic carbon	Walkley and Black rapid titration method	Walkley and Black (1934)
Water soluble organic carbon	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)
Microbial biomass carbon	Fumigation – incubation technique	Jenkinson and Ladd (1976)
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	Jackson (1973)
Total P	Nitric-perchloric (9:4) acid digestion and spectrophotometry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Jackson (1973)
Total K	Nitric-perchloric (9:4) acid digestion and flame photometry (Digital Flame Photometer 130, Systronics, India)	Jackson (1973)
Total Ca, Mg	Nitric-perchloric (9:4) acid digestion and versanate titration method	Hesse (1971)
Total S	Nitric-perchloric (9:4) acid digestion and turbidimetry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Massoumi and Cornfield (1963)
Total Fe, Mn, Zn, Cu	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry (A Analyst 400, Perkin Elmer Inc., USA)	Osiname *et al.* (1973)
Readily soluble B (Ra-B)	0.01 *M* $CaCl_2$ extraction and spectrophotometry (azomethine – H method) (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Hou *et al.,*1994
Specifically adsorbed B (Spa-B)	0.05 *M* KH_2PO_4 extraction and spectrophotometry (azomethine – H method) (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Hou *et al.,*1994
Oxide bound B (Ox-B)	Extraction with 0.2 *M* NH_4-oxalate (pH 3.25) and spectrophotometry (carmine dye method) (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Hou *et al.,*1994
Organically bound B (Org-B)	Extraction with 0.02 *M* HNO_3+ 30% H_2O_2 and spectrophotometry (carmine dye method) (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Hou *et al.,*1994
Residual B (Res-B)	Total B – (Rs-B + Spa-B + Ox-B + Org-B)	Hou *et al.,*1994

Total B	Nitric-perchloric (9:4) acid digestion and spectrophotometry (azomethine – H method) (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Gupta (1967)
Available P	Bray No. 1 extraction and spectrophotometry using phosphomolybdate blue method (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Jackson (1973)
Available K	Neutral 1 *N* ammonium acetate extraction and flame photometry (Digital Flame Photometer 130, Systronics, India)	Jackson (1973)
Available Ca, Mg	Neutral 1*N* ammonium acetate extraction and versanate titration method	Hesse (1971)
Available S	0.15% $CaCl_2$ extraction and turbidimetry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Massoumi and Cornfield (1963)
Available Fe, Mn, Zn, Cu	0.1 *M* HCl extraction and atomic absorption spectrophotometry (A Analyst 400, Perkin Elmer Inc., USA)	Osiname *et al.* (1973)
Available B	Hot water extraction and spectrophotometry (azomethine – H method) (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Gupta (1967)
Biological		
Microbial count (Bacteria, fungi, actinomycetes)	Serial dilution method	Goldman and Green (2008)
Dehydrogenase activity	Colorimetric determination of 2,3,5-triphenyl formazan (TPF)	Casida *et al.* (1964)

Table 5. Standard analytical methods followed for plant analysis

Nutrient	Method	Reference
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 UV-VIS spectrophotometer 2201, Systronics)	Jackson (1973)
K	Nitric-perchloric (9:4) acid digestion and flame photometry (Digital Flame Photometer 130, Systronics, India)	Jackson (1973)

Ca, Mg	Nitric-perchloric (9:4) acid digestion and versanate titration method	Piper (1966)
S	Nitric-perchloric (9:4) acid digestion followed by turbidimetry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Chesnin and Yien (1951)
Fe, Cu, Zn and Mn	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry (A Analyst 400, Perkin Elmer Inc., USA)	Lindsay and Norvell (1978)
B	Nitric-perchloric (9:4) acid digestion and azomethine- H spectrophotometry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Bingham (1982)
Pb, Cd	Nitric-perchloric (9:4) acid digestion and emission spectroscopy (ICP OES Optima 8000, PerkinElmer Inc., USA)	Wei and Yang (2010)

Table 6. Standard analytical methods followed for analysis of quality parameters of tomato and amaranthus

Quality parameter	Method	Reference
Tomato		
Total Soluble Solids (TSS)	Using Digital hand held refractometer (Atago Co Ltd, Tokyo, Japan)	Javanmardi and Kubota (2006)
Lycopene	Extraction with acetone and petroleum ether followed by colorimetric estimation	Sadasivam and Manickam, 1992
Ascorbic acid	Redox titrimetry with 2,6 dichlorophneol indophenols dye	Sadasivam and Manickam, 1992
Amaranthus		
Crude fibre content	Extraction with acid and alkali followed by oven drying and ignition at 550ºC	Sadasivam and Manickam, 1992
β carotene	Extraction with acetone and petroleum ether followed by colorimetric estimation	Srivatsava and Kumar (2009)
Ascorbic acid	Redox titrimetry with 2,6 dichlorophneol indophenols dye	Sadasivam and Manickam, 1992
Oxalate content	Extraction with 3*M* H_2SO_4 followed by titration with 0.05 *M* $KMnO_4$	A.O.A.C (1984)
Nitrate content	Extraction with Sliver sulphate and colorimetric determination using phenol-p-sulphuric acid and ammonium hydroxide	Middleton (2007)

RESULTS

4. RESULTS

A study entitled “Effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics and crop productivity in Ultisols” was conducted from April 2018 to January 2020 at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani with the objective to study the effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics, their retention and leaching and crop productivity in comparison with other organic fertilizers in Ultisols using tomato - amaranthus cropping sequence. The salient results of the study are presented this chapter.

4.1 PRODUCTION AND CHARACTERIZATION OF ORGANIC FERTILIZERS

Ordinary compost (OC), vermicompost (VC), microbial compost (MC), thermochemical organic fertilizer with (F-TOF) and without fortification (TOF) were produced from biodegradable waste. FYM was purchased. The organic fertilizers used in study were analysed for their physico-chemical and biological properties, and the data are presented in tables from 7 to 15.

4.1.1 Physical properties

Colour, odour, moisture content and bulk density of the organic fertilizers are presented in Table 7. FYM was greenish brown in colour, OC and VC were black, MC was greyish black and TOF and F-TOF was in brownish black in colour. All the six organic fertilizers used for the study were odourless. Moisture content varied from 7.89 to 8.20 % with the lowest value for FYM and the highest for OC. The bulk density ranged from 0.24 to 0.43 Mg m^{-3}. The lowest bulk density was recorded by TOF preceded by F-TOF and the highest by OC.

4.1.2 Electrochemical properties

pH and electrical conductivity (EC) of the organic fertilizers are presented in Table 8. pH ranged from 6.62 to 7.62. The highest pH was recorded by OC followed by VC. The lowest value was recorded by F-TOF followed by TOF. EC ranged from 0.20 to 1.59 dS m^{-1}. The lowest value for EC was recorded by FYM and the highest value for F-TOF followed by VC.

Table 7. Physical and electrochemical characteristics of organic fertilizers

Manure	Colour	Odour	Moisture content (%)	Bulk density (Mg m^{-3})	pH	EC (dS m^{-1})
FYM	Greenish brown	Odourless	7.89	0.32	7.24	0.20
OC	Black	Odourless	8.20	0.43	7.62	1.18
VC	Black	Odourless	8.15	0.42	7.43	1.39
MC	Grayish black	Odourless	8.17	0.33	7.28	1.34
TOF	Brownish black	Odourless	8.17	0.24	6.76	1.26
F-TOF	Brownish black	Odourless	8.19	0.25	6.62	1.59

4.1.3 Chemical properties

Organic fertilizers were characterized for their organic carbon pools, nitrogen pools, cellulose, hemicellulose, lignin and nutrient contents.

4.1.3.1 Organic carbon pools

The carbon pools estimated were total organic carbon (TOC), water soluble organic carbon (WSOC), labile carbon (LC) and recalcitrant organic carbon (ROC) and the data are presented in Table 8. TOC ranged from 22.40 to 43.90 %. The highest TOC and ROC was for TOF followed by F-TOF and lowest for FYM. WSOC varied from 372 to 1642 mg kg^{-1} with highest value for TOF and the lowest for MC. The labile carbon was also highest for TOF with a value of 1776 mg kg^{-1}and the lowest for FYM (1044 mg kg^{-1}).

Table 8. Carbon fractions of organic fertilizers

Manure	TOC (%)	WSOC (mg kg^{-1})	Labile carbon (mg kg^{-1})	Recalcitrant organic carbon (%)
FYM	22.40	504	1044	16.65
OC	29.40	810	1323	22.80
VC	31.10	534	1163	23.15
MC	29.89	372	1087	23.74
TOF	43.90	1642	1776	32.78
F-TOF	43.88	1638	1770	31.45

4.1.3.2 Nitrogen pools

Table 9 shows the different nitrogen pools estimated in organic fertilizers. NH_4-N varied from 0.020 to 0.041 %. The lowest value was for FYM and the highest for MC followed by F-TOF. NO_3-N ranged from 0.014 to 0.256 % and the highest content was in MC and lowest for FYM. Organic N varied from 1.496 % in FYM to 2.313 % in MC. Total nitrogen content ranged from 1.53 to 2.61 % with the highest value for MC followed by VC (2.42 %) and F-TOF (2.38 %) and lowest by FYM (1.53 %) preceded by TOF (1.85 %).

Table 9. Nitrogen fractions of organic fertilizers, %

Manure	NH_4-N (%)	NO_3-N (%)	Organic N (%)	Total N (%)
FYM	0.020	0.014	1.496	1.53
OC	0.024	0.080	2.186	2.29
VC	0.034	0.188	2.198	2.42
MC	0.041	0.256	2.313	2.61
TOF	0.038	0.108	1.524	1.85
F-TOF	0.040	0.118	2.222	2.38

4.1.3.3 Cellulose, hemicellulose lignin content and CN ratio

Data on cellulose, hemicellulose and lignin contents of different organic fertilizers were estimated and data are presented in the Table 10. Cellulose content was comparatively higher for FYM and VC compared to other organic fertilizers. The highest value was recorded by FYM (14.22 %) and the lowest by MC (5.33 %). For hemicellulose also the highest value was recorded by FYM (30.82 %), while all other organic fertilizers showed lower values for hemicellulose. In contrast to the above, the lignin content was lowest for FYM (10.49 %) while all others have higher values. The highest value was recorded by TOF (27.9 %) followed by F-TOF (27.5 %). C:N ratio of the organic fertilizer varied from 11.45 to 23.73. The lowest value was for MC preceded by VC (12.85) while the highest value was for TOF.

Table 10. Cellulose, hemicellulose, lignin content and C:N ratio of organic fertilizers

Manure	Cellulose (%)	Hemicellulose (%)	Lignin (%)	C:N ratio
FYM	14.22	30.82	10.49	19.82
OC	8.67	8.63	23.78	12.84
VC	12.00	5.04	24.11	12.85
MC	5.33	5.54	22.11	11.45
TOF	9.33	5.94	27.9	23.73
F-TOF	9.55	6.34	27.5	18.44

4.1.3.4 Macronutrients

P content of organic fertilizers ranged from 0.49 to 1.36 % recording the highest value for VC followed by OC. All others recorded a value below 1.0 and the lowest was for TOF. The K content ranged from 0.94 % for FYM to 2.56 % for F-TOF followed by VC (2.08 %). F-TOF had the highest contents for both Ca and Mg and FYM had the lowest values. The S content was highest for FYM and lowest for TOF.

4.1.3.5 Micronutrients and heavy metals

The micronutrient content of different organic fertilizers is presented in the Table 12. Fe content of the organic fertilizer varied from 3240 to 9580 mg kg^{-1} recording the highest value for FYM and lowest for TOF. Mn content of the organic fertilizers varied from 135.6 to 479.6 mg kg^{-1}. Zn content of the organic fertilizer varied from 107.6 to 254.0 mg kg^{-1}. The highest value was recorded with F-TOF and the lowest with TOF. For the organic fertilizers Cu content varied from 42.8 to 70.8 mg kg^{-1} with highest value for OC and lowest for TOF. The highest value was recorded by VC and lowest by TOF. Boron content of organic fertilizers varied from 1.76 mg kg^{-1} to 4.64 mg kg^{-1} recording the highest value for F-TOF and lowest for FYM. Among the heavy metals, Cd was not detected in any of the organic fertilisers while Pb was detected in small quantities. The Pb content in the organic fertilizer varied from 2.98 to 4.16 mg kg^{-1}. The highest Pb content was with FYM and lowest with OC.

Table 11. Macronutrient contents in organic fertilizers

Manure	P (%)	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})
FYM	0.70	0.94	0.48	0.17	550
OC	1.24	1.86	0.80	0.26	400
VC	1.36	2.08	0.96	0.28	330
MC	0.89	1.80	0.80	0.23	265
TOF	0.49	1.94	0.72	0.21	220
F-TOF	0.85	2.56	1.12	0.78	310

Table 12. Micronutrient and heavy metal (Pb) contents in organic fertilizers, mg kg^{-1}

Manure	Micronutrients and heavy metal Pb (mg kg^{-1})						
	Fe	Mn	Zn	Cu	B	Pb	Cd
FYM	9580	309.6	163.2	56.0	1.76	4.16	Nd
OC	8280	471.6	227.2	65.6	3.04	2.98	Nd
VC	7880	479.6	218.0	70.8	3.20	4.02	Nd
MC	7372	343.2	181.6	63.2	2.88	3.38	Nd
TOF	3240	135.6	107.6	42.8	2.08	3.13	Nd
F-TOF	4828	186.0	254.0	49.6	4.64	3.68	Nd

* Nd- not detected

4.1.4 Biological properties

4.1.4.1 Microbial count

The bacterial count ranged from 6.88 log cfu g^{-1} in TOF to 8.48 log cfu g^{-1} in MC while the fungal count varied from 4.10 log cfu g^{-1} in TOF to 5.27 log cfu g^{-1} in MC. Actinomycetes were not found in any of the organic fertilizers.

4.1.4.2 Dehydogenase activity

Dehydrogenase activity was also lowest for TOF (309.41µg TPF g^{-1} organic fertilizer 24 hr^{-1}) when compared to other organic fertilizers as in the case of microbial count. MC recorded the highest activity (508.26 ug TPF g^{-1} organic fertilizer 24 hr^{-1}) followed by FYM.

Table 13. Biological characteristics of organic fertilizers

Manure	Microbial count (log cfu g^{-1})		Dehydrogenase activity (µg TPF g^{-1} organic fertilizer 24 hr^{-1})
	Bacteria	Fungus	
FYM	7.63	4.28	496.74
OC	7.31	4.64	410.37
VC	7.12	4.67	339.73
MC	8.48	5.27	508.26
TOF	6.88	4.10	309.41
F-TOF	6.99	4.14	309.79

4.1.5 Derived indices- Fertilizing index and clean index

Fertilizing index of organic fertilizers varied from 4.20 to 4.80 in which the lowest value was for TOF and highest for OC, VC and MC. Clean index was highest for TOF followed by F-TOF and other organic fertilizers had a same value for the clean index

Table 14. Fertilizing and clean index of organic fertilizers

Manure	Fertilizing index	Clean index
FYM	4.53	4.50
OC	4.80	4.50
VC	4.80	4.50
MC	4.80	4.50
TOF	4.20	5.00
F-TOF	4.60	4.83

4.2 LEACHING STUDY WITH SOIL COLUMNS

4.2.1 LEACHATE

Leachate collected from soil columns at different intervals were chemically analysed and the results are presented below.

4.2.1.1 pH

pH of the leachate from soil columns at all the sampling periods (Table 15) varied significantly due the addition of organic fertilizers. Throughout the period of study the pH of leachates was slightly acidic ranging from 5.60 to 6.35. Addition of organic fertilizers increased the leachate pH compared to the control treatment. The pH of treatments receiving organic fertilizers shown a decrease up to 8 W of incubation followed by an increase on 12 W which further decreased with the period of incubation. At all sampling periods, the lowest pH was recorded by control treatment while the highest pH by treatment receiving F-TOF.

Table 15. Effect of treatments on leachate pH at different period of incubation

Treatments	pH						
	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_{1} Control	5.99 ^{e}	5.90 ^{d}	5.78 ^{e}	5.64 ^{e}	5. 68 ^{c}	5.60 ^{f}	5.60 ^{d}
T_{2} Soil+FYM	6.05 ^{de}	6.05 ^{c}	6.01 ^{d}	6.09 ^{d}	5.80 ^{bc}	5.75 ^{e}	5.71 ^{c}
T_{3} Soil+OC	6.15 ^{cd}	6.10 ^{c}	6.06 ^{cd}	6.30 ^{bc}	5.87 ^{ab}	5.81 ^{de}	5.78 ^{c}
T_{4} Soil+VC	6.27 ^{ab}	6.22 ^{b}	6.19 ^{b}	6.35 ^{ab}	6.13 ^{ab}	5.96 ^{b}	5.92 ^{ab}
T_{5} Soil+MC	6.22 ^{bc}	6.19 ^{b}	6.14 ^{bc}	6.22 ^{c}	5.99 ^{ab}	5.93 ^{bc}	5.88 ^{b}
T_{6} Soil+TOF	6.07 ^{de}	6.03 ^{c}	6.01 ^{d}	6.10 ^{d}	5.94 ^{ab}	5.85 ^{cd}	5.79 ^{c}
T_{7} Soil+F-TOF	6.35 ^{a}	6.33 ^{a}	6.29 ^{a}	6.42 ^{a}	6.22 ^{a}	6.05 ^{a}	5.99 ^{a}
SEm±	0.037	0.028	0.032	0.039	0.127	0.027	0.027
CD (0.05)	0.112	0.084	0.095	0.118	0.381	0.081	0.081

4.2.1.2 Electrical conductivity (EC)

EC indicate the amount of nutrient ions present in the leachate. There was significant difference in the EC of leachates samples (Table 16) due to the addition of organic fertilizers. EC varied from to 0.235 to 1.310 dS m^{-1} recording the lowest value by control treatment and the highest by F-TOF. The leachate collected at 1 W recorded the highest values for all treatments followed by a decrease towards the end of incubation except a slight increase at 12 W and 16 W of incubation. The leachates collected from treatments receiving FYM, OC, VC and F-TOF showed a slight increase in EC in the 12 W compared to the 8 W while MC showed this increase during 16 W while TOF followed a declining trend throughout the leaching period.

Table 16. Effect of treatments on EC of the leachates at different period of incubation

Treatments	EC (dS m^{-1})						
	1 W	4 W	8 W	12 W	16 W	20 W	24 W
$T_{1\ \mathrm{Control}}$	0.505^{g}	0.415^{d}	0.370^{d}	0.325^{e}	0.320^{c}	0.255^{e}	0.235^{d}
$T_{2\ \mathrm{Soil+FYM}}$	0.795^{f}	0.465^{c}	0.465^{b}	0.495^{bc}	0.465^{a}	0.438^{c}	0.435^{b}
$T_{3\ \mathrm{Soil+OC}}$	1.080^{c}	0.555^{a}	0.475^{b}	0.545^{a}	0.468^{a}	0.466^{a}	0.452^{a}
$T_{4\ \mathrm{Soil+VC}}$	1.125^{b}	0.500^{bc}	0.495^{a}	0.555^{a}	0.472^{a}	0.467^{a}	0.457^{a}
$T_{5\ \mathrm{Soil+MC}}$	1.045^{d}	0.530^{ab}	0.469^{b}	0.460^{cd}	0.475^{a}	0.443^{bc}	0.439^{b}
$T_{6\ \mathrm{Soil+TOF}}$	0.876^{e}	0.488^{c}	0.435^{c}	0.420^{d}	0.440^{b}	0.389^{d}	0.372^{c}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	1.310^{a}	0.540^{ab}	0.485^{a}	0.510^{ab}	0.474^{a}	0.444^{b}	0.440^{b}
SEm±	0.010	0.014	0.003	0.014	0.008	0.002	0.002
CD (0.05)	0.03	0.043	0.010	0.042	0.024	0.006	0.006

4.2.1.3 Total dissolved organic carbon (DOC)

The total dissolved organic carbon in the leachate (Table 17) varied significantly due to the addition of organic fertilizers. The cumulative loss of total DOC varied from 4.06 to 14.54 mg L^{-1} within 24 W showing the highest value for VC followed by OC and lowest value for MC. For all treatments loss of DOC was highest at the first leaching which was one week after the incubation. DOC loss during the first leaching was highest from VC (6.81 mg L^{-1}) followed by OC (6.63 mg L^{-1}) and FYM (6.13 mg L^{-1}). As the incubation time proceeds, the DOC loss decreased recording the lowest values at 24 W.

Table 17. Temporal variation in total dissolved organic carbon (DOC) content of the leachates as affected by treatment, mg L^{-1}

Treatments	Total DOC (mg L^{-1})							Cumulative loss (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
$T_{1\ \mathrm{Control}}$	2.06^{d}	0.66^{d}	0.50^{c}	0.41 ^{d}	0.19^{e}	0.13^{c}	0.11^{b}	4.06 ^{e}
$T_{2\ \mathrm{Soil+FYM}}$	6.13^{a}	3.31^{b}	1.39^{b}	1.27 ^{ab}	0.74^{b}	0.30^{b}	0.25^{a}	13.38 ^{c}
$T_{3\ \mathrm{Soil+OC}}$	6.63^{a}	2.57^{bc}	1.65^{ab}	1.44 ^{a}	0.83^{a}	0.66^{a}	0.30^{a}	14.08 ^{ab}
$T_{4\ \mathrm{Soil+VC}}$	6.81^{a}	3.05^{b}	2.13^{a}	0.90^{bc}	0.78^{ab}	0.56^{a}	0.32^{a}	14.54 ^{a}
$T_{5\ \mathrm{Soil+MC}}$	3.13^{c}	2.23^{c}	1.47^{b}	0.66^{cd}	0.28^{d}	0.26^{b}	0.25^{a}	8.26 ^{d}
$T_{6\ \mathrm{Soil+TOF}}$	5.00^{b}	4.49^{a}	1.72^{ab}	1.50^{a}	0.56^{c}	0.29^{b}	0.26^{a}	13.81 ^{bc}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	5.00^{b}	4.58^{a}	1.59^{ab}	1.50^{a}	0.56^{c}	0.29^{b}	0.28^{a}	13.79 ^{bc}
SEm±	0.26	0.26	0.21	0.13	0.03	0.04	0.02	0.22
CD (0.05)	0.80	0.79	0.63	0.41	0.09	0.11	0.08	0.67

4.2.1.4 Different forms of N

4.2.1.4.1 Ammoniacal - N (NH$_4$-N)

There was a significant difference in the NH$_4$-N content of leachates collected from the different treatments (Table 18). The cumulative loss of NH$_4$-N was lowest for control treatment and highest for VC which was significantly superior to all. Considering the periods of leaching, the highest loss occurred at 1 W for OC, VC, TOF and F-TOF while it was at 4 W for FYM, MC and control treatments. This was followed by a decrease during 8 W and an increase towards 12 W for all treatments receiving organic fertilizers followed by a decrease during the subsequent leaching.

Table 18. NH$_4$-N content in the leachate at different period of incubation, mg L^{-1}

Treatments	NH$_4$ -N (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
$T_{1\ \mathrm{Control}}$	1.87 ^{f}	2.31 ^{e}	1.85 ^{c}	1.79 ^{c}	1.79 ^{c}	1.68	1.56	12.83 ^{f}
$T_{2\ \mathrm{Soil+FYM}}$	2.75 ^{e}	2.89 ^{d}	2.09 ^{bc}	2.34 ^{abc}	2.49 ^{b}	1.68	1.56	15.78 ^{e}
$T_{3\ \mathrm{Soil+OC}}$	5.60 ^{b}	3.67 ^{bc}	2.05 ^{bc}	2.75 ^{a}	2.69 ^{ab}	1.68	1.56	19.99 ^{c}
$T_{4\ \mathrm{Soil+VC}}$	13.30^{a}	4.09 ^{b}	2.32 ^{ab}	2.80 ^{a}	3.09 ^{a}	1.68	1.56	28.82 ^{a}
$T_{5\ \mathrm{Soil+MC}}$	4.20 ^{d}	6.16 ^{a}	2.02 ^{c}	2.64 ^{ab}	2.81 ^{ab}	1.68	1.56	21.07 ^{b}
$T_{6\ \mathrm{Soil+TOF}}$	3.73 ^{d}	3.08 ^{cd}	2.00 ^{c}	2.09 ^{bc}	2.26 ^{bc}	1.68	1.56	16.39 ^{e}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	4.90 ^{c}	3.08 ^{cd}	2.47 ^{a}	2.61 ^{ab}	2.81 ^{ab}	1.68	1.56	19.10 ^{d}
SEm±	0.21	0.22	0.09	0.20	0.19	-	-	0.27
CD (0.05)	0.65	0.67	0.27	0.60	0.59	NS	NS	0.84

4.2.1.4.2 Nitrate -N (NO_3-N)

The treatment effect was significant for NO_3-N content of the leachate and the data are presented in Table 19. The cumulative loss was significantly highest for VC followed by MC and F-TOF. The NO_3-N content in leachates from the control treatment decreased gradually, while others showed a decline up to 4 W followed by gradual increase up to 20 W with FYM as an exception.

Table 19. Effect of treatment on NO_3-N content in the leachate at different period of incubation, mg L^{-1}

Treatments	NO_3-N (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
T_1 Control	17.50^{e}	10.07 ^{e}	9.24 ^{f}	8.56 ^{f}	6.07 ^{e}	5.34 ^{d}	5.25 ^{e}	62.03 ^{g}
T_2 Soil+FYM	18.85^{d}	14.63 ^{c}	12.94 ^{e}	18.13 ^{e}	20.16^{c}	14.00 ^{c}	11.40 ^{d}	110.11 ^{f}
T_3 Soil+OC	19.60^{cd}	14.17 ^{c}	18.84 ^{cd}	20.65 ^{d}	21.51 ^{b}	24.08 ^{a}	13.99 ^{c}	132.84 ^{d}
T_4 Soil+VC	21.56^{b}	19.25 ^{b}	19.73 ^{c}	26.07 ^{a}	25.54 ^{a}	23.82 ^{a}	16.06 ^{b}	152.03 ^{a}
T_5 Soil+MC	20.00^{cd}	20.59 ^{a}	21.34 ^{b}	24.19 ^{b}	22.18 ^{b}	22.40 ^{b}	17.63 ^{a}	148.33 ^{b}
T_6 Soil+TOF	20.30^{bc}	10.74^{de}	17.87 ^{d}	21.95 ^{c}	18.67 ^{d}	23.52^{ab}	11.55 ^{d}	124.60 ^{e}
T_7 Soil+F-TOF	24.85 ^{a}	11.76 ^{d}	24.03 ^{a}	22.64 ^{c}	21.13^{bc}	24.10 ^{a}	13.47 ^{c}	141.98 ^{c}
SEm±	0.43	0.43	0.45	0.38	0.37	0.38	0.41	0.43
CD (0.05)	1.30	1.28	1.36	1.15	1.12	1.15	1.22	1.30

4.2.1.4.3 Organic N

Significant difference was observed for the organic N content of the leachates due to the addition of organic fertilizers and is given in Table 20. The cumulative loss of organic N varied from 1.45 to 5.29 mg L^{-1}. Leaching loss was highest for VC followed by OC. Comparing the leaching periods the loss of organic N was highest at 1 W of incubation and the highest loss was from VC followed by OC. Organic N content in the leachates declined with the subsequent leaching and the loss was lowest for control treatment at all leaching intervals.

Table 20. Effect of treatments on organic N content in the leachate at different period of incubation, mg L^{-1}

Treatments	Organic N (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
$T_{1\ \text{Control}}$	0.74^{e}	0.24^{e}	0.18^{d}	0.15^{d}	0.07^{c}	0.05^{d}	0.04^{c}	1.45^{c}
$T_{2\ \text{Soil+FYM}}$	2.04^{bc}	1.18^{b}	0.50^{c}	0.45^{a}	0.26^{a}	0.11^{c}	0.09^{b}	4.63^{a}
$T_{3\ \text{Soil+OC}}$	2.28^{ab}	0.92^{cd}	0.59^{b}	0.52^{a}	0.30^{a}	0.24^{a}	0.11^{a}	4.94^{a}
$T_{4\ \text{Soil+VC}}$	2.54^{a}	1.09^{bc}	0.76 a	0.32^{bc}	0.28^{a}	0.20^{b}	0.11^{a}	5.29^{a}
$T_{5\ \text{Soil+MC}}$	1.12^{d}	0.80^{d}	0.53^{bc}	0.24^{cd}	0.10^{c}	0.09^{c}	0.09^{b}	2.95^{b}
$T_{6\ \text{Soil+TOF}}$	1.79^{c}	1.60^{a}	0.61^{b}	0.45^{ab}	0.20^{b}	0.10^{c}	0.09^{b}	4.84^{a}
$T_{7\ \text{Soil+F-TOF}}$	1.79^{c}	1.64^{a}	0.57^{bc}	0.45^{ab}	0.20^{b}	0.10^{c}	0.10^{ab}	4.84^{a}
SEm±	0.10	0.07	0.02	0.05	0.01	0.01	0.00	0.23
CD (0.05)	0.30	0.20	0.07	0.14	0.04	0.03	0.01	0.71

4.2.1.4.4 Total N

The cumulative total N content in the leachate varied from 76.31 to 185.86 mg L^{-1} and the treatment effects were significant (Table 21). The highest loss was for VC followed by MC and F-TOF. The total N for control treatment decreased gradually. The organic fertilizer treated columns showed a decrease on 4 W and 8 W of incubation and a gradual increase on 12 W and 16 W leaching and declined afterwards.

Table 21. Effect of treatments on total N content in the leachate at different period of incubation, mg L^{-1}

Treatments	Total N (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
$T_{1\ \text{Control}}$	20.17^{f}	12.53^{f}	11.32^{e}	10.61^{f}	7.86^{f}	7.02^{d}	6.81^{e}	76.31^{e}
$T_{2\ \text{Soil+FYM}}$	23.88^{e}	17.96^{cd}	15.49^{d}	21.64^{e}	22.65^{d}	15.68^{c}	13.45^{d}	130.75^{d}
$T_{3\ \text{Soil+OC}}$	27.48^{c}	18.43^{c}	21.13^{c}	24.32^{d}	24.71^{bc}	25.87^{a}	15.84^{c}	157.76^{b}
$T_{4\ \text{Soil+VC}}$	37.14^{a}	24.51^{b}	23.10^{b}	28.87^{a}	28.62^{a}	25.82^{a}	17.81^{b}	185.86^{a}
$T_{5\ \text{Soil+MC}}$	25.41^{de}	27.64^{a}	23.60^{b}	27.35^{b}	24.98^{b}	24.08^{b}	19.29^{a}	172.34^{a}
$T_{6\ \text{Soil+TOF}}$	25.91^{cd}	15.44^{e}	19.86^{c}	24.65^{d}	20.93^{e}	25.74^{a}	13.30^{d}	145.83^{c}
$T_{7\ \text{Soil+F-TOF}}$	31.63^{b}	16.51^{de}	26.49^{a}	25.91^{c}	23.94^{c}	26.31^{a}	15.12^{c}	165.90^{b}
SEm±	0.58	0.48	0.46	0.27	0.31	0.27	0.29	3.56
CD (0.05)	1.76	1.48	1.41	0.82	0.96	0.84	0.89	10.91

4.2.1.5 Total P

The phosphorus content was detected in the leachate for the first two leachings only *i.e.*, first and fourth week leaching (Table 22). Afterward there was no loss of P through the leachates from the soil columns. Even though, the cumulative P loss significantly varied among the treatments. Highest cumulative P loss was recorded by F-TOF (1.81 mg L^{-1}) followed by OC (1.29 mg L^{-1}) and the lowest was from control (0.40 mg L^{-1})

Table 22. Effect of treatments on total P content in the leachate at different period of incubation, mg L^{-1}

Treatments	Total P (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
$T_{1\ \text{Control}}$	0.23 ^{e}	0.17 ^{d}	-	-	-	-	-	0.40 ^{e}
$T_{2\ \text{Soil+FYM}}$	0.63 ^{c}	0.20 ^{d}	-	-	-	-	-	0.83 ^{c}
$T_{3\ \text{Soil+OC}}$	0.92 ^{b}	0.37 ^{c}	-	-	-	-	-	1.29 ^{b}
$T_{4\ \text{Soil+VC}}$	0.67 ^{c}	0.18 ^{d}	-	-	-	-	-	0.85 ^{c}
$T_{5\ \text{Soil+MC}}$	0.43 ^{d}	0.50 ^{b}	-	-	-	-	-	0.93 ^{c}
$T_{6\ \text{Soil+TOF}}$	0.49 ^{d}	0.19 ^{d}	-	-	-	-	-	0.68 ^{d}
$T_{7\ \text{Soil+F-TOF}}$	1.26 ^{a}	0.55 ^{a}	-	-	-	-	-	1.81 ^{a}
SEm±	0.04	0.01	-	-	-	-	-	0.04
CD (0.05)	0.13	0.04	-	-	-	-	-	0.11

4.2.1.6 Total K

There was a noticeable increase in the K content of leachates due to the addition of organic fertilizers and are presented in Table 23. The cumulative K loss varied from 246.80 to 333.36 mg L^{-1}. The highest K loss was from F-TOF followed by VC and TOF and lowest was from the control treatment

Table 23. Temporal variation in total K content of the leachates as affected by treatments, mg L^{-1}

Treatments	Total K (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
T$_1$ Control	55.00^{g}	50.88^{d}	32.51 ^{f}	32.42 ^{d}	29.20 ^{d}	23.67 ^{e}	23.13 ^{e}	246.80 ^{g}
T$_2$ Soil+FYM	63.34^{e}	55.45^{b}	35.20 ^{e}	36.75 ^{c}	36.00 ^{c}	31.00 ^{c}	26.05 ^{d}	283.79 ^{f}
T$_3$ Soil+OC	60.00^{f}	55.00^{bc}	36.30 ^{d}	43.28 ^{b}	42.40 ^{b}	30.00 ^{cd}	26.83 ^{d}	293.80 ^{d}
T$_4$ Soil+VC	69.16^{b}	64.17^{a}	40.35 ^{b}	42.88 ^{b}	42.40 ^{b}	33.67 ^{b}	31.76 ^{b}	324.38 ^{b}
T$_5$ Soil+MC	67.64^{c}	52.25^{d}	35.94 ^{de}	36.35 ^{c}	36.81 ^{c}	29.00 ^{d}	29.60 ^{c}	287.58 ^{e}
T$_6$ Soil+TOF	66.25^{d}	53.75^{c}	38.50^{c}	42.88 ^{b}	42.40 ^{b}	33.50 ^{b}	30.50 ^{c}	307.77 ^{c}
T$_7$ Soil+F-TOF	72.09^{a}	55.46^{b}	41.80^{a}	45.73 ^{a}	48.40 ^{a}	35.67 ^{a}	34.23 ^{a}	333.36 ^{a}
SEm±	55.00	50.88	32.51	32.42	29.20	23.67	23.13	246.80
CD (0.05)	63.34	55.45	35.20	36.75	36.00	31.00	26.05	283.79

4.2.1.7 Total Ca

The cumulative loss of Ca varied from 193.64 to 273.86 mg with the highest loss from VC followed by MC and OC. The total Ca content in the leachates gradually decreased towards the end of leaching for all the treatments, and control always recorded the lowest values.

Table 24. Temporal variation in total Ca content of the leachates as affected by treatments, mg L^{-1}

Treatments	Total Ca (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
T$_1$ Control	47.50^{f}	39.00^{f}	27.14^{c}	23.68^{e}	21.60^{f}	19.00^{d}	15.73^{c}	193.64^{g}
T$_2$ Soil+FYM	54.75^{e}	48.75^{c}	36.06^{b}	31.82^{c}	30.00^{d}	22.00^{c}	16.65^{b}	240.03^{f}
T$_3$ Soil+OC	74.16^{a}	52.71^{b}	36.30^{ab}	34.60^{b}	32.40^{c}	22.00^{c}	16.78^{b}	268.95^{c}
T$_4$ Soil+VC	72.50^{b}	55.08^{a}	36.66^{ab}	35.12^{b}	36.00^{a}	20.00^{d}	18.50^{a}	273.86^{a}
T$_5$ Soil+MC	67.50^{d}	54.75^{a}	36.84^{ab}	39.40^{a}	34.00^{b}	23.00^{c}	16.65^{b}	272.14^{b}
T$_6$ Soil+TOF	66.66^{d}	43.00^{e}	36.10^{b}	30.32^{d}	26.50^{e}	24.50^{b}	16.65^{b}	243.73^{e}
T$_7$ Soil+F-TOF	70.84^{c}	44.92^{d}	37.26^{a}	31.90^{c}	29.95^{d}	27.00^{a}	17.15^{b}	259.02^{d}
SEm±	0.37	0.57	0.35	0.39	0.36	0.38	0.29	0.47
CD (0.05)	1.11	1.72	1.05	1.17	1.09	1.15	0.88	1.41

4.2.1.8 Total Mg

The cumulative loss of Mg varied from 80.25 to 144.41 mg L^{-1}. The loss was significantly highest for F-TOF followed by VC and OC. The total Mg content of the leachates decreased gradually towards the end of the leaching in all the treatments. In

F-TOF, the highest leaching loss was at first leaching and decreased in the subsequent leachings with a slight increase at 12 W. An increase in Mg content for treatments receiving organic fertilizers were noted for 8 W onwards and for most of them, highest values were noted on 12 W of incubation.

Table 25. Effect of treatments on total Mg content in the leachates at different period of incubation, mg L^{-1}

Treatments	Total Mg (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
T_1 Control	13.50^{e}	9.90^{d}	19.80^{c}	17.92^{d}	10.08^{c}	4.80^{d}	4.25^{d}	80.25^{e}
T_2 Soil+FYM	17.25^{d}	11.45^{c}	20.38^{b}	20.71^{c}	11.21^{bc}	5.90^{cd}	5.16^{c}	92.06^{d}
T_3 Soil+OC	19.00^{bc}	12.40^{bc}	21.40^{a}	21.99^{b}	11.90^{b}	6.45^{c}	5.74^{bc}	98.88^{c}
T_4 Soil+VC	19.75^{b}	12.10^{bc}	20.74^{b}	22.33^{b}	13.11^{a}	7.85^{b}	6.05^{b}	104.43^{b}
T_5 Soil+MC	18.50^{c}	12.45^{b}	20.65^{b}	21.69^{b}	11.68^{b}	6.20^{c}	5.83^{bc}	97.00^{c}
T_6 Soil+TOF	19.50^{bc}	11.55^{bc}	20.32^{bc}	21.24^{c}	10.30^{c}	5.20^{d}	4.99^{cd}	93.09^{d}
T_7 Soil+F-TOF	40.00^{a}	25.95^{a}	21.56^{a}	24.52^{a}	13.64^{a}	9.50^{a}	9.24^{a}	144.41^{a}
SEm±	0.36	0.32	0.34	0.32	0.25	0.32	0.29	0.75
CD (0.05)	1.07	0.97	0.52	0.95	0.78	0.95	0.88	2.25

4.2.1.9 Total S

The cumulative loss of S varied from 1.96 to 4.19 mg (Table 26). The highest loss was from FYM treated soil columns followed by OC and VC. The S loss from the control treatment decreased gradually towards the end of leaching. While the leachates from soil columns with organic fertilizer treatments showed a decrease up to 12 W of leaching with TOF and F-TOF as exception. Later an increase was recorded on 16 W and declined in subsequent leaching.

Table 26. Effect of treatments on total S content in the leachates at different period of incubation, mg L^{-1}

Treatments	Total S (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
$T_{1\,\text{Control}}$	0.29^{c}	0.32^{c}	0.40^{c}	0.32^{d}	0.29^{d}	0.19^{b}	0.16^{b}	1.96 ^{e}
$T_{2\,\text{Soil+FYM}}$	0.65^{b}	0.95^{a}	0.79^{a}	0.58^{b}	0.84^{b}	0.23^{ab}	0.17^{ab}	4.19 ^{a}
$T_{3\,\text{Soil+OC}}$	0.48^{b}	0.86^{a}	0.68^{a}	0.71^{a}	0.79^{b}	0.25^{ab}	0.22^{a}	3.98 ^{ab}
$T_{4\,\text{Soil+VC}}$	0.33^{c}	0.84^{a}	0.68^{a}	0.52^{c}	0.92^{a}	0.26^{a}	0.21^{a}	3.77 ^{b}
$T_{5\,\text{Soil+MC}}$	0.35 ^{c}	0.68^{b}	0.55^{b}	0.50^{c}	0.99^{a}	0.20^{ab}	0.18^{ab}	3.45 ^{c}
$T_{6\,\text{Soil+TOF}}$	0.31^{c}	0.45^{c}	0.51^{bc}	0.55^{b}	0.58^{c}	0.20^{ab}	0.17^{ab}	2.77 ^{d}
$T_{7\,\text{Soil+F-TOF}}$	0.87^{a}	0.70^{b}	0.56^{b}	0.59^{ab}	0.79^{b}	0.22^{ab}	0.17^{ab}	3.90 ^{a}
SEm±	0.07	0.06	0.05	0.05	0.04	0.02	0.02	0.14
CD (0.05)	0.20	0.17	0.15	0.13	0.11	0.06	0.05	0.34

4.2.1.10 Total Fe

The leaching loss of Fe from soil columns under different organic fertilizer treatments, for a period of 24 weeks is given in the Table 27. The highest cumulative loss of Fe was from the treatment OC (4.71 mg L^{-1}) and it was on par with the treatments VC and MC. The lowest cumulative loss of Fe (4.09 mg L^{-1}) was from the absolute control (T_1).

Table 27. Effect of treatments on total Fe content in the leachates at different period of incubation, mg L^{-1}

Treatments	Total Fe (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
$T_{1\,\text{Control}}$	0.573 ^{d}	0.560 ^{c}	0.580 ^{b}	0.593 ^{b}	0.593 ^{b}	0.590^{c}	0.603 ^{b}	4.09^{c}
$T_{2\,\text{Soil+FYM}}$	0.708 ^{b}	0.578^{b}	0.585 ^{a}	0.615 ^{ab}	0.608 ^{ab}	0.613^{b}	0.605 ^{b}	4.31^{bc}
$T_{3\,\text{Soil+OC}}$	1.108 ^{a}	0.590^{b}	0.593 ^{a}	0.605 ^{b}	0.600 ^{b}	0.608^{b}	0.613^{ab}	4.71^{a}
$T_{4\,\text{Soil+VC}}$	0.820 ^{b}	0.580^{b}	0.585 ^{a}	0.635 ^{a}	0.600 ^{b}	0.675^{a}	0.610^{ab}	4.50^{ab}
$T_{5\,\text{Soil+MC}}$	0.828 ^{b}	0.605 ^{a}	0.583 ^{a}	0.588 ^{b}	0.610 ^{ab}	0.615^{b}	0.615 ^{a}	4.44^{ab}
$T_{6\,\text{Soil+TOF}}$	0.628 ^{c}	0.585^{b}	0.580 ^{b}	0.595 ^{b}	0.603 ^{ab}	0.620^{b}	0.625^{a}	4.24^{bc}
$T_{7\,\text{Soil+F-TOF}}$	0.640 ^{c}	0.585^{b}	0.590 ^{a}	0.603 ^{b}	0.613 ^{a}	0.610^{b}	0.618^{ab}	4.26^{bc}
SEm±	0.004	0.003	0.002	0.005	0.003	0.006	0.004	0.070
CD (0.05)	0.015	0.012	0.009	0.021	0.012	0.025	0.015	0.28

4.2.1.11 Total Mn

The leaching loss Mn from soil columns under different treatments, for a period of 24 weeks is given in the Table 28. The highest cumulative loss of Mn was from the treatment VC (3.973 mg L^{-1}) followed by OC. For all treatments leaching loss of Mn was highest at first leaching which was one week after the incubation and the leaching loss declined afterwards. The lowest cumulative loss of Mn was from the absolute control (T_1).

Table 28. Effect of treatments on total Mn content in the leachates at different period of incubation, mg L^{-1}

Treatments	Total Mn (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
$T_{1\ \mathrm{Control}}$	1.066^{d}	0.496^{c}	0.230^{e}	0.294^{c}	0.242^{b}	0.210^{f}	0.184^{e}	2.720^{d}
$T_{2\ \mathrm{Soil+FYM}}$	1.214^{c}	0.616^{b}	0.336^{c}	0.259^{c}	0.261^{b}	0.265^{c}	0.033^{f}	3.383^{b}
$T_{3\ \mathrm{Soil+OC}}$	1.248^{b}	0.413^{d}	0.384^{b}	0.255^{d}	0.350^{a}	0.275^{b}	0.229^{c}	3.808^{a}
$T_{4\ \mathrm{Soil+VC}}$	1.374^{a}	0.272^{e}	0.409^{a}	0.318^{b}	0.271^{b}	0.231^{d}	0.235^{b}	3.973^{a}
$T_{5\ \mathrm{Soil+MC}}$	0.983^{e}	0.657^{a}	0.321^{d}	0.277^{c}	0.360^{a}	0.316^{a}	0.284^{a}	3.325^{b}
$T_{6\ \mathrm{Soil+TOF}}$	0.757^{g}	0.665^{a}	0.334^{c}	0.318^{b}	0.284^{b}	0.212^{f}	0.238^{b}	2.998^{c}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	0.895^{f}	0.680^{a}	0.421^{a}	0.371^{a}	0.293^{b}	0.216^{e}	0.195^{d}	3.323^{b}
SEm±	0.011	0.012	0.007	0.012	0.011	0.002	0.000	0.111
CD (0.05)	0.033	0.036	0.021	0.035	0.031	0.004	0.003	0.332

4.2.1.15 Total Zn

The highest cumulative loss of Zn was from the treatment OC (1.145 mg L^{-1}) followed by VC and FYM (Table 29). For all treatments leaching loss of Zn was highest at the first leaching which was one week after the incubation and it decreased towards the end of incubation. The lowest cumulative loss of Zn (0.765 mg L^{-1}) was from the absolute control (T_1).

Table 29. Effect of treatments on total Zn content in the leachates at different period of incubation, mg L^{-1}

Treatments	Total Zn (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
T$_1$ Control	0.431^{d}	0.069^{d}	0.025^{c}	0.078^{b}	0.078^{b}	0.044^{c}	0.041^{b}	0.765^{f}
T$_2$ Soil+FYM	0.471^{c}	0.138^{b}	0.056^{c}	0.089^{b}	0.089^{cb}	0.094^{b}	0.085^{a}	1.023^{c}
T$_3$ Soil+OC	0.509^{a}	0.141^{ab}	0.092^{a}	0.120^{a}	0.090^{b}	0.112^{a}	0.080^{a}	1.145^{a}
T$_4$ Soil+VC	0.494^{b}	0.120^{c}	0.074^{b}	0.116^{a}	0.104^{ab}	0.091^{b}	0.078^{a}	1.078^{b}
T$_5$ Soil+MC	0.517^{a}	0.035^{e}	0.012^{d}	0.065^{c}	0.116^{a}	0.108^{a}	0.083^{a}	0.935^{d}
T$_6$ Soil+TOF	0.423^{d}	0.059^{d}	0.068^{b}	0.080^{b}	0.090^{b}	0.053^{c}	0.076^{a}	0.850^{e}
T$_7$ Soil+F-TOF	0.432^{d}	0.152^{a}	0.076^{b}	0.082^{b}	0.086^{b}	0.052^{c}	0.047^{b}	0.928^{d}
SEm±	0.004	0.003	0.003	0.004	0.004	0.003	0.003	0.007
CD (0.05)	0.014	0.012	0.010	0.016	0.014	0.011	0.013	0.020

4.2.1.16 Total Cu

The leaching loss Cu from soil columns under different treatments, for a period of 24 weeks is given in the Table 30. The highest cumulative loss of Cu was from the treatment F-TOF (0.080 mg L^{-1}) followed by VC and OC. The lowest cumulative loss of Cu (0.059 mg L^{-1}) was from the absolute control (T$_1$). For all treatments leaching loss of Cu was highest at the first leaching which was one week after the incubation, which further decreased towards 24 W.

Table 30. Effect of treatments on total Cu content in the leachates at different period of incubation, mg L^{-1}

Treatments	Total Cu (mg L^{-1})							CL (mg L^{-1})
	1 W	4W	8 W	12 W	16 W	20 W	24 W	
T$_1$ Control	0.017^{ab}	0.005^{b}	0.010^{ab}	0.008^{b}	0.007^{c}	0.008^{b}	0.005^{b}	0.059^{c}
T$_2$ Soil+FYM	0.012^{b}	0.006^{b}	0.007^{b}	0.010^{b}	0.007^{c}	0.010^{b}	0.011^{a}	0.063^{c}
T$_3$ Soil+OC	0.012^{b}	0.005^{b}	0.009^{ab}	0.008^{b}	0.008^{b}	0.012^{ab}	0.011^{a}	0.065^{c}
T$_4$ Soil+VC	0.013^{ab}	0.005^{b}	0.007^{b}	0.013^{a}	0.011^{b}	0.016^{a}	0.008^{b}	0.073^{b}
T$_5$ Soil+MC	0.015^{ab}	0.007^{b}	0.001^{c}	0.007^{b}	0.016^{a}	0.010^{b}	0.005^{b}	0.061^{c}
T$_6$ Soil+TOF	0.010^{b}	0.008^{b}	0.008^{ab}	0.009^{b}	0.007^{c}	0.008^{b}	0.010^{a}	0.060^{c}
T$_7$ Soil+F-TOF	0.018^{a}	0.016^{a}	0.011^{a}	0.011^{ab}	0.005^{c}	0.010^{b}	0.009^{a}	0.080^{a}
SEm±	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.002
CD (0.05)	0.006	0.004	0.003	0.003	0.003	0.005	0.003	0.006

4.2.1.17 Total B

Organic fertilizer addition significantly influenced the total B content in the leachate and is presented in the Table 31. The cumulative loss of B varied from 0.090 to 0.166 mg L^{-1}. The highest B loss was from F-TOF treated soil followed by OC and VC. The total B content in the leachates gradually decreased upto the end of the leaching for all the treatments.

Table 31. Effect of treatments on total B content in the leachates at different period of incubation, mg L^{-1}

Treatments	Total B (mg L^{-1})							CL (mg L^{-1})
	1 W	4 W	8 W	12 W	16 W	20 W	24 W	
T_{1} Control	0.046^{c}	0.025^{e}	0.0135^{d}	0.004^{d}	0.001^{c}	0.001^{b}	0.001^{b}	0.090^{f}
T_{2} Soil+FYM	0.051^{bc}	0.026^{cde}	0.0148^{d}	0.006^{d}	0.002^{bc}	0.002^{a}	0.002^{a}	0.105^{e}
T_{3} Soil+OC	0.056^{ab}	0.032^{b}	0.0275^{ab}	0.012^{ab}	0.004^{b}	0.003^{a}	0.002^{a}	0.136^{b}
T_{4} Soil+VC	0.055^{ab}	0.031^{bc}	0.0223^{bc}	0.008^{bc}	0.003^{b}	0.003^{a}	0.003^{a}	0.124^{c}
T_{5} Soil+MC	0.054^{ab}	0.029^{bcd}	0.0190^{cd}	0.007^{cd}	0.003^{b}	0.003^{a}	0.002^{a}	0.116^{cd}
T_{6} Soil+TOF	0.053^{ab}	0.027^{de}	0.0165^{cd}	0.006^{cd}	0.003^{b}	0.003^{a}	0.003^{a}	0.111^{de}
T_{7} Soil+F-TOF	0.058^{a}	0.044^{a}	0.0300^{a}	0.021^{a}	0.007^{a}	0.004^{a}	0.003^{a}	0.166^{a}
SEm±	0.002	0.002	0.002	0.002	0.0007	0.0007	0.001	0.003
CD(0.05)	0.005	0.005	0.005	0.005	0.002	0.0022	0.003	0.010

4.2.1.17 Heavy metals

Heavy metals Cd and Pb were below the detectable limits.

4.2.2 LEACHED SOIL

The data on depth wise chemical characteristics of soils of different treatments after leaching for 24 weeks are presented in Tables from 32 to 67

4.2.2.1 pH

The effect of treatments on soil pH was significant. Addition of organic fertilizers increased the pH of the surface layer and the highest pH before leaching was recorded by OC (Table 32). Leaching for 24 weeks made significant changes in pH of the soils at different depths. Comparing the pH of the leached soil with that of initial unleached soil (0 D) it was observed that pH of the surface layer

(0-15 cm) decreased and lower layers (15-90 cm) increased than the initial values, with control as an exception. For control, pH of the soil at different depths decreased due to leaching. F-TOF recorded highest pH for 0-15 cm depth, MC for 15- 30 cm depth and F-TOF for 30-90 cm depth.

Table 32. Effect of treatments on pH of the leached soil at different depths

Treatments	pH							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \mathrm{Control}}$	5.05 ^{g}	4.98 ^{f}	5.04	4.99 ^{e}	5.04	5.02 ^{d}	5.04	5.01 ^{f}
$T_{2\ \mathrm{Soil+FYM}}$	6.44 ^{c}	5.48 ^{d}	5.05	5.31 ^{d}	5.05	5.72 ^{b}	5.05	5.22 ^{e}
$T_{3\ \mathrm{Soil+OC}}$	6.61 ^{a}	5.52 ^{d}	5.05	5.34 ^{d}	5.05	5.68 ^{b}	5.05	5.39 ^{b}
$T_{4\ \mathrm{Soil+VC}}$	6.56 ^{b}	6.11 ^{c}	5.05	5.50 ^{c}	5.05	5.69 ^{b}	5.05	5.30 ^{d}
$T_{5\ \mathrm{Soil+MC}}$	6.47 ^{c}	6.18 ^{b}	5.04	5.84 ^{a}	5.04	5.38 ^{c}	5.04	5.32 ^{c}
$T_{6\ \mathrm{Soil+TOF}}$	6.39 ^{d}	5.36 ^{e}	5.04	5.40 ^{d}	5.04	5.73 ^{b}	5.04	5.32 ^{c}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	6.31 ^{e}	6.28 ^{a}	5.05	5.69 ^{b}	5.05	5.80 ^{a}	5.05	5.62^{a}
SEm ±	0.018	0.023	-	0.031	-	0.023	-	0.021
CD (0.05)	0.055	0.068	NS	0.092	NS	0.069	NS	0.063

4.2.2.2 Electric conductivity (EC)

Addition of organic fertilizers increased the EC of the surface layer (0-15 cm) and the highest EC before leaching was recorded by F-TOF which was significantly superior to all other treatments. This was followed by VC (Table 33). Leaching for 24 weeks decreased the EC of the surface layer for all treatments and the highest EC was recorded by MC. However, in the lower depths (15-30, 30-60 and 60-90 cm) EC of organic fertilizers added treatments showed an increase compared to the initial values. At the end of leaching for all the four depths, lowest EC was recorded by the control and it was lower than the initial values.

Table 33. Effect of treatments on EC of the leached soil at different depths, dS m^{-1}

Treatments	EC (dS m^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0thday	24 W	0 D	24 W
T$_{1\ \text{Control}}$	0.10 ^{g}	0.06 ^{e}	0.10	0.07 ^{d}	0.09	0.08 ^{e}	0.09	0.07 ^{d}
T$_{2\ \text{Soil+FYM}}$	0.32 ^{e}	0.12 ^{d}	0.09	0.10 ^{d}	0.08	0.12 ^{cd}	0.09	0.10 ^{cd}
T$_{3\ \text{Soil+OC}}$	0.44 ^{d}	0.19 ^{c}	0.09	0.20 ^{b}	0.09	0.14 ^{bc}	0.09	0.13 ^{b}
T$_{4\ \text{Soil+VC}}$	0.59 ^{b}	0.24 ^{b}	0.10	0.17 ^{c}	0.09	0.16 ^{ab}	0.09	0.16 ^{a}
T$_{5\ \text{Soil+MC}}$	0.53 ^{c}	0.26 ^{a}	0.09	0.19 ^{bc}	0.09	0.14 ^{bc}	0.08	0.16 ^{a}
T$_{6\ \text{Soil+TOF}}$	0.29 ^{f}	0.11 ^{d}	0.08	0.10 ^{d}	0.09	0.10 ^{de}	0.09	0.11 ^{c}
T$_{7\ \text{Soil+F-TOF}}$	0.64 ^{a}	0.25 ^{ab}	0.09	0.23^{a}	0.09	0.17 ^{a}	0.09	0.17 ^{a}
SEm ±	0.11	0.010	-	0.008	-	0.010	-	0.005
CD (0.05)	0.32 e	0.030	NS	0.024	NS	0.029	NS	0.014

4.2.2.3 Carbon pools

4.2.2.3.1 Total organic carbon (TOC)

Treatment effect on total organic carbon was significant only up to 30 cm depth (Table 34). The highest value for TOC was recorded at 0 D for all treatments. Leaching decreased the TOC content of the surface layer (0-15 cm) and enhanced that of sub-surface layer (15-30 cm). In surface and sub surface layer of leached soil, the highest value for TOC was maintained by TOF and F-TOF. At lower depths (30-90 cm) the treatment effect on TOC was not significant

Table 34. Effect of treatments on TOC content in leached soil at different depths, %

Treatments	TOC (%)							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T$_{1\ \text{Control}}$	1.13 ^{d}	0.96 ^{e}	1.12	0.98 ^{d}	1.1	1.12	1.10	1.11
T$_{2\ \text{Soil+FYM}}$	1.75 ^{c}	1.5 ^{d}	1.12	1.26 ^{c}	1.11	1.12	1.10	1.12
T$_{3\ \text{Soil+OC}}$	1.84 ^{bc}	1.62 ^{c}	1.11	1.28^{bc}	1.11	1.12	1.10	1.13
T$_{4\ \text{Soil+VC}}$	1.89 ^{b}	1.78 ^{b}	1.10	1.31^{ab}	1.10	1.12	1.10	1.12
T$_{5\ \text{Soil+MC}}$	1.85^{bc}	1.59 ^{c}	1.12	1.27 ^{c}	1.11	1.12	1.10	1.12
T$_{6\ \text{Soil+TOF}}$	2.21 ^{a}	2.02 ^{a}	1.13	1.34 ^{a}	1.10	1.12	1.10	1.13
T$_{7\ \text{Soil+F-TOF}}$	2.20 ^{a}	2.05 ^{a}	1.12	1.33^{a}	1..11	1.12	1.10	1.13
SEm ±	0.035	0.025	-	0.011	-	-	-	-
CD (0.05)	0.105	0.075	NS	0.034	NS	NS	NS	NS

4.2.2.3.2 Water soluble organic carbon (WSOC)

The WSOC of the surface layer of the unleached soil and that of all the layers of leached soil was significantly influenced by treatments (Table 35). For the unleached soil, F-TOF recorded the highest value in the surface layer followed by TOF. Leaching decreased the WSOC content of all the treatments in the surface layers, while an increase was noticed in the lower layers. Leached soil exhibited the highest WSOC content at 15-30 cm depth for all treatments except control. In the surface layer MC had the highest value and in lower layers for VC. For all the four depths, control treatment recorded the lowest value.

Table 35.Effect of treatments on WSOC content in leached soil at different depths, mg kg^{-1}

Treatments	WSOC (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	7.20 ^{g}	3.6 ^{e}	7.2	4.2 ^{f}	7.1	4.8 ^{d}	7.0`	4.2 ^{d}
$T_{2\ \text{Soil+FYM}}$	64.80 ^{c}	9.6 ^{d}	7.3	25.6 ^{e}	7.1	12.6 ^{c}	7.0	7.8 ^{c}
$T_{3\ \text{Soil+OC}}$	60.60 ^{d}	13.8 ^{c}	7.3	32.4 ^{cd}	7.1	14.4 ^{c}	7.1	13.2 ^{b}
$T_{4\ \text{Soil+VC}}$	54.00 ^{e}	25.8 ^{b}	7.2	37.8 ^{a}	7.1	21.0 ^{a}	7.0	16.8 ^{a}
$T_{5\ \text{Soil+MC}}$	34.80 ^{f}	28.8 ^{a}	7.3	30.6 ^{d}	7.1	18.6 ^{b}	7.0	16.6 ^{a}
$T_{6\ \text{Soil+TOF}}$	111.60 ^{b}	13.8 ^{c}	7.2	34.2^{bc}	7.1	16.8 ^{b}	7.1	15.6^{ab}
$T_{7\ \text{Soil+F-TOF}}$	133.20 ^{a}	14.4 ^{c}	7.2	34.8 ^{b}	7.1	18.0 ^{b}	7.0	15.6^{ab}
SEm ±	0.29	0.814	-	0.729	-	0.701	-	1.199
CD (0.05)	0.876	2.443	NS	2.187	NS	2.102	NS	3.597

4.2.2.3.3 Labile carbon

As in the case of WSOC, treatments with thermochemical organic fertilizer had the highest labile carbon (LC) content for unleached soil (Table 36). Leaching had changed the trend and only up to 30 cm these treatments had higher LC compared to conventional organic fertilizers. For 30-60 cm depth, VC recorded highest LC content and it was higher than their 0 D value. For all other treatments an increase in LC compared to initial values was noticed only in the 15-30 cm layer. For 60-90 cm all the organic fertilizer added treatments were on par with each other and the labile carbon content was lower than their initial (0 D) value. However control recorded the lowest value for all the four depths and they were lower than their initial values.

Table 36. Effect of treatments on labile carbon content in leached soil at different depths, mg kg^{-1}

Treatments	Labile carbon (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	525.38^{g}	208.13^{d}	520.23	224.23^{d}	519.34	226.12^{c}	519.02	224.63^{b}
$T_{2\ \text{Soil+FYM}}$	1144.13^{c}	428.63^{cd}	520.21	663.00^{bc}	520.07	512.25^{b}	519.56	496.50^{a}
$T_{3\ \text{Soil+OC}}$	929.25^{f}	562.50^{bc}	521.80	673.50^{abc}	520.56	519.00^{b}	520.32	487.50^{a}
$T_{4\ \text{Soil+VC}}$	1081.13^{e}	847.13^{a}	521.99	673.88^{abc}	521.80	593.25^{a}	519.88	495.75^{a}
$T_{5\ \text{Soil+MC}}$	1118.20^{d}	758.25^{ab}	521.67	624.38^{c}	52056	504.00^{b}	519.99	498.00^{a}
$T_{6\ \text{Soil+TOF}}$	1648.10^{b}	957.38^{a}	520.99	713.25^{ab}	519.99	507.00^{b}	520.23	490.50^{a}
$T_{7\ \text{Soil+F-TOF}}$	1668.00^{a}	961.88^{a}	521.45	723.00^{a}	520.34	517.50^{b}	520.12	488.25^{a}
SEm ±	2.92	82.75	-	18.75	-	15.99	-	15.59
CD (0.05)	8.76	248.26	NS	56.26	NS	47.97	NS	46.78

4.2.2.3.4 Microbial biomass carbon

All the treatments had the highest microbial biomass carbon (MBC) content (Table 37) on 0 D which decreased with leaching. The thermochemical organic fertilizers had higher MBC compared to conventional organic fertilizers. Leaching decreased MBC in surface layer while an increase in lower layers was noticed for most of the treatments except control. But for depth 30-60 cm, MBC for VC increased than their initial value. After leaching, MBC was highest for F-TOF followed by TOF to a depth of 0-30 cm, VC for 30-60 cm and MC for 60-90 cm depth. At the end of leaching, MBC of the organic fertilizer added treatments for the depth 60-90 cm were on par with each other and were slightly lower than their 0 D value.

Table 37. Effect of treatments on MBC content in leached soil at different depths, mg kg^{-1}

Treatments	MBC (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T_{1} Control	26.27 ^{e}	10.41 ^{e}	26.08	11.21 ^{f}	25.89	11.31 ^{d}	25.75	11.23 ^{b}
T_{2} Soil+FYM	57.21^{c}	21.43 ^{d}	25.99	33.15 ^{d}	25.89	25.61^{bc}	25.79	24.83 ^{a}
T_{3} Soil+OC	46.46 ^{d}	28.13 ^{c}	26.18	33.68 ^{c}	26.01	25.95 ^{b}	25.75	24.38 ^{a}
T_{4} Soil+VC	54.06 ^{c}	42.36 ^{b}	26.12	33.69 ^{c}	25.87	27.66 ^{a}	25.71	24.79 ^{a}
T_{5} Soil+MC	69.91 ^{a}	47.91 ^{a}	25.87	31.22 ^{e}	25.95	25.20 ^{c}	25.72	24.90 ^{a}
T_{6} Soil+TOF	59.64 ^{bc}	47.87 ^{a}	26.21	35.66 ^{b}	25.84	25.35^{bc}	25.77	24.53 ^{a}
T_{7} Soil+F-TOF	60.12 ^{b}	48.09 ^{a}	26.20	36.15 ^{a}	25.95	25.88 ^{b}	25.76	24.41 ^{a}
SEm ±	0.58	1.19	-	0.14	-	0.22	-	0.70
CD (0.05)	1.73	3.56	NS	0.423	NS	0.647	NS	2.11

4.2.2.3.5 Recalcitrant organic carbon

Recalcitrant organic carbon (ROC) significantly varied among the treatments on 0 D in the surface layer and for leached soil at surface (0-15 cm) and sub-surface (15-30 cm) layer (Table 38). The thermochemical organic fertilizers had higher ROC compared to conventional organic fertilizers. After 24 weeks of leaching, ROC of the surface layer decreased from that of 0 D for for all treatments. In the leached soil, the highest value for ROC at 0-15 and 15-30 cm depths was recorded by F-TOF followed by TOF. At 15-30 cm depth, the treatments such as F-TOF, TOF, VC, MC and OC were statistically on par with other for their ROC content. At lower depths (30-90 cm) the treatment effect on ROC was not significant.

Table 38. Effect of treatments on ROC content in leached soil at different depths, %

Treatments	ROC (%)							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\,\text{Control}}$	0.74 ^{f}	0.47 ^{e}	0.74	0.73 ^{d}	0.71	0.72	0.70	0.71
$T_{2\,\text{Soil+FYM}}$	1.21 ^{e}	1.15 ^{c}	0.72	0.90 ^{b}	0.71	0.72	0.70	0.72
$T_{3\,\text{Soil+OC}}$	1.26 ^{d}	1.15 ^{c}	0.73	0.94 ^{ab}	0.71	0.73	0.70	0.76
$T_{4\,\text{Soil+VC}}$	1.35 ^{c}	1.06 ^{d}	0.72	0.94 ^{ab}	0.71	0.75	0.70	0.73
$T_{5\,\text{Soil+MC}}$	1.27 ^{d}	1.04 ^{d}	0.73	0.93 ^{ab}	0.71	0.76	0.70	0.75
$T_{6\,\text{Soil+TOF}}$	1.52 ^{a}	1.48 ^{a}	0.72	0.99^{a}	0.71	0.76	0.70	0.72
$T_{7\,\text{Soil+F-TOF}}$	1.49 ^{a}	1.44 ^{a}	0.72	0.98 ^{a}	0.71	0.76	0.70	0.76
SEm ±	0.01	0.018	-	0.022	-	-	-	-
CD (0.05)	0.032	0.055	NS	0.065	NS	NS	NS	NS

4.2.2.4 Nitrogen pools

4.2.2.4.1 Ammonical nitrogen (NH_4-N)

NH_4-N showed significant variation in the surface layer for both unleached as well as leached soil, while in the lower layers significant difference was noticed only for the leached soil. NH_4-N was highest in the surface layer on 0 D and decreased with leaching. Treatments receiving OC, FYM, TOF and control showed lower NH_4-N content after leaching in all the layers while other treatments showed an increase in layers from 15 to 90 cm. NH_4-N was highest for VC for 0-15 cm and 60-90 cm, while MC got the highest value for 15-30 cm and F-TOF for 30-60 cm.

Table 39. Effect of treatments on NH_4-N content in leached soil at different depths, mg kg^{-1}

Treatments	NH_4- N (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\,\text{Control}}$	28.00 ^{f}	18.12 ^{d}	27.98	17.15 ^{d}	27.97	17.63 ^{e}	27.95	16.74 ^{d}
$T_{2\,\text{Soil+FYM}}$	33.60 ^{e}	22.80 ^{c}	28.00	21.89 ^{c}	27.99	21.65 ^{d}	27.95	20.36 ^{c}
$T_{3\,\text{Soil+OC}}$	38.00 ^{d}	29.20 ^{b}	27.97	28.69 ^{b}	27.95	27.96^{bc}	27.95	27.10^{ab}
$T_{4\,\text{Soil+VC}}$	50.40 ^{b}	34.00^{a}	27.99	32.41 ^{a}	27.97	30.58 ^{b}	27.95	29.34 ^{a}
$T_{5\,\text{Soil+MC}}$	78.40 ^{a}	32.80 ^{a}	28.01	34.25 ^{a}	27.99	31.28 ^{b}	27.96	28.54^{ab}
$T_{6\,\text{Soil+TOF}}$	44.80 ^{c}	28.80 ^{b}	27.99	26.34 ^{b}	27.99	25.32 ^{c}	27.96	24.98 ^{b}
$T_{7\,\text{Soil+F-TOF}}$	50.40 ^{b}	30.40^{b}	27.99	33.69 ^{a}	27.99	33.40 ^{a}	27.99	28.14^{ab}
SEm ±	0.58	0.66	-	0.80	-	1.15	-	1.19
CD (0.05)	1.75	1.99	NS	2.39	NS	3.44	NS	3.57

4.2.2.4.2 Nitrate nitrogen (NO_3-N)

NO_3-N content of surface layer for both unleached (0 D) and leached soil (24 W) and all layers for leached soil was significantly influenced by the treatments. The highest NO_3-N content in the surface layer was recorded by the treatment receiving MC on both 0 D as well as 24 W. For the depth 30-60 cm also MC recorded the highest value while F-TOF for 15-30 cm and OC for 60-90 cm. At the end of leaching most of the treatments significantly differed from others though some were on par with each other.

Table 40. Effect of treatments on NO_3-N content in leached soil at different depths, mg kg^{-1}

Treatments	NO_3-N (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	28.4 ^{g}	24.20 ^{f}	27.99	22.80 ^{d}	27.96	20.40 ^{e}	27.92	19.20 ^{e}
$T_{2\ \text{Soil+FYM}}$	30.8 ^{f}	39.20 ^{e}	27.98	38.40 ^{a}	27.96	61.60 ^{b}	27.93	50.40 ^{b}
$T_{3\ \text{Soil+OC}}$	47.2 ^{e}	61.60 ^{b}	28.00	39.20 ^{c}	27.96	56.00 ^{c}	27.93	61.60 ^{a}
$T_{4\ \text{Soil+VC}}$	74.6 ^{b}	50.40 ^{c}	28.00	44.80 ^{b}	27.96	49.92 ^{d}	27.93	39.20 ^{d}
$T_{5\ \text{Soil+MC}}$	91.4 ^{a}	67.20 ^{a}	27.99	42.93 ^{b}	27.95	72.78 ^{a}	27.92	49.69 ^{c}
$T_{6\ \text{Soil+TOF}}$	54.8 ^{d}	44.80 ^{d}	27.99	40.40 ^{c}	27.96	48.79 ^{d}	27.93	45.60 ^{d}
$T_{7\ \text{Soil+F-TOF}}$	62.6 ^{c}	50.40 ^{c}	27.99	50.40 ^{a}	27.96	56.86 ^{c}	27.93	52.40 ^{b}
SEm ±	1.62	1.16	-	1.25	-	1.13	-	1.16
CD (0.05)	4.85	3.47	NS	3.76	NS	3.40	NS	3.47

4.2.2.4.3 Organic nitrogen

Organic N concentration in the unleached soil at surface layer and all the layers for leached soil was significantly influenced by organic fertilizer addition (Table 41). The organic N content of surface layer of all treatments decreased after leaching and highest value in the surface layer before and after leaching was recorded by MC followed by VC, OC and F-TOF. VC recorded the highest value at 15 30 cm depth. For organic fertilizer added treatments, organic N content for the depth 15-30 cm showed an increase compared to their initial values. For the depth 30-60 and 60-90 cm, organic N content decreased than their initial values.

Table 41.Effect of treatments on organic N content in leached soil at different depths, mg kg^{-1}

Treatments	Organic N (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T1 Control	933.60^{c}	906.14^{f}	932.24	912.08^{g}	931.51	915.43^{a}	931.12	917.52^{a}
T2 Soil+FYM	1308.9^{b}	1037.79^{d}	932.68	1013.85^{e}	931.26	891.85^{c}	930.67	900.18^{b}
T3 Soil+OC	1477.2^{a}	1085.70^{b}	933.04	1020.36^{d}	931.09	915.24^{a}	930.87	886.42^{d}
T4 Soil+VC	1470.2^{a}	1090.81^{b}	932.57	1103.31^{a}	931.38	915.43^{a}	931.00	902.25^{b}
T5 Soil+MC	1473.4^{a}	1118.99^{a}	932.25	1040.87^{b}	931.31	893.740^{c}	930.37	892.47^{c}
T6 Soil+TOF	1303.7^{b}	1020.90^{e}	932.77	1007.52^{f}	931.05	906.50^{b}	930.86	898.22^{b}
T7 Soil+F-TOF	1472.9^{a}	1054.70^{c}	932.18	1024.09^{c}	931.48	909.53^{b}	930.96	909.30^{a}
SEm ±	2.33	2.24	-	1.49	-	1.53	-	1.45
CD (0.05)	7.00	6.72	NS	4.48	NS	4.58	NS	4.35

4.2.2.4.4 Total N

Before and after leaching total N content in surface and sub surface layer was highest for MC while from 30 to 90 cm depth, F-TOF had the highest values. For depth 15-30 cm, total N increased than their initial value, except for control. For the lower two depths, the total N decreased than the initial values for all the treatments.

Table 42. Effect of treatments on total N content in leached soil at different depths, mg kg^{-1}

Treatments	Total N (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T1 Control	990^{f}	951.46^{f}	988.21	952.03^{f}	987.44	953.46^{e}	986.99	953.46^{d}
T2 Soil+FYM	1373^{e}	1099.79^{d}	988.66	1074.14^{e}	987.21	975.10^{d}	986.55	970.94^{bc}
T3 Soil+OC	1563^{c}	1176.61^{b}	989.01	1088.25^{c}	987.00	999.20^{ab}	986.75	975.12^{b}
T4 Soil+VC	1595^{b}	1175.32^{b}	988.56	1180.52^{d}	987.31	995.93^{b}	986.88	970.79^{bc}
T5 Soil+MC	1643^{a}	1218.99^{a}	988.25	1118.05^{a}	987.25	997.46^{ab}	986.25	970.70^{bc}
T6 Soil+TOF	1403^{d}	1094.50^{e}	988.75	1074.26^{e}	987.00	980.61^{c}	986.75	968.80^{c}
T7 Soil+F-TOF	1585^{b}	1135.50^{c}	988.16	1108.18^{a}	987.43	999.79^{a}	986.88	989.84^{a}
SEm ±	3.5	1.63	-	1.86	-	1.21	-	1.71
CD (0.05)	10.50	4.90	NS	5.59	NS	3.63	NS	5.13

4.2.2.5 Total nutrients and heavy metals

4.2.2.5.1 Total P

Total P content of the unleached surface layer and all the layers of leached soil significantly varied among the treatments (Table 43). In the surface layer, total P was highest on 0 D and decreased with leaching. Except for surface layer in all other three layers, total P increased than their initial value due to the organic fertilizer addition followed by leaching. For the depth 0-15, 15-30 and 30-60 cm highest value was recorded for VC followed OC and MC. For depth 60-90 cm, highest value was for F-TOF followed by OC and VC.

Table 43. Effect of treatments on total P content in leached soil at different depths, mg kg^{-1}

Treatments	Total P (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\text{ Control}}$	410.0^{g}	405^{f}	408	406^{g}	407.25	408^{d}	407	412^{d}
$T_{2\text{ Soil+FYM}}$	585.0^{e}	474^{d}	408	470^{d}	407.25	430^{bc}	407	418^{c}
$T_{3\text{ Soil+OC}}$	720.0^{b}	523^{b}	408	517^{b}	407.25	444^{a}	407	430^{b}
$T_{4\text{ Soil+VC}}$	750.0^{a}	541^{a}	408	538^{a}	407.25	447^{a}	407	428^{b}
$T_{5\text{ Soil+MC}}$	632.5^{c}	494^{c}	408	488^{c}	407.25	435^{b}	407	422^{c}
$T_{6\text{ Soil+TOF}}$	532.5^{f}	450^{e}	408	439^{f}	407.25	426^{c}	407	421^{c}
$T_{7\text{ Soil+F-TOF}}$	622.5^{d}	480^{d}	408	448^{e}	407.25	442^{a}	407	439^{a}
SEm ±	2.34	2.66		1.93		2.27		1.84
CD (0.05)	7.01	7.99	NS	5.78	NS	6.81	NS	5.52

4.2.2.5.2 Total K

Total K of the unleached surface layer and all the layers of leached soil varied significantly among the treatments (Table 44). Due the organic fertilizer addition total K was highest in the surface layer and it decreased with leaching. For 15-30 cm depth, all treatment showed an increase in total K content than their initial value except for control and FYM. F-TOF maintained highest total K content at all depths, even after the leaching for 24 weeks.

Table 44. Effect of treatments on total K content in leached soil at different depths, mg kg^{-1}

Treatments	Total K (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \mathrm{Control}}$	800^{g}	720^{f}	798	750^{f}	798	700^{f}	797	690^{d}
$T_{2\ \mathrm{Soil+FYM}}$	1035^{f}	770^{e}	798	790^{e}	798	725^{e}	797	710^{c}
$T_{3\ \mathrm{Soil+OC}}$	1265^{d}	795^{d}	798	805^{d}	798	760^{bc}	797	745^{b}
$T_{4\ \mathrm{Soil+VC}}$	1320^{b}	815^{b}	798	820^{c}	798	755^{cd}	797	750^{b}
$T_{5\ \mathrm{Soil+MC}}$	1250^{e}	820^{b}	798	830^{b}	798	750^{d}	797	745^{b}
$T_{6\ \mathrm{Soil+TOF}}$	1285^{c}	805^{c}	798	825^{bc}	798	765^{b}	797	745^{b}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	1440^{a}	830^{a}	798	850^{a}	798	780^{a}	797	765^{a}
SEm ±	4.38	2.82	-	2.79	-	2.60	-	2.30
CD (0.05)	13.13	8.47	NS	8.38	NS	7.81	NS	6.90

4.2.2.5.3 Total Ca

Total Ca of the unleached surface layer and all the layers of leached soil varied significantly among the treatments (Table 45). Total Ca content was highest for F-TOF in the surface layer of the unleached soil and all the layers of leached soil. Compared to the initial values, total Ca showed a decrease in all the soil layers due to leaching. For all treatment highest Ca concentration was recorded in 15-30 cm depth.

Table 45. Effect of treatments on total Ca content in leached soil at different depths, mg kg^{-1}

Treatments	Total Ca (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \mathrm{Control}}$	330^{f}	258^{f}	330	262^{d}	328	260^{c}	328	258^{d}
$T_{2\ \mathrm{Soil+FYM}}$	450^{e}	268^{e}	330	275^{c}	328	262^{bc}	328	260^{cd}
$T_{3\ \mathrm{Soil+OC}}$	530^{c}	274^{cd}	330	280^{c}	328	265^{bc}	328	261^{cd}
$T_{4\ \mathrm{Soil+VC}}$	530^{c}	272de	330	278^{c}	328	266^{b}	328	262^{bcd}
$T_{5\ \mathrm{Soil+MC}}$	570^{b}	283^{b}	330	294^{b}	328	267^{b}	328	263^{bc}
$T_{6\ \mathrm{Soil+TOF}}$	510^{d}	279^{bc}	330	292^{b}	328	266^{b}	328	266^{b}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	610^{a}	290^{a}	330	310^{a}	328	280^{a}	328	276^{a}
SEm ±	2.04	1.71	-	2.01	-	1.90	-	1.45
CD (0.05)	6.13	5.13	NS	6.04	NS	5.70	NS	4.35

4.2.2.5.4 Total Mg

Total Mg content of the leached soil significantly varied among the treatments for all the four depths while for unleached soil it was significant only in the surface layer (Table 46). Before leaching, the surface layer had the highest Mg content and it decreased in all treatments due to leaching. After leaching, in all depths, total Mg content decreased than their initial values. Mg recorded the highest value for in F-TOF followed by VC at all four depths**.**

Table 46.Effect of treatments on total Mg content in leached soil at different depths,mg kg^{-1}

Treatments	Total Mg (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T_1 Control	140.0 ^{g}	77.89 ^{d}	139	78.69 ^{c}	138.69	77.78 ^{c}	138.01	75.54 ^{c}
T_2 Soil+FYM	182.5 ^{f}	79.36 ^{cd}	139	82.45 ^{b}	139.00	81.23 ^{b}	138.25	79.40 ^{b}
T_3 Soil+OC	205.0 ^{c}	82.56 ^{c}	139	83.99 ^{b}	138.66	82.34 ^{b}	138.12	79.89 ^{b}
T_4 Soil+VC	210.0 ^{b}	88.14 ^{b}	139	85.23 ^{b}	138.55	83.80 ^{b}	138.21	78.89 ^{b}
T_5 Soil+MC	197.5 ^{d}	86.14 ^{b}	139	83.90 ^{b}	138.99	81.67 ^{b}	138.14	77.42 ^{b}
T_6 Soil+TOF	192.5 ^{e}	82.34 ^{c}	139	82.78^{b}	138.66	82.24 ^{b}	138.01	78.56 ^{b}
T_7 Soil+F-TOF	335.0 ^{a}	94.2 ^{a}	139	95.78 ^{a}	138.96	89.99 ^{a}	138.42	87.10 ^{a}
SEm ±	1.46	1.27	-	1.45	-	1.03	-	0.96
CD (0.05)	4.37	3.81	NS	3.35	NS	3.09	NS	2.88

4.2.2.5.5 Total S

Total S of the unleached surface layer and all the layers of leached soil varied significantly among the treatments (Table 47). In the surface layer the total S was highest at 0 D which decreased with leaching. After leaching, in all depths, total S decreased than their initial values. For 0-15 cm depth the highest value was for FYM followed by OC and F-TOF. In the surface layer of leached soil, all the organic fertilizers amended treatments were statistically on par with each other for their sulphur content, except FYM. At 15-30 cm depth, all the treatments were statistically on par with each other, except control.

Table 47. Effect of treatments on total S content in leached soil at different depths, mg kg^{-1}

Treatments	Total S (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T1 Control	480.00 ^{d}	459.00 ^{c}	478	466.00 ^{b}	478	458.00	477	458.00
T2 Soil+FYM	507.50 ^{a}	461.58 ^{a}	478	468.28 ^{a}	478	459.78	477	459.47
T3 Soil+OC	500.00 ^{b}	460.33 ^{b}	478	467.33 ^{a}	478	459.33	477	459.33
T4 Soil+VC	496.50^{bc}	459.53 ^{b}	478	466.53 ^{a}	478	459.58	477	458.53
T5 Soil+MC	493.25 ^{b}	459.45 ^{b}	478	467.35 ^{a}	478	458.90	477	458.45
T6 Soil+TOF	491.00 ^{c}	460.05 ^{b}	478	466.59 ^{a}	478	458. 55	477	458.52
T7 Soil+F-TOF	495.50 ^{c}	460.10 ^{b}	478	466.85 ^{a}	478	458.85	477	458.85
SEm ±	1.58	0.32	-	0.78	-	-	-	-
CD (0.05)	4.76	0.90	NS	1.54	NS	NS	NS	NS

4.2.2.5.6 Total Fe

Total Fe content of the surface layer of soil before leaching and all the soil layers after leaching varied significantly among treatments (Table 48). In the surface layer, the total Fe was highest on 0 D (before leaching) which decreased with leaching while the lower layers showed an increase in total Fe content after leaching. For unleached surface layer (0-15 cm) and leached soil at all the four depths, the highest value for Fe was with FYM.

Table 48. Effect of treatments on total Fe content in leached soil at different depths, mg kg^{-1}

Treatments	Total Fe (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T1 Control	643 ^{g}	633 ^{e}	640	635 ^{d}	638	636 ^{c}	639	630 ^{d}
T2 Soil+FYM	983 ^{a}	743 ^{a}	640	698 ^{a}	639	654 ^{a}	638	650 ^{a}
T3 Soil+OC	928 ^{b}	732^{b}	639	689 ^{b}	638	652 ^{a}	640	645 ^{b}
T4 Soil+VC	898 ^{c}	725 ^{b}	640	688 ^{b}	639	650 ^{a}	638	648 ^{a}
T5 Soil+MC	873 ^{d}	729 ^{b}	640	697 ^{a}	638	644 ^{b}	640	640 ^{c}
T6 Soil+TOF	724 ^{f}	674 ^{d}	638	672 ^{c}	639	638 ^{c}	638	632 ^{d}
T7 Soil+F-TOF	774 ^{e}	690 ^{c}	640	674 ^{c}	639	642 ^{b}	640	640 ^{c}
SEm ±	3.48	2.65	-	2.41	-	1.99	-	1.04
CD (0.05)	10.45	7.94	NS	6.22	NS	4.34	NS	3.02

4.2.2.5.7 Total Mn

Total Mn of soil before and after leaching varied significantly among treatments (Table 49). In the surface layer, total Mn was highest at 0 D which decreased with leaching. For 0-15 cm depth, total Mn before leaching (at 0 D) was highest with VC followed by OC, MC and FYM and they were statistically on par with each other. After leaching, highest value was recorded by VC followed by OC, and they were statistically on par with each other. Total Mn of the leached soil at the lower depths (15-30, 30-60 and 60-90 cm) did not vary significantly among the treatments

Table 49. Effect of treatments on total Mn content in leached soil at different depths, mg kg^{-1}

Treatments	Total Mn (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	84.23 ^{d}	75.80 ^{d}	84.23	76.4	78.9	78.9	77.56	77.56
$T_{2\ \text{Soil+FYM}}$	91.97 ^{ab}	82.80 ^{b}	84.23	79.4	79.41	79.41	78.54	78.54
$T_{3\ \text{Soil+OC}}$	96.02 ^{a}	86.19 ^{ab}	84.23	81.6	77.58	79.58	77.12	79.12
$T_{4\ \text{Soil+VC}}$	96.22 ^{a}	86.95 ^{a}	84.23	82.6	79.56	79.56	78.96	78.96
$T_{5\ \text{Soil+MC}}$	92.81 ^{ab}	83.84 ^{b}	84.23	80.6	78.25	78.25	77.89	77.89
$T_{6\ \text{Soil+TOF}}$	87.62 ^{cd}	78.89 ^{c}	84.23	80.6	79.41	79.41	78.96	78.96
$T_{7\ \text{Soil+F-TOF}}$	88.88 ^{bc}	79.56 ^{c}	84.23	81.42	78.52	78.52	77.58	78.99
SEm ±	1.45	0.816	-	-	-	-	-	-
CD (0.05)	4.34	2.42	NS	NS	NS	NS	NS	NS

4.2.2.5.8 Total Zn

Total Zn content of the unleached and leached surface layer of soil varied significantly among treatments (Table 50). In the surface layer, total Zn was highest at 0 D which decreased with leaching. For 0-15 cm depth, total Zn before leaching was highest with F-TOF followed by OC and VC and after leaching highest value was recorded by F-TOF followed by VC and OC and they were statistically on par with each other. Total Zn of the leached soil at the lower depths (15-30, 30-60 and 60-90 cm) did not vary significantly among treatment

Table 50. Effect of treatments on total Zn content in leached soil at different depths, mg kg^{-1}

Treatments	Total Zn (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\text{ Control}}$	75.00 ^{c}	72.20 ^{c}	72	69.00	70	66.00	69	70.0
$T_{2\text{ Soil+FYM}}$	79.08 ^{ab}	76.10 ^{b}	71	72.00	70	69.00	70	70.8
$T_{3\text{ Soil+OC}}$	80.68 ^{a}	77.45 ^{ab}	73	71.20	71	69.60	69	70.2
$T_{4\text{ Soil+VC}}$	80.45 ^{a}	77.96 ^{ab}	70	70.20	70	69.80	70	70.4
$T_{5\text{ Soil+MC}}$	79.54 ^{ab}	76.56 ^{b}	70	71.40	70	70.20	70	70.4
$T_{6\text{ Soil+TOF}}$	77.69 ^{b}	74.85 ^{b}	70	71.00	71	69.80	70	70.4
$T_{7\text{ Soil+F-TOF}}$	81.35 ^{a}	78.49 ^{a}	72	72.40	70	71.00	70	70.2
SEm ±	0.754	0.627	-	-	-	-	-	-
CD (0.05)	2.26	1.88	NS	NS	NS	NS	NS	NS

4.2.2.5.9 Total Cu

Total Cu of the unleached and leached surface layer of soil varied significantly among treatments (Table 51). In the surface layer, the total Cu was highest at 0 D which decreased with leaching. For 0-15 cm depth, total Cu before leaching was highest with VC followed by OC, MC, FYM and F-TOF and they were statistically on par with each other. After leaching, the highest value was recorded by VC followed by OC, MC and FYM and they were statistically on par with each other. Total Cu of the leached soil at the lower depths (15-30, 30-60 and 60-90 cm) did not vary significantly among treatments.

Table 51. Effect of treatments on total Cu content in leached soil at different depths, mg kg^{-1}

Treatments	Total Cu (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\text{ Control}}$	24.60 ^{c}	20.80 ^{c}	24.2	24.8	24.2	24.2	24.7	24.7
$T_{2\text{ Soil+FYM}}$	26.00 ^{ab}	22.31 ^{ab}	24.3	25.2	24.3	24.3	24.2	24.2
$T_{3\text{ Soil+OC}}$	26.24 ^{ab}	22.56 ^{ab}	24.6	24.12	24.6	24.6	24.5	24.5
$T_{4\text{ Soil+VC}}$	26.37 ^{a}	22.89 ^{a}	24.5	25.4	24.5	24.5	24.6	24.6
$T_{5\text{ Soil+MC}}$	26.18 ^{ab}	22.50 ^{ab}	24.7	24.16	24.7	24.7	24.2	24.2
$T_{6\text{ Soil+TOF}}$	25.67 ^{b}	21.91 ^{b}	24.2	26.14	24.2	24.2	24.6	24.6
$T_{7\text{ Soil+F-TOF}}$	25.84 ^{ab}	22.10 ^{b}	24.3	26.28	24.3	24.3	24.8	24.5
SEm ±	0.22	0.80	-	-	-	-	-	-
CD (0.05)	0.669	0.76	NS	NS	NS	NS	NS	NS

4.2.2.5.10 Total B

Total B content in the surface layer for both unleached as well as leached soil varied significantly and in lower layers significant difference was noticed only in leached soil (Table 52). Total B content was highest in the surface layer on 0 D and decreased with leaching. In the unleached surface layer, highest total B content (5.54 mg kg^{-1}) was recorded with F-TOF followed by VC (5.18 mg kg^{-1}) and OC (5.14mg kg^{-1}) and they were on par with each other. In the surface layer of leached soil, the highest B content was recorded with F-TOF. It was followed by VC, MC and OC and they were statistically on par with each other. In the control, the total B concentration decreased at all the four depths than their initial value due to leaching. For the depths 30-60 and 60-90 cm, the treatment received organic fertilizers were on par with each other for their B concentration

Table 52.Total B content in leached soil at different depths as affected by treatments, mg kg^{-1}

Treatments	Total B (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T$_1$ Control	4.38 ^{d}	4.12 ^{d}	4.38	4.18 ^{c}	4.38	4.33 ^{b}	4.38	4.35 ^{b}
T$_2$ Soil+FYM	4.82 ^{c}	4.34 ^{c}	4.38	4.29 ^{b}	4.38	4.36 ^{a}	4.38	4.38 ^{a}
T$_3$ Soil+OC	5.14 ^{b}	4.55 ^{b}	4.38	4.31^{b}	4.38	4.38 ^{a}	4.38	4.39 ^{a}
T$_4$ Soil+VC	5.18 ^{b}	4.57 ^{b}	4.38	4.32 ^{b}	4.38	4.38 ^{a}	4.38	4.40 ^{a}
T$_5$ Soil+MC	5.10 ^{b}	4.56 ^{b}	4.38	4.31 ^{b}	4.38	4.37 ^{a}	4.38	4.39 ^{a}
T$_6$ Soil+TOF	4.90 ^{c}	4.40 ^{c}	4.38	4.29 ^{b}	4.38	4.37 ^{a}	4.38	4.38 ^{a}
T$_7$ Soil+F-TOF	5.54 ^{a}	4.80 ^{a}	4.38	4.44 ^{a}	4.38	4.40 ^{a}	4.38	4.41 ^{a}
SEm ±	0.046	0.053	-	0.026	-	0.023	-	-
CD (0.05)	0.14	0.15	NS	0.08	NS	0.06	NS	0.04

4.2.2.5.11 Total heavy metals

Among the heavy metals, Cd was not detected in any of the soil samples while Pb had shown its presence in all the treatments. Hence the results of Pb alone are presented.

Total Pb content of unleached soil in the surface layer and leached soil at surface and sub-surface layer varied significantly among the treatments (Table 53). In the unleached surface layer the highest Pb content was with FYM (0.249 mg kg^{-1}) and all other treatments except control and OC was statistically on par with it. Similarly in the surface layer of leached soil, the Pb content was highest in FYM and other treatment such as VC, MC, TOF and F-TOF was statistically on par with it. The treatment OC and control did not varied significantly for the Pb content in the surface layer of leached soil. In the sub-surface layer all the treatment received organic fertilizers were statistically on par with each other for their Pb content. In lower depths beyond 30 cm there was no significant difference between the treatments for their Pb content

Table 53. Total Pb content in leached soil at different depths as affected by treatments, mg kg^{-1}

Treatments	Total Pb (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	0.155 ^{c}	0.150 ^{b}	0.151	0.151 ^{b}	0.150	0.15	0.151	0.152
$T_{2\ \text{Soil+FYM}}$	0.249 ^{a}	0.194 ^{ab}	0.152	0.179 ^{a}	0.152	0.155	0.151	0.151
$T_{3\ \text{Soil+OC}}$	0.201 ^{b}	0.172 ^{b}	0.156	0.164 ^{ab}	0.151	0.151	0.153	0.152
$T_{4\ \text{Soil+VC}}$	0.247 ^{a}	0.222 ^{a}	0.155	0.166 ^{ab}	0.151	0.157	0.152	0.153
$T_{5\ \text{Soil+MC}}$	0.231 ^{a}	0.214 ^{a}	0.155	0.165 ^{ab}	0.151	0.154	0.151	0.154
$T_{6\ \text{Soil+TOF}}$	0.224 ^{a}	0.184 ^{ab}	0.156	0.170 ^{ab}	0152	0.158	0.150	0.154
$T_{7\ \text{Soil+F-TOF}}$	0.238 ^{a}	0.201 ^{ab}	0.155	0.176 ^{a}	0.153	0.155	0.151	0.154
SEm ±	0.015	0.014	-	0.008	.-	-	-	-
CD (0.05)	0.042	0.039	NS	0.024	NS	NS	NS	NS

4.2.2.6 Available nutrients

4.2.2.6.1 Available phosphorus

Available P content of the surface layer of unleached soil and all the layers of leached soil significantly varied between treatments (Table 54). Except in control, F-TOF and TOF treatments in all other treatments available P in the surface layer was higher than their 0 D value. However in other depths, for all the treatments, available

P was lower than their initial value. For 0-15 cm depth, available P was the highest for VC and it was on par with OC and FYM. For depth 15-30 cm, highest value was for VC followed by MC and OC and was on par with each other. For depth 30-60 cm, highest value was for FYM followed by OC and F-TOF and they were on par with each other. For depth 60-90 cm, highest value was for F-TOF followed by OC and VC.

Table 54. Effect of treatments on available P in the leached soil at different depths mg kg^{-1}

Treatments	Available P (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T_1 Control	36.05^{d}	21.53^{e}	35.66	25.50^{c}	35.41	24.78^{d}	35.11	16.52^{d}
T_2 Soil+FYM	39.62^{b}	49.43^{a}	35.85	32.30^{b}	35.41	35.08^{a}	35.11	17.43^{cd}
T_3 Soil+OC	40.00^{b}	49.94^{a}	35.24	32.67^{ab}	35.21	34.72^{a}	35.10	20.38^{ab}
T_4 Soil+VC	40.17^{b}	52.32^{a}	35.66	36.67^{a}	35.11	29.90^{c}	35.07	20.30^{abc}
T_5 Soil+MC	40.50^{b}	45.08^{b}	35.99	33.00^{ab}	35.21	27.00^{d}	35.10	18.97^{abcd}
T_6 Soil+TOF	38.50^{c}	31.75^{d}	35.89	29.30^{bc}	35.21	30.92^{bc}	35.21	17.85^{bcd}
T_7 Soil+F-TOF	43.23^{a}	37.23^{c}	35.56	31.48^{b}	35.17	33.03^{ab}	35.07	21.47^{a}
SEm ±	0.58	1.05	-	1.43	-	0.83	-	0.97
CD (0.05)	1.75	3.15	NS	4.28	NS	2.48	NS	2.90

4.2.2.6.2 Available potassium

Available K content of the leached soil varied significantly among the treatments for all the four depths (Table 55). Available K in surface layer was higher than 0 D value for all treatments except for control and FYM. For lower depths, all treatments showed an increase in the available K content than their initial values. For depth 0-15, 15-30 and 60-90 cm, highest value was for F-TOF followed by TOF. For depth 30-60 cm, highest value was for OC followed by VC and F-TOF.

Table 55.Effect of treatments on available K in the leached soil at different depths mg kg^{-1}

Treatments	Available K (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \mathrm{Control}}$	125.00^{e}	75.00^{g}	125.00	133.33^{g}	123.55	191.67^{g}	123.52	175.00^{f}
$T_{2\ \mathrm{Soil+FYM}}$	137.50^{d}	100.00^{f}	1250.0	141.67^{f}	123.66	208.33^{f}	123.45	183.33^{e}
$T_{3\ \mathrm{Soil+OC}}$	139.54^{d}	191.67^{c}	125.00	250.00^{c}	123.45	350.00^{a}	123.66	275.00^{b}
$T_{4\ \mathrm{Soil+VC}}$	143.45^{c}	150.00^{d}	125.00	183.33^{e}	123.89	333.33^{b}	123.44	258.33^{c}
$T_{5\ \mathrm{Soil+MC}}$	139.45^{d}	141.67^{e}	125.00	200.00^{d}	124.12	283.33^{e}	123.44	233.33^{d}
$T_{6\ \mathrm{Soil+TOF}}$	149.39^{b}	200.00^{b}	125.00	333.33^{b}	124.22	300.00^{d}	123.66	291.59^{a}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	184.40^{a}	258.33^{a}	125.00	341.67^{a}	123.66	325.00^{c}	123.53	291.67^{a}
SEm ±	1.17	1.10	-	1.56	-	1.23	-	1.60
CD (0.05)	3.51	3.31	NS	4.67	NS	3.68	NS	4.79

4.2.2.6.3 Available calcium

Available Ca in all the depths of leached soil was higher than their initial value, except for control (Table 56). For depth 0-15 cm, highest available Ca was for F-TOF. It was followed by VC, MC, OC and TOF and they were on par with each other. For lower depths, 15-30, 30-60 and 60-90 cm depth, MC recorded the highest value, followed by VC and F-TOF for first two depths. For 60-90 cm, MC was followed by F-TOF and TOF.

Table 56.Effect of treatments on available Ca in the leached soil at different depths mg kg^{-1}

Treatments	Available Ca (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \mathrm{Control}}$	180.00^{e}	153.33^{d}	179.00	158.00^{e}	178.99	171.00^{e}	178.55	170.00^{f}
$T_{2\ \mathrm{Soil+FYM}}$	190.00^{d}	259.80^{c}	179.00	233.56^{d}	178.56	203.46^{d}	178.44	186.67^{e}
$T_{3\ \mathrm{Soil+OC}}$	194.00^{c}	266.89^{b}	179.00	239.04^{c}	178.66	222.90^{c}	178.14	198.67^{d}
$T_{4\ \mathrm{Soil+VC}}$	197.00^{b}	263.24^{bc}	179.22	246.98^{b}	178.99	234.67^{b}	178.21	205.87^{c}
$T_{5\ \mathrm{Soil+MC}}$	195.00^{bc}	268.37^{b}	179.22	257.8^{a}	178.89	245.67^{a}	178.21	243.56^{a}
$T_{6\ \mathrm{Soil+TOF}}$	193.00^{c}	265.67^{b}	179.12	235.67^{cd}	178.98	233.78^{b}	178.24	218.19^{b}
$T_{7\mathrm{Soil+FTOF}}$	279.00^{a}	275.45^{a}	179.23	246.56^{b}	178.59	233.03^{b}	178.24	219.34^{b}
SEm ±	0.67	1.72		1.40		1.48		1.48
CD(0.05)	2.01	5.17	NS	4.186	NS	4.45	NS	4.45

4.2.2.6.4 Available magnesium

The available Mg was highest in the surface layer at the 0 D which decreased with leaching (Table 57). In all treatments, available Mg decreased than their initial value for all the four depths. The available Mg recorded was the highest for F-TOF for all the four depth, followed by TOF for 0-15 cm depth, and FYM for the lower depths viz., 15-30, 30-60 and 60-90 cm. The lowest value was recorded for control.

Table 57. Available Mg in the leached soil at different depths as influenced by the treatments, mg kg^{-1}

Treatments	Available Mg (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	105 ^{c}	42 ^{d}	102	64 ^{d}	101	66 ^{c}	100	62 ^{d}
$T_{2\ \text{Soil+FYM}}$	106 ^{c}	68 ^{c}	102	72 ^{b}	101	72 ^{b}	101	70 ^{b}
$T_{3\ \text{Soil+OC}}$	108 ^{bc}	66 ^{c}	101	73 ^{b}	101	69^{bc}	101	68 ^{bc}
$T_{4\ \text{Soil+VC}}$	110 ^{b}	78 ^{b}	103	68 ^{c}	102	69^{bc}	101	66 ^{c}
$T_{5\ \text{Soil+MC}}$	108 ^{bc}	69 ^{c}	102	66 ^{cd}	101	68^{bc}	101	69 ^{bc}
$T_{6\ \text{Soil+TOF}}$	106 ^{c}	66 ^{c}	101	68 ^{c}	102	68^{bc}	101	71 ^{ab}
$T_{7\ \text{Soil+F-TOF}}$	210 ^{a}	86 ^{a}	101	88 ^{a}	102	86 ^{a}	101	74 ^{a}
SEm ±	0.84	1.87		1.30		1.68		1.25
CD (0.05)	2.53	5.62	NS	3.91	NS	5.03	NS	3.74

4.2.2.6.5 Available sulphur

Available S was highest in the surface layer at 0 D for all treatments (Table 58). For the depths such as 0-15, 30-60 and 60-90 cm available S decreased than their initial value after leaching. For 15-30 cm available S increased than their initial except for control. Available sulphur was highest for FYM in the surface layer and for F-TOF in the lower depths (Table 58). For depth 0-15 cm FYM was on par with F-TOF, VC, MC and TOF. For depth 15-30 cm, F-TOF was followed by TOF and OC. For depth 30-60 cm, F-TOF was followed by TOF and MC. For depth 60-90 cm, F-TOF, TOF and MC were on par with each other.

Table 58.Effect of treatments on available S in the leached soil at different depths, mg kg^{-1}

Treatments	Available S (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T_1 Control	14.50 ^{d}	12.50 ^{c}	13.75	11.50 ^{d}	13.55	5.50 ^{c}	13.21	5.33 ^{c}
T_2 Soil+FYM	18.50 ^{b}	23.33 ^{a}	13.99	29.00^{bc}	13.55	10.60 ^{a}	13.15	8.17 ^{a}
T_3 Soil+OC	16.75 ^{c}	16.83^{bc}	13.89	27.17 ^{b}	13.54	7.50^{bc}	13.16	6.17^{bc}
T_4 Soil+VC	16.25 ^{c}	19.67^{ab}	13.89	24.50^{bc}	13.45	6.67 ^{c}	13.14	7.33^{ab}
T_5 Soil+MC	16.75 ^{c}	19.00^{ab}	13.99	21.00 ^{c}	13.55	9.50^{ab}	13.25	8.17 ^{a}
T_6 Soil+TOF	15.20 ^{d}	19.00^{ab}	13.75	27.67 ^{b}	13.45	11.17 ^{a}	13.24	8.33 ^{a}
T_7 Soil+F-TOF	21.50 ^{a}	21.67^{a}	13.89	33.00 ^{a}	13.55	11.50 ^{a}	13.19	9.17 ^{a}
SEm ±	0.29	1.45	-	1.31	-	0.85	-	0.63
CD (0.05)	0.876	4.35	NS	3.94	NS	2.54	NS	1.88

4.2.2.6.6 Available Fe

Available Fe content in the surface layer of unleached soil and leached soil at four different depths varied significantly among treatments (Table 59). In the unleached surface layer, the highest value for available Fe was recorded for F-TOF followed by TOF. In the leached soil, the available Fe in the surface layer recorded highest for MC followed by VC. The highest value for available Fe in the leached soil at 15-30 and 30-90 cm depths were recorded by VC and F-TOF, respectively. Available Fe content in the surface layer of unleached soil and leached soil at four different depths was lowest for absolute control (T_1).

Table 59.Effect of treatments on available Fe in the leached soil at different depths,mg kg^{-1}

Treatments	Available Fe (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T_1 Control	4.28 ^{f}	3.29 ^{g}	4.28	3.40 ^{d}	4.25	3.16 ^{e}	4.24	3.11 ^{d}
T_2 Soil+FYM	6.06 ^{d}	4.91 ^{e}	4.28	3.43 ^{d}	4.26	3.23 ^{e}	4.25	3.18 ^{d}
T_3 Soil+OC	5.39 ^{e}	5.02 ^{d}	4.27	5.84 ^{a}	4.27	3.86 ^{c}	4.26	3.12 ^{d}
T_4 Soil+VC	6.09 ^{d}	6.41 ^{b}	4.25	5.73 ^{a}	4.25	4.38 ^{b}	4.25	3.73 ^{c}
T_5 Soil+MC	6.58 ^{c}	6.57 ^{a}	4.28	4.40 ^{c}	4.26	3.32 ^{d}	4.24	3.18 ^{d}
T_6 Soil+TOF	14.32 ^{b}	4.66 ^{f}	4.26	4.93 ^{b}	4.25	4.40 ^{b}	4.25	4.89 ^{b}
T_7 Soil+F-TOF	19.56 ^{a}	6.03 ^{c}	4.25	5.01 ^{b}	4.25	6.24 ^{a}	4.26	5.46 ^{a}
SEm ±	0.009	0.026	-	0.037	-	0.025	-	0.057
CD (0.05)	0.028	0.078	NS	0.111	NS	0.075	NS	0.17

4.2.2.6.7 Available Mn

Available Mn content in the surface layer of unleached soil and leached soil at four different depths varied significantly among treatments (Table 60). In the unleached surface layer and leached soil at 30-60 and 60-90 cm, highest value for available Mn was recorded by VC. In leached soil at 0-15 and 15- 30 cm depth, the highest value for available Mn was recorded by F-TOF. Available Mn content in the surface layer of unleached soil and leached soil at four different depths was lowest for absolute control (T$_1$).

Table 60. Available Mn in the leached soil at different depths as influenced by the treatments, mg kg^{-1}

Treatments	Available Mn (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \mathrm{Control}}$	2.19^{f}	2.06^{f}	2.28	2.04^{e}	2.26	2.38^{d}	2.25	2.34^{e}
$T_{2\ \mathrm{Soil+FYM}}$	2.39^{c}	2.71^{d}	2.28	2.50^{b}	2.26	2.52^{bc}	2.25	2.44^{d}
$T_{3\ \mathrm{Soil+OC}}$	2.28^{e}	2.73^{d}	2.28	2.46^{bc}	2.26	2.53^{bc}	2.25	2.51^{c}
$T_{4\ \mathrm{Soil+VC}}$	2.24^{e}	3.33^{b}	2.28	2.66^{a}	2.26	2.64^{a}	2.25	2.74^{a}
$T_{5\ \mathrm{Soil+MC}}$	2.32^{d}	3.13^{c}	2.28	2.44^{c}	2.26	2.55^{b}	2.25	2.56^{b}
$T_{6\ \mathrm{Soil+TOF}}$	2.49^{b}	2.22^{e}	2.28	2.34^{d}	2.26	2.36^{d}	2.25	2.46^{d}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	3.06^{a}	3.48^{a}	2.28	2.71^{a}	2.26	2.48^{c}	2.25	2.46^{d}
SEm ±	0.022	0.019	-	0.017	-	0.019	-	0.013
CD (0.05)	0.067	0.056	NS	0.052	NS	0.057	NS	0.038

4.2.2.6.8 Available Zn

Available Zn content in the surface layer of unleached soil and leached soil at four different depths varied significantly among treatments (Table 61). At the surface layer (0-15 cm depth) before leaching, highest value was recorded by F-TOF. In leached soil at 0-15, 30-60 and 60-60 cm depth, the highest value for available Zn was recorded by the treatment F-TOF. At 15-30 cm depth, the highest value for available Zn was recorded by VC. Available Zn content in the surface layer of unleached soil and leached soil at four different depths was lowest for absolute control (T$_1$).

Table 61.Effect of treatments on available Zn in the leached soil at different depths mg kg^{-1}

Treatments	Available Zn (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\,\mathrm{Control}}$	0.75 ^{c}	0.565 ^{d}	0.458	0.438 ^{f}	0.455	0.450 ^{f}	0.455	0.458 ^{e}
$T_{2\,\mathrm{Soil+FYM}}$	0.77 ^{bc}	0.790 ^{c}	0.455	0.596 ^{d}	0.455	0.550 ^{b}	0.455	0.526 ^{b}
$T_{3\,\mathrm{Soil+OC}}$	0.79 ^{bc}	0.814 ^{c}	0.454	0.594 ^{d}	0.455	0.560 ^{b}	0.455	0.508 ^{c}
$T_{4\,\mathrm{Soil+VC}}$	0.81 ^{b}	1.026 ^{b}	0.455	0.704 ^{a}	0.455	0.532 ^{c}	0.455	0.538 ^{a}
$T_{5\,\mathrm{Soil+MC}}$	0.78 ^{bc}	1.004 ^{b}	0.454	0.558 ^{e}	0.456	0.502 ^{d}	0.455	0.486 ^{d}
$T_{6\,\mathrm{Soil+TOF}}$	0.78 ^{bc}	0.794 ^{c}	0.455	0.642 ^{c}	0.455	0.462 ^{e}	0.455	0.522 ^{b}
$T_{7\,\mathrm{Soil+F\text{-}TOF}}$	1.34 ^{a}	1.116 ^{a}	0.455	0.656 ^{b}	0.456	0.582 ^{a}	0.455	0.540 ^{a}
SEm ±	0.017	0.015	-	0.002	-	0.004	-	0.004
CD (0.05)	0.050	0.044	NS	0.005	NS	0.012	NS	0.011

4.2.2.6.9 Available Cu

Available Cu content in the surface layer of unleached soil and leached soil at four different depths varied significantly among treatments (Table 62). In the unleached surface layer, the highest value for available Cu was recorded for VC followed by OC. In leached soil, at 0-15, 30-60 and 60-90 cm, highest value for available Cu was recorded by F-TOF and for 15-30 cm depth the highest value was recorded by VC. Available Cu content in the surface layer of unleached and leached soil at four different depths was lowest for absolute control (T_1)

Table 62.Effect of treatments on available Cu in the leached soil at different depths mg kg^{-1}

Treatments	Available Cu (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\,\mathrm{Control}}$	0.352 ^{b}	0.252 ^{e}	0.261	0.242 ^{g}	0.201	0.196 ^{f}	0.200	0.168 ^{g}
$T_{2\,\mathrm{Soil+FYM}}$	0.357 ^{a}	0.282 ^{d}	0.261	0.274 ^{e}	0.202	0.236 ^{c}	0.200	0.196 ^{d}
$T_{3\,\mathrm{Soil+OC}}$	0.361 ^{a}	0.274 ^{d}	0.261	0.282 ^{d}	0.201	0.312 ^{b}	0.201	0.186 ^{e}
$T_{4\,\mathrm{Soil+VC}}$	0.362 ^{a}	0.340 ^{b}	0.261	0.366 ^{a}	0.201	0.222 ^{d}	0.200	0.236 ^{b}
$T_{5\,\mathrm{Soil+MC}}$	0.354 ^{a}	0.318 ^{c}	0.261	0.298 ^{c}	0.202	0.230 ^{c}	0.200	0.180 ^{f}
$T_{6\,\mathrm{Soil+TOF}}$	0.354 ^{a}	0.276 ^{d}	0.261	0.258 ^{f}	0.201	0.204 ^{e}	0.201	0.216 ^{c}
$T_{7\,\mathrm{Soil+F\text{-}TOF}}$	0.363 ^{a}	0.370 ^{a}	0.261	0.304 ^{b}	0.202	0.384 ^{a}	0.200	0.290 ^{a}
SEm ±	0.003	0.003	-	0.002	-	0.002	-	0.001
CD (0.05)	0.010	0.008	NS	0.006	NS	0.007	NS	0.002

4.2.2.7 Boron fractions

4.2.2.7.1 Readily available B

Readily available B in the surface soil for both unleached as well as leached soil varied significantly among the treatments (Table 63). At the same time, before the leaching of soil column, concentration of B in the lower depths (15-90 cm) was almost uniform and they did not significantly vary among the treatments. In the surface layer, highest value (0.070 mg kg^{-1}) was recorded with the treatment F-TOF and it was followed by VC (0.062 mg kg^{-1}) and OC (0.060 mg kg^{-1}) before leaching. After leaching, the highest value for readily available B was recorded with F-TOF (0.151 mg kg^{-1}) was followed by VC and MC. At lowers depths (15-30, 30-60 and 60-90 cm), there was no significant difference between treatments for their readily available B content due to the addition of organic fertilizers and leaching.

Table 63. Effect of treatments on readily available B content in leached soil at different depths, mg kg^{-1}

Treatments	Readily available B (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	0.041^{c}	0.124^{c}	0.041	0.025	0.040	0.030	0.039	0.031
$T_{2\ \text{Soil+FYM}}$	0.052^{b}	0.137^{b}	0.041	0.032	0.040	0.032	0.039	0.032
$T_{3\ \text{Soil+OC}}$	0.060^{a}	0.146^{a}	0.041	0.033	0.040	0.032	0.039	0.032
$T_{4\ \text{Soil+VC}}$	0.062^{a}	0.150^{a}	0.041	0.034	0.040	0.032	0.039	0.032
$T_{5\ \text{Soil+MC}}$	0.058^{b}	0.149^{a}	0.041	0.033	0.040	0.032	0.039	0.032
$T_{6\ \text{Soil+TOF}}$	0.050^{b}	0.138^{b}	0.041	0.032	0.040	0.032	0.039	0.032
$T_{7\ \text{Soil+F-TOF}}$	0.070^{a}	0.151^{a}	0.041	0.033	0.040	0.032	0.039	0.032
SEm ±	0.036	0.023	-	-	-	-	-	-
CD (0.05)	0.11	0.07	NS	NS	NS	NS	NS	NS

4.2.2.7.2 Specifically adsorded B

Specifically adsorbed B in the surface layer of unleached and leached soil varied significantly among the treatments (Table 64). Before leaching, highest value in the surface layer was recorded with F-TOF (0.104 mg kg^{-1}) followed by VC and

OC. Specifically adsorbed B in the surface layer of leached soil increased than their initial value and the highest value (0.202 mg kg^{-1}) was recorded with F-TOF followed by VC and MC. In lower depths (15-30, 30-60 and 60-90 cm), there was no significant difference between the treatments for their specifically adsorbed B content.

Table 64. Effect of treatments on specifically adsorbed B content in leached soil at different depths before and after leaching, mg kg^{-1}

Treatments	Specifically adsorded B (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
T_1 Control	0.061 ^{e}	0.165 ^{d}	0.061	0.057 ^{b}	0.061	0.058	0.060	0.054
T_2 Soil+FYM	0.077 ^{d}	0.183 ^{c}	0.061	0.076 ^{a}	0.061	0.059	0.060	0.056
T_3 Soil+OC	0.090 ^{b}	0.195 ^{b}	0.061	0.077 ^{a}	0.061	0.056	0.060	0.056
T_4 Soil+VC	0.092 ^{b}	0.201^a	0.061	0.079 ^{a}	0.061	0.056	0.060	0.056
T_5 Soil+MC	0.086 ^{c}	0.198 ^{a}	0.061	0.077 ^{a}	0.061	0.056	0.060	0.056
T_6 Soil+TOF	0.075 ^{d}	0.184 ^{c}	0.061	0.076 ^{a}	0.061	0.056	0.060	0.056
T_7 Soil+F-TOF	0.104 ^{a}	0.202 ^{a}	0.061	0.078 ^{a}	0.061	0.056	0.060	0.056
SEm ±	0.03	0.016	-		-	-	-	-
CD (0.05)	0.08	0.05	NS	NS	NS	NS	NS	NS

4.2.2.7.3 Oxide bound B

Oxide bound B in the surface layer of leached and unleached soil differed significantly (Table 65). In the surface layer the highest value for oxide bound B (0.035 mg kg^{-1}) was recorded with F-TOF followed by VC and OC. After leaching in the surface layer, the highest value (0.101 mg kg^{-1}) was recorded with F-TOF followed by VC and MC. The concentration of oxide bound B increased in the surface layer at the end of the leaching. Organic fertilizers received treatments were statistically on par with each other for the oxide bound B at 15-30 cm depth. But at lower depths (30-60 and 60-90 cm) there was no significant difference among the treatments after leaching.

Table 65. Effect of treatments on oxide bound B content in leached soil at different depths, mg kg^{-1}

Treatments	Oxide bound B (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	0.020 ^{d}	0.082 ^{c}	0.020	0.018 ^{b}	0.019	0.017	0.019	0.017
$T_{2\ \text{Soil+FYM}}$	0.026 ^{c}	0.092 ^{b}	0.020	0.028 ^{a}	0.019	0.018	0.019	0.018
$T_{3\ \text{Soil+OC}}$	0.030 ^{b}	0.098 ^{a}	0.020	0.029 ^{a}	0.019	0.018	0.019	0.018
$T_{4\ \text{Soil+VC}}$	0.031 ^{a}	0.100 ^{a}	0.020	0.029 ^{a}	0.019	0.018	0.019	0.018
$T_{5\ \text{Soil+MC}}$	0.029 ^{b}	0.099 ^{a}	0.020	0.029 ^{a}	0.019	0.018	0.019	0.018
$T_{6\ \text{Soil+TOF}}$	0.025 ^{c}	0.092 ^{b}	0.020	0.028 ^{a}	0.019	0.018	0.019	0.018
$T_{7\ \text{Soil+F-TOF}}$	0.035 ^{a}	0.101 ^{a}	0.020	0.029 ^{a}	0.019	0.018	0.019	0.018
SEm ±	0.016	0.02	-	0.01	-	-	-	-
CD (0.05)	0.05	0.06	NS	0.03	NS	NS	NS	NS

4.2.2.7.4 Organically bound B

Organically bound B in the surface and sub-surface layer of leached soil varied significantly among the treatments (Table 66). At 0 D, the highest value for organically bound B in the surface layer was recorded with F-TOF (0.157 mg kg^{-1}) followed by VC and OC. After leaching, the highest value in the surface layer was recorded by F-TOF (0.454 mg kg^{-1}) followed by VC and MC. At 15-30 cm depth, treatments which received organic fertilizers were statistically on par with each other and beyond 30 cm; there was no significant difference among the treatments.

Table 66. Effect of treatments on organically bound B content in leached soil at different depths, mg kg^{-1}

Treatments	Organically bound B (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ \text{Control}}$	0.091 ^{d}	0.247 ^{d}	0.091	0.087 ^{b}	0.090	0.087	0.089	0.087
$T_{2\ \text{Soil+FYM}}$	0.116 ^{c}	0.412 ^{c}	0.091	0.108 ^{a}	0.090	0.095	0.089	0.095
$T_{3\ \text{Soil+OC}}$	0.135 ^{b}	0.439 ^{b}	0.091	0.109 ^{a}	0.090	0.097	0.089	0.096
$T_{4\ \text{Soil+VC}}$	0.138 ^{b}	0.452 ^{a}	0.091	0.112 ^{a}	0.090	0.096	0.089	0.096
$T_{5\ \text{Soil+MC}}$	0.129 ^{b}	0.446 ^{a}	0.091	0.119 ^{a}	0.090	0.097	0.089	0.095
$T_{6\ \text{Soil+TOF}}$	0.113 ^{c}	0.414 ^{c}	0.091	0.106 ^{a}	0.090	0.095	0.089	0.094
$T_{7\ \text{Soil+F-TOF}}$	0.157 ^{a}	0.454 ^{a}	0.091	0.125 ^{a}	0.090	0.096	0.089	0.096
SEm ±	0.04	0.033	-	0.06	-	-	-	-
CD (0.05)	0.12	0.10	NS	0.18	NS	NS	NS	NS

4.2.2.7.5 Residual B

Residual B in the surface layer of leached and unleached soil differed significantly (Table 67). Before leaching, highest value for residual B in the surface layer (0-15 cm) was recorded for F-TOF (5.174 mg kg^{-1}) followed by VC and OC. After leaching, the highest value for residual B in the surface layer was recorded with F-TOF (4.133 mg kg^{-1}) followed by VC and MC. In all the four depth, the residual B decreased than their initial value due leaching. In the lower depths (15-30, 30-60 and 60-90 cm) there was no significant difference among the treatments for their residual B content.

Table 67. Effect of treatments on residual B content in leached soil at different depths, mg kg^{-1}

Treatments	Residual B (mg kg^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	0 D	24 W	0 D	24 W	0 D	24 W	0 D	24 W
$T_{1\ Control}$	4.167 ^{d}	3.502 ^{d}	4.167	4.164	4.167	4.160	4.167	4.160
$T_{2\ Soil+FYM}$	4.550 ^{c}	3.756 ^{c}	4.167	4.165	4.167	4.160	4.167	4.160
$T_{3\ Soil+OC}$	4.826 ^{b}	4.002 ^{b}	4.167	4.163	4.167	4.161	4.167	4.160
$T_{4\ Soil+VC}$	4.857 ^{b}	4.116 ^{a}	4.167	4.164	4.167	4.162	4.167	4.160
$T_{5\ Soil+MC}$	4.798 ^{b}	4.059 ^{a}	4.167	4.162	4.167	4.161	4.167	3.616
$T_{6\ Soil+TOF}$	4.636 ^{c}	3.772 ^{c}	4.167	4.160	4.167	4.161	4.167	4.160
$T_{7\ Soil+F\text{-}TOF}$	5.174 ^{a}	4.133 ^{a}	4.167	4.164	4.167	4.162	4.167	4.160
SEm ±	0.053	0.05	-	-	-	-	-	-
CD (0.05)	0.16	0.15	NS	NS	NS	NS	NS	NS

4.2.2.8 Heavy metals

Avaialble Cd and Pb were not detected in any of the soil samples

4.3 INCUBATION STUDY

The electrochemical properties and nutrient release from the organic fertilizer amended soil incubated at field capacity for a period of 24 weeks are presented in Tables 68 to 93.

4.3.1 pH

pH of the soil varied significantly at all sampling periods and it was in acidic range (Table 68). The control treatment exhibited a lower pH compared to other treatments and showed a declining trend throughout the incubation period. During the incubation, the highest pH was maintained by F-TOF and the lowest by control. Organic fertilizers added treatments showed an increase in pH on first week, followed by a decrease at 4 W. On 8 W, pH again increased for organic fertilizers added treatments followed by a decline towards the end of incubation.

Table 68. Effect of treatments on soil pH at different periods of incubation

Treatments	pH							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
$T_{1\ \text{Control}}$	5.05^{g}	4.83^{g}	4.73^{g}	4.69^{g}	4.62^{f}	4.61^{g}	4.60^{f}	4.58^{f}
$T_{2\ \text{Soil+FYM}}$	6.44^{c}	6.48^{e}	5.36^{f}	5.69^{f}	5.19^{e}	4.97^{f}	4.98^{e}	4.76^{e}
$T_{3\ \text{Soil+OC}}$	6.61^{a}	6.64^{c}	5.96^{d}	6.22^{d}	5.68^{d}	5.43^{e}	5.40^{d}	5.19^{c}
$T_{4\ \text{Soil+VC}}$	6.56^{b}	6.61^{d}	5.83^{e}	6.33^{c}	5.87^{c}	5.80^{c}	5.48^{c}	5.22^{c}
$T_{5\ \text{Soil+MC}}$	6.47^{c}	6.68^{b}	6.17^{b}	6.64^{b}	5.90^{bc}	5.95^{b}	5.55^{b}	5.30^{b}
$T_{6\ \text{Soil+TOF}}$	6.39^{d}	6.35^{f}	6.07^{c}	6.39^{c}	5.92^{b}	5.64^{d}	5.51^{bc}	4.93^{d}
$T_{7\ \text{Soil+F-TOF}}$	6.31^{e}	6.73^{a}	6.21^{a}	6.73^{a}	6.26^{a}	6.10^{a}	5.67^{a}	5.44^{a}
SEm±	0.018	0.010	0.010	0.023	0.016	0.019	0.022	0.013
CD (0.05)	0.055	0.030	0.030	0.070	0.048	0.057	0.066	0.040

4.3.2 EC

EC of the different treatments varied significantly during the incubation (Table 69). At all the sampling intervals, control recorded the lowest EC. The treatment that has received F-TOF maintained a higher EC throughout the incubation followed by VC. From 12 W onwards treatments F-TOF was statistically on par with treatment VC for EC. In general an increase in EC was noted for all treatments up to 12 W, though some of the organic fertilizers received treatments showed further increase.

Table 69. Effect of treatments on soil EC at different periods of incubation, dS m^{-1}

Treatments	EC (dS m^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_{1} Control	0.10^{g}	0.13^{g}	0.16^{g}	0.18^{e}	0.21^{e}	0.20^{f}	0.19^{e}	0.19^{g}
T_{2} Soil+FYM	0.32^{e}	0.38^{e}	0.44^{e}	0.52^{d}	0.47^{d}	0.40^{e}	0.39^{d}	0.37^{f}
T_{3} Soil+OC	0.44^{d}	0.40^{d}	0.52^{d}	0.74^{c}	0.79^{b}	0.71^{b}	0.73^{a}	0.63^{d}
T_{4} Soil+VC	0.59^{b}	0.65^{b}	0.71^{b}	0.78^{b}	0.81^{ab}	0.73^{ab}	0.72^{a}	0.69^{ab}
T_{5} Soil+MC	0.53^{c}	0.59^{c}	0.69^{c}	0.72^{c}	0.80^{b}	0.65^{c}	0.67^{b}	0.65^{c}
T_{6} Soil+TOF	0.29^{f}	0.24^{f}	0.39^{f}	0.45^{d}	0.56^{c}	0.61^{d}	0.57^{c}	0.50^{e}
T_{7} Soil+F-TOF	0.64^{a}	0.68^{a}	0.75^{a}	0.84^{a}	0.82^{a}	0.75^{a}	0.73^{a}	0.71^{a}
SEm±	0.005	0.004	0.003	0.012	0.005	0.010	0.004	0.011
CD (0.05)	0.015	0.012	0.01	0.035	0.015	0.030	0.012	0.02

4.3.3 Carbon pools

4.2.3.1 TOC

TOC of the soil varied significantly among the treatments (Table 70). TOC recorded the highest value on 0 D for all treatments which gradually decreased towards the end of the incubation. On 0 D, the highest TOC was recorded by TOF which was statistically on par with F-TOF and on 24 W F-TOF recorded the highest value which was on par with TOF. The TOC content was lowest for control treatment.

Table 70. Effect of treatments on TOC content of soil at different periods of incubation, %

Treatments	TOC (%)							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	1.13 ^{d}	1.04 ^{e}	0.94 ^{f}	0.93 ^{e}	0.90 ^{e}	0.84 ^{e}	0.84 ^{e}	0.82 ^{e}
T_2 Soil+FYM	1.75 ^{c}	1.70 ^{d}	1.66 ^{e}	1.60 ^{d}	1.54 ^{d}	1.50 ^{d}	1.43 ^{d}	1.40 ^{d}
T_3 Soil+OC	1.84 ^{bc}	1.81 ^{c}	1.78 ^{d}	1.74 ^{c}	1.71 ^{c}	1.68 ^{c}	1.65 ^{c}	1.63 ^{c}
T_4 Soil+VC	1.89 ^{b}	1.84 ^{b}	1.81 ^{b}	1.80 ^{b}	1.76 ^{b}	1.74 ^{b}	1.70 ^{b}	1.68 ^{b}
T_5 Soil+MC	1.85 ^{bc}	1.83 ^{bc}	1.79 ^{c}	1.74 ^{c}	1.71 ^{c}	1.69 ^{c}	1.68 ^{b}	1.66 ^{bc}
T_6 Soil+TOF	2.21 ^{a}	2.18 ^{a}	2.14 ^{a}	2.11 ^{a}	2.08 ^{a}	2.04 ^{a}	2.03 ^{a}	1.96 ^{a}
T_7 Soil+F-TOF	2.20 ^{a}	2.19 ^{a}	2.14 ^{a}	2.10 ^{a}	2.07 ^{a}	2.05 ^{a}	2.04 ^{a}	1.97 ^{a}
SEm±	0.035	0.010	0.002	0.007	0.007	0.010	0.009	0.011
CD (0.05)	0.105	0.030	0.007	0.022	0.020	0.030	0.028	0.034

4.3.3.2 Water soluble organic carbon (WSOC)

There was a significant variation in the WSOC content in the soil due to the addition of organic fertilizers (Table 71). The highest value for WSOC was recorded on 0 D by F-TOF which was significantly superior to all others, followed by TOF. After one week of incubation WSOC decreased in TOF, F-TOF, OC and control treatments. At 4 W all the treatments showed a decrease followed by an increase on 8 W except for control. Later the WSOC content of all treatments decreased till the end of incubation. Among the treatments, WSOC was the highest for F-TOF up to 4 W and from 8 W onwards highest value was maintained by VC.

Table 71. Effect of treatments on WSOC content of soil at different periods of incubation, mg kg^{-1}

Treatments	WSOC (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T$_1$ Control	7.20^{g}	35.40^{f}	26.40^{d}	31.20^{g}	21.60^{e}	7.20^{f}	6.80^{f}	6.30^{e}
T$_2$ Soil+FYM	64.80^{c}	65.40^{d}	45.60^{ab}	66.60^{c}	52.80^{b}	33.60^{c}	30.00^{b}	16.20^{b}
T$_3$ Soil+OC	60.60^{d}	45.60^{e}	42.60^{bc}	72.80^{b}	51.00^{bc}	37.80^{b}	27.00^{c}	10.80^{c}
T$_4$ Soil+VC	54.00^{e}	69.00^{c}	40.20^{c}	76.80^{a}	70.00^{a}	44.40^{a}	39.00^{a}	19.80^{a}
T$_5$ Soil+MC	34.80^{f}	64.20^{d}	30.60^{d}	55.20^{e}	37.80^{d}	27.00^{e}	24.00^{d}	7.80^{d}
T$_6$ Soil+TOF	111.60^{b}	78.00^{b}	43.20^{abc}	50.40^{f}	48.60^{c}	31.80^{d}	14.40^{e}	12.00^{c}
T$_7$ Soil+F-TOF	133.20^{a}	85.20^{a}	48.00^{a}	61.20^{d}	36.60^{d}	27.60^{e}	15.00^{e}	11.40^{c}
SEm±	0.29	1.17	1.75	1.02	1.32	0.58	0.87	0.65
CD (0.05)	0.876	3.51	5.25	3.07	3.95	1.75	2.62	2.01

4.3.3.3 Labile carbon

Labile carbon content was significantly influenced by the treatments throughout incubation period (Table 72) and the highest value was always maintained by F-TOF. Up to 12 W of incubation the treatment TOF was second in labile carbon content and later the trend was changed. Labile carbon content of all the treatments increased to a certain stage of incubation and then declined. Labile carbon increased up to 4 W for control, FYM and MC, upto 8 W for VC, F-TOF and TOF and up to 12 W for OC.

Table 72. Effect of treatments on labile carbon content of soil at different periods of incubation, mg kg^{-1}

Treatments	Labile carbon (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T$_1$ Control	525.38^{g}	592.88^{f}	829.13^{g}	707.63^{g}	523.13^{f}	543.38^{g}	446.63^{f}	440.00^{g}
T$_2$ Soil+FYM	1144.13^{c}	1113.75^{e}	1130.63^{e}	1105.88^{e}	1108.13^{c}	907.88^{e}	855.00^{d}	840.38^{e}
T$_3$ Soil+OC	929.25^{f}	1117.13^{e}	1143.00^{d}	1175.63^{d}	1243.13^{b}	1033.8^{d}	934.88^{b}	1058.63^{b}
T$_4$ Soil+VC	1081.13^{e}	1229.63^{c}	1231.88^{c}	1283.63^{c}	1092.38^{d}	1193.6^{b}	921.38^{c}	1024.88^{c}
T$_5$ Soil+MC	1118.2^{d}	1156.50^{d}	1113.75^{f}	1044.00^{f}	1038.38^{e}	771.75^{f}	837.00^{e}	884.25^{d}
T$_6$ Soil+TOF	1648.1^{b}	1672.88^{b}	1540.13^{b}	1657.13^{b}	1395.00^{a}	1163.25^{c}	918.00^{c}	819.00^{f}
T$_7$Soil+F-TOF	1668.00^{a}	1693.00^{a}	1686.38^{a}	1677.38^{a}	1398.38^{a}	1348.88^{a}	973.13^{a}	1095.75^{a}
SEm±	2.92	1.46	1.17	2.77	3.50	1.75	3.36	2.04
CD (0.05)	8.76	4.37	3.51	8.31	10.50	5.25	10.07	6.13

4.3.3.4 Microbial biomass carbon

MBC content of the soil varied significantly due to the addition of organic fertilizers (Table 73). MBC increased up to 12 W of incubation for FYM and OC, while up to 8 W for VC, MC, TOF and F-TOF. On 0 D and 1 W of incubation, the highest value for MBC was recorded by MC followed by F-TOF and TOF. But during the subsequent samplings, the highest value was recorded by F-TOF. In control treatment the MBC increased from 0 D up to 8 W and declined afterwards.

Table 73. Effect of treatments on MBC content of soil at different periods of incubation, mg kg^{-1}

Treatments	Microbial biomass carbon (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T1 Control	26.27^{e}	29.64^{f}	41.46^{e}	35.38^{e}	26.16^{e}	27.17^{f}	22.33^{d}	22.00^{c}
T2 Soil+FYM	57.21^{c}	59.69^{d}	56.53^{d}	55.29^{cd}	55.41^{c}	45.39^{d}	42.75^{c}	42.02^{b}
T3 Soil+OC	46.46^{d}	55.86^{e}	57.15^{d}	58.78^{c}	62.16^{b}	51.69^{c}	46.74^{ab}	52.93^{a}
T4 Soil+VC	54.06^{c}	61.48^{c}	61.59^{c}	64.18^{b}	54.62^{cd}	59.68^{b}	46.07^{ab}	51.24^{a}
T5 Soil+MC	69.91^{a}	75.83^{a}	55.69^{d}	52.20^{d}	51.92^{d}	38.59^{e}	41.85^{c}	44.21^{b}
T6 Soil+TOF	59.64^{bc}	64.66^{bc}	69.01^{b}	72.86^{a}	69.75^{a}	58.16^{b}	45.90^{b}	50.95^{b}
T7 Soil+F-TOF	60.12^{b}	65.23^{b}	71.32^{a}	76.87^{a}	69.92^{a}	67.44^{a}	48.66^{a}	54.79^{a}
SEm±	0.58	1.17	1.36	1.75	0.70	1.60	0.87	1.75
CD(0.05)	1.73	3.50	4.09	5.25	2.09	4.81	2.62	5.25

4.3.3.5 Recalcitrant organic carbon (ROC)

The treatment effect was significant for ROC content throughout the incubation period (Table 74). The control treatment showed the lowest values. The highest value was for TOF and it was statistically on par with F-TOF. All the treatments had their highest values on 0 D. In general, the ROC for all treatments decreased except by a small spell of increase for certain treatments during 4 W.

Table 74. Effect of treatments on ROC content of soil at different periods of incubation, %

Treatments	Recalcitrant organic carbon (%)							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	0.74^{f}	0.64^{c}	0.63^{g}	0.53^{g}	0.50^{d}	0.48^{e}	0.44^{f}	0.40^{g}
T_2 Soil+FYM	1.21^{e}	1.15^{b}	1.14^{f}	0.90^{f}	0.79^{c}	1.01^{c}	0.98^{d}	0.82^{d}
T_3 Soil+OC	1.26^{d}	1.18^{b}	1.20^{e}	1.13^{e}	1.23^{b}	1.04^{c}	0.81^{c}	0.79^{e}
T_4 Soil+VC	1.35^{c}	1.15^{b}	1.36^{c}	1.25^{c}	1.16^{b}	0.87^{d}	0.68^{e}	0.72^{f}
T_5 Soil+MC	1.27^{d}	1.13^{b}	1.30^{d}	1.23^{d}	1.15^{b}	1.11^{b}	1.16^{b}	1.09^{c}
T_6 Soil+TOF	1.52^{a}	1.45^{a}	1.40^{a}	1.39^{a}	1.37^{a}	1.35^{a}	1.34^{a}	1.33^{a}
T_7 Soil+F-TOF	1.49^{a}	1.43^{a}	1.38^{a}	1.37^{a}	1.34^{a}	1.32^{a}	1.33^{a}	1.31^{a}
SEm±	0.01	0.028	0.003	0.005	0.031	0.013	0.019	0.006
CD (0.05)	0.032	0.085	0.03	0.015	0.093	0.040	0.057	0.02

4.3.4 Nitrogen pools

4.3.4.1 Ammoniacal nitrogen (NH_4 -N)

NH_4- N content of the soil varied significantly due to the addition of organic fertilizers (Table 75). It increased up to 12 W of incubation and decreased afterwards. From 0 D up to 12 W, the highest NH_4 -N content was recorded for VC, while F-TOF took that place afterwards.

Table 75. NH_4 -N content of soil at different periods of incubation, mg kg^{-1}

Treatments	NH_4- N (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	28.6^{c}	30.3^{b}	50.4^{f}	53.2^{e}	42.4^{f}	30.6^{c}	29.6^{c}	27.4^{d}
T_2 Soil+FYM	33.3^{b}	36.4^{a}	63.6^{d}	92.4^{b}	110.4^{d}	40.8^{b}	39.6^{b}	36.6^{c}
T_3 Soil+OC	34.6^{b}	37.4^{a}	68.4^{c}	94.6^{b}	124.6^{c}	44.8^{b}	41.4^{b}	39.6^{b}
T_4 Soil+VC	38.2^{a}	39.4^{a}	74.6^{a}	104.8^{a}	142.4^{a}	43.4^{ab}	42.6^{ab}	40.6^{b}
T_5 Soil+MC	38.2^{a}	40.6^{a}	76.4^{a}	70.4^{c}	127.2^{c}	45.8^{a}	44.4^{a}	42.6^{ab}
T_6 Soil+TOF	37.5^{a}	38.2^{a}	54.2^{e}	58.6^{d}	72.6^{e}	42.4^{b}	40.6^{b}	39.6^{b}
T_7 Soil+F-TOF	36.5^{a}	39.4^{a}	72.8^{ab}	96.8^{b}	138.4^{b}	46.6^{a}	45.3^{a}	43.4^{a}
SEm±	0.58	1.56	1.20	1.75	1.32	1.29	1.62	2.04
CD (0.05)	1.75	4.69	3.59	5.25	3.95	3.88	2.85	1.84

4.3.4.2 Nitrate nitrogen (NO_3-N)

NO_3-N content of soil varied significantly due to the addition of organic fertilizers (Table 76). NO_3-N content showed a decrease towards the first week and afterwards an increase up to 16 W followed by a decline. During the incubation, the highest value for NO_3-N was recorded by VC followed by F-TOF and MC at 16 W.

Table 76. NO_3-N content of the soil at different periods of incubation, mg kg^{-1}

Treatments	NO_3-N (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	28.4^{g}	27.4^{f}	36.0^{g}	41.6^{g}	47.2^{f}	40.2^{e}	38.2^{f}	37.45^{g}
T_2 Soil+FYM	30.8^{f}	28.4^{f}	73.2^{f}	95.6^{e}	105.6^{d}	112.4^{d}	73.2^{e}	90.00^{e}
T_3 Soil+OC	47.2^{e}	33.6^{e}	102.4^{d}	106.8^{d}	123.6^{c}	130.6^{c}	112.4^{c}	97.2^{d}
T_4 Soil+VC	74.6^{c}	68.4^{c}	118.0^{b}	123.6^{b}	151.6^{a}	168.4^{a}	123.6^{b}	109.2^{b}
T_5 Soil+MC	91.4^{b}	77.2^{b}	109.2^{c}	112.4^{c}	133.6^{b}	134.8^{c}	115.4^{c}	101.2^{c}
T_6 Soil+TOF	54.8^{d}	46.6^{d}	84.4^{e}	87.4^{f}	90.8^{e}	99.6^{e}	84.4^{d}	73.2^{f}
T_7 Soil+F-TOF	112.6^{a}	98.8^{a}	129.2^{a}	135.6^{a}	155.4^{a}	168.4^{a}	139.6^{a}	124.2^{a}
SEm±	1.62	0.73	1.22	1.63	1.75	1.46	1.16	1.32
CD (0.05)	4.85	2.18	3.66	4.88	5.25	4.37	3.48	3.96

4.3.4.3 Organic nitrogen

There was significant difference among the organic N content of treatments (Table 77). At all the sampling intervals highest value was recorded by MC which was significantly superior to all other treatments, followed by OC up to 16 W and by VC at 20 W and 24 W. In all the sampling intervals, control recorded the lowest value. Organic N content of the soil at different periods of incubation

Table 77. Organic N content of soil at different periods of incubation, mg kg^{-1}

Treatments	Organic N (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	933.0^{f}	932.3^{f}	901.6^{g}	856.0^{f}	889.6^{f}	919.2^{f}	922.2^{g}	925.15^{g}
T_2 Soil+FYM	1308.9^{e}	1308.2^{e}	1207.0^{f}	1167.0^{e}	1175.0^{e}	1219.8^{e}	1260.2^{f}	1246.4^{f}
T_3 Soil+OC	1481.2^{b}	1492.0^{b}	1362.2^{b}	1331.6^{b}	1344.8^{b}	1387.6^{b}	1409.2^{c}	1426.2^{c}
T_4 Soil+VC	1483.9^{b}	1487.2^{b}	1351.4^{c}	1329.0^{b}	1346.6^{b}	1380.0^{c}	1426.1^{b}	1442.4^{b}
T_5 Soil+MC	1513.4^{a}	1525.2^{a}	1429.2^{a}	1403.4^{a}	1439.0^{a}	1462.4^{a}	1483.2^{a}	1499.2^{a}
T_6 Soil+TOF	1360.7^{d}	1368.2^{d}	1274.0^{e}	1244.0^{d}	1263.6^{d}	1311.0^{d}	1328.0^{e}	1340.2^{e}
T_7 Soil+F-TOF	1434.2^{c}	1446.8^{c}	1340.6^{d}	1311.0^{c}	1314.8^{c}	1381.2^{c}	1402.8^{d}	1420.2^{d}
SEm±	2.33	2.04	1.29	2.04	2.92	1.60	1.75	1.94
CD(0.05)	7.00	6.13	3.88	6.12	8.76	4.81	5.25	5.83

4.3.5 Total macronutrients

Total N, P, K, Ca, Mg and S content in soil varied significantly among the treatments due to the addition of organic fertilizers (Table 78). Total N recorded highest with MC, which was followed by VC and F-TOF and they were on par with each other. For total P highest value was recorded with VC followed by OC. In the case of total K highest value was recorded with F-TOF followed by VC and TOF. Similarly, for Ca, F-TOF recorded the highest value followed by MC. For total Mg and S highest value was recorded by FYM followed by OC.

Table 78.Effect of treatments on total macronutrients content in the soil at 0 D,mg kg^{-1}

Treatments	Total macronutrients (mg kg^{-1})					
	N	P	K	Ca	Mg	S
T_1 Control	990^{f}	410.0^{g}	800^{g}	330^{f}	140.0^{g}	480.00^{d}
T_2 Soil+FYM	1373^{e}	585.0^{e}	1035^{f}	450^{e}	182.5^{f}	507.50^{a}
T_3 Soil+OC	1563^{c}	720.0^{b}	1265^{d}	530^{c}	205.0^{c}	500.00^{b}
T_4 Soil+VC	1595^{b}	750.0^{a}	1320^{b}	530^{c}	210.0^{b}	496.50^{bc}
T_5 Soil+MC	1643^{a}	632.5^{c}	1250^{e}	570^{b}	197.5^{d}	493.25^{b}
T_6 Soil+TOF	1403^{d}	532.5^{f}	1285^{c}	510^{d}	192.5^{e}	491.00^{c}
T_7 Soil+F-TOF	1585^{b}	622.5^{d}	1440^{a}	610^{a}	335.0^{a}	495.50^{c}
SEm±	3.50	2.34	4.38	2.04	1.46	1.58
CD (0.05)	10.50	7.01	13.13	6.13	4.37	4.76

4.3.6 Total micronutrients and heavy metals

The total micronutrient content in the soil during incubation is presented in the Table 79. The total micronutrient content of the soil varied significantly among the treatments. During the incubation, the highest Fe content was recorded for FYM (T_2) followed by OC (T_3) and VC (T_4). The total Fe content was comparatively lower in the treatments received TOF and F-TOF. The Mn content was highest with VC and it was on par with OC and MC. The highest total Zn content was recorded for F-TOF and it was on par with OC and VC. The highest Cu content during incubation was recorded by OC and it was on par with treatments such as OC, VC, MC FYM and F-TOF. For all the four micronutrients, the lowest value during incubation was recorded by absolute control (T_1). For total boron highest value was recorded with F-TOF followed by VC.

Cd was not detected in the soil and hence the data on Pb alone are presented. The total Pb content in the soil during incubation varied significantly among the treatments (Table 79). All the treatments that received organic fertilizers were statistically on par with each other except OC. The OC amended soil had comparatively lower Pb content. The lowest Pb content was in control

Table 79. Effect of treatments on total micronutrients and Pb in the soil at 0 D

Treatments	Total micronutrients (mg kg^{-1})					
	Fe	Mn	Zn	Cu	B	Pb
$T_{1\ \mathrm{Control}}$	643 ^{g}	84.23 ^{d}	75.00 ^{c}	24.60 ^{c}	4.38 ^{g}	0.155 ^{c}
$T_{2\ \mathrm{Soil+FYM}}$	983 ^{a}	91.97 ^{ab}	79.08 ^{ab}	26.00 ^{ab}	4.82 ^{f}	0.249 ^{a}
$T_{3\mathrm{Soil+OC}}$	928 ^{b}	96.02 ^{a}	80.68 ^{a}	26.24 ^{ab}	5.14 ^{c}	0.201 ^{b}
$T_{4\mathrm{Soil+VC}}$	898 ^{c}	96.22 ^{a}	80.45 ^{a}	26.37 ^{a}	5.18 ^{b}	0.247 ^{a}
$T_{5\mathrm{Soil+MC}}$	873 ^{d}	92.81 ^{ab}	79.54 ^{ab}	26.18 ^{ab}	5.10 ^{d}	0.231 ^{a}
$T_{6\mathrm{Soil+TOF}}$	724 ^{f}	87.62 ^{cd}	77.69 ^{b}	25.67 ^{b}	4.90 ^{e}	0.224 ^{a}
$T_{7\mathrm{Soil+F\text{-}TOF}}$	774 ^{e}	88.88 ^{bc}	81.35 ^{a}	25.84 ^{ab}	5.54 ^{a}	0.238 ^{a}
SEm±	3.10	1.45	0.89	0.22	0.01	0.015
CD (0.05)	9.31	4.34	2.66	0.669	0.030	0.042

4.3.8 Avaialable nutrients

4.3.8.1 Available P

Available P content of soil varied significantly due to the addition of organic fertilizers throughout the incubation period (Table 80). For all treatments availability of P increased from 0 D up to 8 W and declined afterwards. On 0 D available P recorded highest for F-TOF. Later throughout the sampling intervals, highest value for available P was recorded by VC followed by OC.

Table 80. Available P content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available P (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T$_1$ Control	36.05^{d}	39.48^{c}	38.25^{c}	38.61^{c}	37.58^{c}	37.69^{d}	37.94^{d}	36.51^{d}
T$_2$ Soil+FYM	39.62^{bc}	63.62^{b}	70.62^{b}	73.36^{b}	64.40^{b}	59.61^{c}	54.21^{c}	50.79^{c}
T$_3$ Soil+OC	40.00^{bc}	71.65^{a}	74.37^{b}	87.78^{a}	75.97^{a}	78.35^{a}	67.68^{b}	71.74^{a}
T$_4$ Soil+VC	40.17^{bc}	73.57^{a}	80.36^{a}	88.59^{a}	76.81^{a}	78.37^{a}	75.43^{a}	72.97^{a}
T$_5$ Soil+MC	40.50^{b}	68.32^{ab}	70.8^{b}	74.80^{b}	73.73^{a}	74.12^{ab}	65.24^{b}	70.81^{a}
T$_6$ Soil+TOF	38.50^{c}	41.78^{c}	41.50^{c}	41.61^{c}	40.69^{c}	41.72^{d}	40.21^{d}	40.99^{d}
T$_7$ Soil+F-TOF	43.23^{a}	70.87^{a}	72.52^{b}	76.16^{b}	72.24^{a}	73.64^{b}	70.00^{b}	65.80^{b}
SEm±	0.58	2.16	1.46	2.01	1.56	1.55	1.75	1.63
CD(0.05)	1.75	6.48	4.37	6.04	4.67	4.66	5.25	4.88

4.3.8.2 Available K

There was significant difference in the availability of K in the soil due to the addition of organic fertilizers (Table 81). For all treatments except TOF and F-TOF, available K increased up to 12 W of incubation and then declined whereas for TOF and F-TOF, increase was observed up to 16 W. Throughout the incubation, available K was recorded highest for F-TOF and the lowest in control.

Table 81. Available K content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available K (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T$_{1}$ Control	125.00^{e}	125.00^{f}	131.25^{f}	135.00^{g}	137.50^{g}	131.25^{g}	125.00^{g}	125.00^{g}
T$_{2}$ Soil+FYM	137.50^{d}	131.25^{e}	175.00^{e}	226.25^{f}	310.50^{f}	286.25^{f}	270.00^{f}	257.50^{f}
T$_{3}$ Soil+OC	139.54^{d}	162.50^{c}	200.75^{d}	310.00^{d}	457.50^{c}	432.50^{c}	423.75^{d}	409.54^{c}
T$_{4}$ Soil+VC	143.45^{c}	181.25^{b}	225.00^{b}	340.00^{b}	485.50^{b}	475.00^{b}	468.75^{b}	443.45^{b}
T$_{5}$ Soil+MC	139.45^{d}	151.45^{d}	210.75^{c}	328.75^{c}	363.75^{d}	351.25^{e}	351.25^{e}	309.45^{e}
T$_{6}$ Soil+TOF	149.39^{b}	166.25^{c}	205.50^{cd}	276.25^{e}	340.00^{e}	375.50^{d}	438.75^{c}	393.39^{d}
T$_{7}$Soil+F-TOF	184.40^{a}	206.25^{a}	305.75^{a}	438.75^{a}	517.50^{a}	542.50^{a}	501.25^{a}	454.40^{a}
SEm±	1.17	1.23	1.84	1.48	0.73	1.03	1.10	1.28
CD(0.05)	3.51	4.75	5.52	4.44	2.18	3.10	3.30	3.85

4.3.8.3 Available Ca

The treatments had significantly influenced the available Ca content of soil throughout the incubation period (Table 82). Towards the first week all the treatments had shown an increase. But as incubation proceeded the different treatments showed a varied behaviour. However, the treatment F-TOF maintained highest value for available Ca throughout the incubation followed by VC and the lowest value by control.

Table 82. Available Ca content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available Ca (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T$_{1}$ Control	180^{e}	185^{e}	186^{f}	189^{g}	195^{f}	185^{g}	172^{f}	170^{e}
T$_{2}$ Soil+FYM	190^{d}	210^{c}	225^{c}	240^{e}	270^{d}	265^{e}	255^{e}	248^{c}
T$_{3}$ Soil+OC	194^{c}	213^{c}	235^{c}	289^{c}	310^{b}	305^{c}	300^{c}	298^{a}
T$_{4}$ Soil+VC	197^{b}	218^{b}	244^{b}	295^{b}	318^{a}	325^{a}	309^{b}	300^{a}
T$_{5}$ Soil+MC	195^{bc}	210^{c}	225^{d}	254^{d}	281^{c}	288^{d}	284^{d}	286^{b}
T$_{6}$ Soil+TOF	193^{c}	196^{d}	212^{e}	220^{f}	226^{e}	231^{f}	255^{e}	245^{d}
T$_{7}$ Soil+F-TOF	279^{a}	285^{a}	315^{a}	325^{a}	320^{a}	315^{b}	305^{a}	298^{a}
SEm±	0.67	1.46	1.36	1.34	1.55	1.94	1.16	0.87
CD (0.05)	2.01	4.37	4.09	4.02	4.65	5.83	3.48	2.62

4.3.8.4 Available Mg

Available Mg content of organic fertilizer added treatments increased gradually up to 8 W and declined afterwards (Table 83). Throughout the incubation period Mg availability was the highest with F-TOF which was significantly superior to all others and was followed by VC up to 8 W and by MC from 12 W onwards.

Table 83. Available Mg content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available Mg (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T1 $_{\text{Control}}$	105^{c}	108^{c}	118^{f}	125^{e}	121^{e}	118^{f}	114^{g}	112^{f}
T2 $_{\text{Soil+FYM}}$	106^{bc}	112^{bc}	124^{e}	132^{d}	126^{d}	129^{d}	120^{f}	114^{e}
T3 $_{\text{Soil+OC}}$	108^{b}	115^{b}	132^{c}	151^{c}	132^{c}	132^{c}	128^{d}	125^{c}
T4 $_{\text{Soil+VC}}$	110^{b}	115^{b}	144^{b}	159^{b}	132^{c}	129^{d}	131^{c}	127^{b}
T5 $_{\text{Soil+MC}}$	108^{b}	112^{bc}	128^{d}	152^{c}	141^{b}	141^{b}	135^{b}	128^{b}
T6 $_{\text{Soil+TOF}}$	106^{bc}	110^{c}	119^{f}	124^{e}	128^{d}	126^{e}	123^{e}	120^{d}
T7 $_{\text{Soil+F-TOF}}$	210^{a}	214^{a}	226^{a}	245^{a}	258^{a}	167^{a}	154^{a}	149^{a}
SEm±	0.84	1.23	1.02	1.75	1.60	0.44	0.77	0.58
CD (0.05)	2.53	3.68	3.07	5.25	4.81	1.32	2.32	1.74

4.3.8.5 Available S

Available S varied significantly among the treatments throughout the incubation period due to the addition organic fertilizers (Table 84). Throughout out the incubation highest value for available S was recorded by FYM and F-TOF and they were statistically on par with each other.

Table 84. Available S content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available S (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T1 $_{\text{Control}}$	14.50^{d}	15.10^{c}	16.50^{d}	14.00^{d}	12.50^{e}	11.30^{f}	10.50^{d}	10.20^{f}
T2 $_{\text{Soil+FYM}}$	18.50^{b}	20.75^{a}	24.75^{a}	32.25^{a}	41.50^{a}	45.75^{a}	41.50^{a}	36.50^{b}
T3 $_{\text{Soil+OC}}$	16.75^{c}	17.25^{b}	21.50^{b}	25.25^{b}	31.70^{b}	36.67^{c}	40.75^{a}	35.50^{bc}
T4 $_{\text{Soil+VC}}$	16.25^{c}	17.85^{b}	20.50^{b}	25.75^{b}	33.50^{b}	36.75^{c}	39.25^{a}	34.50^{c}
T5 $_{\text{Soil+MC}}$	16.75^{c}	17.70^{b}	19.80^{b}	23.65^{b}	30.34^{c}	32.75^{d}	35.50^{b}	31.75^{d}
T6 $_{\text{Soil+TOF}}$	15.20^{d}	16.50^{b}	17.25^{c}	19.25^{c}	22.25^{d}	24.25^{e}	25.25^{c}	23.50^{e}
T7 $_{\text{Soil+F-TOF}}$	21.50^{a}	22.45^{a}	25.50^{a}	29.35^{a}	39.75^{a}	42.75^{b}	40.60^{a}	38.76^{a}
SEm±	0.29	0.77	0.87	1.02	0.66	0.44	0.91	0.96
CD (0.05)	0.876	2.32	2.62	3.07	1.94	1.32	2.73	2.09

4.3.8.6 Available Fe

Throughout the incubation the highest value was retained by F-TOF which was significantly superior to all others (Table 85). All the treatments showed a decrease in Fe content towards the end of incubation, though some of the treatments showed occasional increase.

Table 85. Available Fe content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available Fe (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	4.28 ^{f}	3.61 ^{e}	2.97 ^{f}	3.46 ^{e}	3.29 ^{d}	3.62 ^{c}	3.32 ^{c}	3.73 ^{c}
T_2 Soil+FYM	6.06 ^{d}	4.66 ^{d}	3.74 ^{e}	4.17 ^{d}	5.36 ^{c}	4.95 ^{b}	5.06 ^{b}	4.17 ^{b}
T_3 Soil+OC	5.39 ^{e}	6.02 ^{c}	4.98 ^{d}	6.06 ^{b}	6.59 ^{a}	4.92 ^{b}	5.26 ^{b}	4.34 ^{b}
T_4 Soil+VC	6.09 ^{d}	5.93 ^{c}	5.97 ^{b}	6.08 ^{b}	6.08 ^{b}	4.95 ^{b}	5.22 ^{b}	4.57 ^{b}
T_5 Soil+MC	6.58 ^{c}	6.05 ^{c}	5.37 ^{c}	5.29 ^{c}	5.18 ^{d}	4.74 ^{b}	4.61 ^{b}	4.15 ^{b}
T_6 Soil+TOF	7.32 ^{b}	12.88 ^{b}	5.40 ^{c}	5.21 ^{c}	5.26 ^{d}	5.06 ^{b}	5.01 ^{b}	4.02 ^{b}
T_7 Soil+F-TOF	8.56 ^{a}	13.49 ^{a}	6.19 ^{a}	6.45 ^{a}	6.67 ^{a}	6.13 ^{a}	6.14 ^{a}	5.36 ^{a}
SEm±	0.009	0.112	0.039	0.030	0.030	0.316	0.256	0.237
CD(0.05)	0.028	0.337	0.117	0.091	0.091	0.947	0.769	0.710

4.3.8.7 Available Mn

Available Mn content in the soil (Table 86) varied significantly among the treatments. During the incubation, the highest value up to 4 W was recorded by F-TOF and from 8 W onwards, VC has recorded highest value. During the incubation, the lowest value for available Mn was recorded for control (T_1). In all organic fertilizer amended soil, available Mn increased up to 12 W and declined afterwards, with MC and TOF as exceptions where Mn increased up to16 W and then decline

Table 86. Available Mn content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available Mn (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	2.19 ^{f}	2.14 ^{f}	2.09 ^{e}	2.17 ^{g}	2.2 ^{g}	2.33 ^{g}	2.46 ^{f}	2.41 ^{e}
T_2 Soil+FYM	2.39 ^{c}	2.42 ^{b}	2.27 ^{d}	3.44 ^{d}	4.21 ^{c}	4.04 ^{v}	3.68 ^{d}	3.28 ^{c}
T_3 Soil+OC	2.28 ^{e}	2.30 ^{d}	2.52 ^{b}	4.79 ^{b}	4.95 ^{b}	4.27 ^{b}	4.49 ^{b}	3.42 ^{b}
T_4 Soil+VC	2.24 ^{e}	2.26 ^{e}	2.43 ^{c}	5.10 ^{a}	5.92 ^{a}	4.42 ^{a}	5.59 ^{a}	3.49 ^{a}
T_5 Soil+MC	2.32 ^{d}	2.29 ^{d}	2.49 ^{b}	3.53 ^{c}	3.73 ^{d}	3.93 ^{d}	3.18 ^{d}	3.42 ^{b}
T_6 Soil+TOF	2.49 ^{b}	2.34 ^{c}	2.44 ^{c}	2.60 ^{f}	2.66 ^{f}	2.82 ^{e}	2.77 ^{e}	2.74 ^{d}
T_7 Soil+F-TOF	3.06 ^{a}	2.98 ^{a}	2.92 ^{a}	2.82 ^{e}	3.01 ^{e}	2.66 ^{f}	3.77 ^{c}	3.25 ^{c}
SEm±	0.022	0.009	0.001	0.013	0.014	0.017	0.010	0.012
CD(0.05)	0.067	0.028	0.004	0.038	0.042	0.050	0.030	0.037

4.3.8.8 Available Zn

Available Zn content (Table 87) of the soil varied significantly among the treatments. During the incubation, the highest value for available Zn was recorded by F-TOF followed by OC. The lowest value for available Zn during the incubation period was recorded by absolute control (T_1). In soils amended with all organic fertilizers, available Zn increased up to 12 W except TOF where it increased up to 16 W and then declined.

Table 87. Available Zn content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available Zn (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	0.75 ^{c}	0.69 ^{c}	0.71 ^{e}	0.7 ^{f}	0.68 ^{e}	0.67 ^{g}	0.63 ^{f}	0.56 ^{g}
T_2 Soil+FYM	0.77 ^{bc}	0.79 ^{b}	0.84 ^{c}	0.96 ^{d}	1.15 ^{c}	0.97 ^{e}	0.87 ^{d}	0.76 ^{e}
T_3 Soil+OC	0.79 ^{bc}	0.83 ^{b}	0.94 ^{b}	1.14 ^{b}	1.26 ^{b}	1.18 ^{b}	1.07 ^{b}	1.05 ^{b}
T_4 Soil+VC	0.81 ^{b}	0.81 ^{b}	0.89 ^{bc}	1.04 ^{c}	1.15 ^{c}	1.06 ^{c}	0.93 ^{c}	0.8 ^{c}
T_5 Soil+MC	0.78 ^{bc}	0.8 ^{b}	0.86 ^{c}	0.98 ^{d}	1.17 ^{c}	1.01 ^{c}	0.93 ^{c}	0.86 ^{c}
T_6 Soil+TOF	0.78 ^{bc}	0.74 ^{c}	0.79 ^{d}	0.84 ^{e}	0.88 ^{d}	0.9 ^{f}	0.81 ^{e}	0.65 ^{f}
T_7 Soil+F-TOF	1.34 ^{a}	1.38 ^{a}	1.42 ^{a}	1.54 ^{a}	1.56 ^{a}	1.5 ^{a}	1.53 ^{a}	1.44 ^{a}
SEm±	0.017	0.022	0.019	0.010	0.013	0.011	0.014	0.012
CD(0.05)	0.050	0.056	0.057	0.030	0.040	0.034	0.043	0.037

4.3.8.9 Available Cu

Available Cu (Table 88) content of the soil varied significantly among the treatments. Throughout the incubation period, highest value for available Cu was recorded by VC and F-TOF and they were statistically on par with each other. However, during the incubation, the lowest value for available Cu was recorded with the control treatment (T_1). In all treatments available Cu in the soil increased up to 12 W except in TOF where availability increased up to 16 W.

Table 88. Available Cu content of soil at different periods of incubation, mg kg^{-1}

Treatments	Available Cu (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	0.352^{b}	0.336^{b}	0.341^{d}	0.344^{f}	0.346^{d}	0.339^{c}	0.326^{c}	0.324^{d}
T_2 Soil+FYM	0.357^{a}	0.361^{a}	0.368^{b}	0.372^{d}	0.379^{b}	0.366^{b}	0.353^{b}	0.346^{c}
T_3 Soil+OC	0.361^{a}	0.367^{a}	0.371^{b}	0.381^{c}	0.383^{b}	0.379^{a}	0.366^{ab}	0.356^{bc}
T_4 Soil+VC	0.362^{a}	0.364^{a}	0.378^{a}	0.392^{a}	0.389^{a}	0.376^{a}	0.369^{ab}	0.358^{b}
T_5 Soil+MC	0.354^{a}	0.367^{a}	0.376^{a}	0.388^{b}	0.379^{b}	0.375^{a}	0.359^{b}	0.348^{c}
T_6 Soil+TOF	0.354^{a}	0.344^{a}	0.347^{c}	0.351^{e}	0.358^{c}	0.363^{b}	0.351^{b}	0.347^{c}
T_7 Soil+F-TOF	0.363^{a}	0.357^{a}	0.385^{a}	0.383^{c}	0.393^{a}	0.384^{a}	0.377^{a}	0.374^{a}
SEm±	0.003	0.006	0.003	0.002	0.019	0.003	0.004	0.003
CD(0.05)	0.010	0.016	0.008	0.004	0.007	0.010	0.011	0.009

4.3.9 Boron fractions

4.3.9.1 Readily available B (Ra-B)

Readily available boron varied among the treatments throughout the incubation period (Table 89). There was a gradual increase in the amount of readily available B up to 12 W and afterward decreased gradually for all treatments. The highest value was recorded with the treatment F-TOF throughout the incubation period, which was followed by VC and OC. The lower most value was recorded by the absolute control.

Table 89. Readily available B in the soil at different periods of incubation, mg kg^{-1}

Treatments	Readily available B (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	0.041^{c}	0.036^{f}	0.056^{f}	0.088^{d}	0.078^{d}	0.076^{c}	0.078^{e}	0.074^{d}
T_2 Soil+FYM	0.052^{b}	0.049^{d}	0.130^{e}	0.156^{c}	0.193^{c}	0.188^{b}	0.183^{cd}	0.180^{c}
T_3 Soil+OC	0.060^{a}	0.054^{c}	0.149^{b}	0.186^{a}	0.206^{b}	0.200^{ab}	0.193^{b}	0.190^{b}
T_4 Soil+VC	0.062^{a}	0.059^{b}	0.151^{b}	0.188^{a}	0.207^{b}	0.200^{ab}	0.195^{b}	0.191^{b}
T_5 Soil+MC	0.058^{b}	0.053^{c}	0.143^{c}	0.179^{ab}	0.204^{b}	0.195^{b}	0.189^{bc}	0.186^{b}
T_6 Soil+TOF	0.050^{b}	0.047^{e}	0.139^{d}	0.171^{b}	0.196^{c}	0.187^{b}	0.181^{d}	0.179^{c}
T_7 Soil+F-TOF	0.070^{a}	0.090^{a}	0.156^{a}	0.190^{a}	0.222^{a}	0.217^{a}	0.212^{a}	0.205^{a}
SEm±	0.036	0.0007	0.0010	0.0050	0.0017	0.0057	0.0023	0.0233
CD(0.05)	0.11	0.002	0.003	0.015	0.005	0.017	0.007	0.005

4.3.9.2 Specifically adsorbed B (Spa-B)

Specifically adsorbed B also varied significantly between the treatments throughout the incubation period (Table 90). Concentration of specifically adsorbed B in the soil increased upto 12 W and afterwards declined gradually. The highest value was recorded with the treatment F-TOF throughout the incubation period, which was followed by VC and OC. The lowest was recorded with the absolute control.

Table 90. Specifically adsorbed B in the soil at different periods of incubation, mg kg^{-1}

Treatments	Specifically adsorbed B (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	0.061 e	0.054^{d}	0.066^{g}	0.091^{e}	0.088^{e}	0.092^{e}	0.082^{d}	0.081^{g}
T_2 Soil+FYM	0.077 d	0.073^{c}	0.195^{f}	0.235^{d}	0.289^{d}	0.282^{d}	0.274^{c}	0.270^{e}
T_3 Soil+OC	0.090 b	0.081^{b}	0.223^{c}	0.278^{a}	0.308^{bc}	0.300^{b}	0.289^{b}	0.284^{c}
T_4 Soil+VC	0.092 b	0.089^{a}	0.226^{b}	0.281^{a}	0.311^{b}	0.299^{b}	0.292^{b}	0.286^{b}
T_5 Soil+MC	0.086 c	0.080^{b}	0.215^{d}	0.268^{b}	0.306^{bc}	0.292^{c}	0.284^{bc}	0.279^{d}
T_6 Soil+TOF	0.075 d	0.071^{c}	0.208^{e}	0.257^{c}	0.294^{cd}	0.280^{d}	0.272^{c}	0.268^{f}
T_7 Soil+F-TOF	0.104 a	0.092^{a}	0.234^{a}	0.284^{a}	0.332^{a}	0.325^{a}	0.318^{a}	0.307^{a}
SEm±	0.03	0.0023	0.0007	0.0023	0.0050	0.0007	0.0040	0.0020
CD (0.05)	0.08	0.007	0.002	0.007	0.015	0.002	0.012	0.002

4.3.9.3 Oxide bound B (Ox-B)

Oxide bound B varied significantly between the treatments throughout the incubation period (Table 91). The highest value was recorded with treatment F-TOF throughout the incubation period. It was followed by VC and OC. There was a gradual increase in content of oxide bound B up to 12 W and declined afterwards. The lowest value was recorded with the absolute control.

Table 91. Oxide bound B in the soil at different periods of incubation, mg kg^{-1}

Treatments	Oxide bound B (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	0.020 ^{d}	0.018 ^{d}	0.028 ^{b}	0.014 ^{b}	0.018 ^{e}	0.015 ^{e}	0.014 ^{e}	0.014 ^{d}
T_2 Soil+FYM	0.026 ^{c}	0.024 ^{c}	0.065 ^{g}	0.078 ^{e}	0.096 ^{d}	0.098 ^{d}	0.094 ^{d}	0.090 ^{c}
T_3 Soil+OC	0.030 ^{b}	0.027 ^{b}	0.074 ^{d}	0.093 ^{b}	0.103^{cd}	0.11 ^{c}	0.096 ^{c}	0.095^{bc}
T_4 Soil+VC	0.031 ^{a}	0.030 ^{b}	0.075 ^{c}	0.094 ^{b}	0.104^{bc}	0.13 ^{c}	0.097 ^{c}	0.095^{bc}
T_5 Soil+MC	0.029 ^{b}	0.027 ^{b}	0.072 ^{e}	0.089 ^{c}	0.102^{cd}	0.107^{cd}	0.109 ^{c}	0.093 ^{c}
T_6 Soil+TOF	0.025 ^{c}	0.024 ^{c}	0.069 ^{f}	0.086 ^{d}	0.09 ^{cd}	0.093 ^{d}	0.097 ^{d}	0.089 ^{c}
T_7 Soil+F-TOF	0.035 ^{a}	0.036 ^{a}	0.078 ^{a}	0.095 ^{a}	0.108 ^{a}	0.111 ^{a}	0.106 ^{a}	0.102 ^{a}
SEm±	0.016	0.0020	0.0003	0.0010	0.0023	0.0017	0.0010	0.0023
CD(0.05)	0.05	0.005	0.001	0.003	0.007	0.005	0.003	0.008

4.3.9.4 Organically bound B (Org-B)

Organically bound B recorded the highest value with treatment F-TOF throughout the incubation period (Table 92). It was followed by VC and OC. The lowest content was recorded with control.

Table 92. Organically bound B in the soil at different periods of incubation, mg kg^{-1}

Treatments	Organically bound B (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	0.091 ^{d}	0.075 ^{g}	0.070 ^{f}	0.069 ^{g}	0.068 ^{f}	0.068 ^{f}	0.068 ^{e}	0.067 ^{d}
T_2 Soil+FYM	0.116 ^{c}	0.110 ^{e}	0.292^{fe}	0.352 ^{f}	0.434 ^{e}	0.423 ^{d}	0.411 ^{d}	0.405 ^{c}
T_3 Soil+OC	0.135 ^{b}	0.122 ^{c}	0.334^{bc}	0.417 ^{c}	0.463^{bc}	0.450 ^{b}	0.433 ^{b}	0.427 ^{b}
T_4 Soil+VC	0.138 ^{b}	0.133 ^{b}	0.339^{ab}	0.422 ^{b}	0.466 ^{b}	0.449 ^{b}	0.438 ^{b}	0.430 ^{b}
T_5 Soil+MC	0.129 ^{b}	0.120 ^{d}	0.322^{cd}	0.403 ^{d}	0.459 ^{c}	0.438 ^{c}	0.426 ^{c}	0.419 ^{b}
T_6 Soil+TOF	0.113 ^{c}	0.107 ^{f}	0.313 ^{d}	0.385 ^{e}	0.441 ^{d}	0.420 ^{e}	0.407 ^{d}	0.403 ^{c}
T_7 Soil+F-TOF	0.157 ^{a}	0.137 ^{a}	0.351 ^{a}	0.427 ^{a}	0.499 ^{a}	0.487 ^{a}	0.477 ^{a}	0.461 ^{a}
SEm±	0.04	0.0007	0.0050	0.0017	0.0023	0.0007	0.0023	0.0023
CD (0.05)	0.12	0.002	0.015	0.005	0.007	0.002	0.007	0.012

4.3.9.5 Residual B (Res-B)

Residual B content significantly varied among the treatments throughout the incubation period (Table 93). The highest value was recorded with the treatment F-TOF followed by VC and OC and lowest value by absolute control.

Table 93. Residual B in the soil at different periods of incubation, mg kg^{-1}

Treatments	Residual B (mg kg^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
T_1 Control	4.167 d	4.197^{e}	4.160^{f}	4.118^{d}	4.128^{b}	4.129^{b}	4.138^{b}	4.144^{b}
T_2 Soil+FYM	4.550 c	4.563^{d}	4.139^{e}	3.999^{f}	3.808^{g}	3.833^{d}	3.862^{d}	3.876^{c}
T_3 Soil+OC	4.826 b	4.855^{b}	4.360^{bc}	4.166^{c}	4.061^{d}	4.091^{b}	4.129^{b}	4.145^{b}
T_4 Soil+VC	4.857 b	4.870^{b}	4.389^{b}	4.195^{b}	4.092^{c}	4.133^{b}	4.159^{b}	4.178^{b}
T_5 Soil+MC	4.798 b	4.821^{b}	4.348^{c}	4.161^{c}	4.029^{e}	4.079^{b}	4.106^{b}	4.122^{b}
T_6 Soil+TOF	4.636 c	4.651^{c}	4.171^{d}	4.002^{e}	3.871^{f}	3.921^{c}	3.950^{c}	3.961^{c}
T_7 Soil+F-TOF	5.174 a	5.185^{a}	4.722^{a}	4.545^{a}	4.377^{a}	4.403^{a}	4.428^{a}	4.464^{a}
SEm±	0.053	0.0183	0.0100	0.0050	0.0023	0.0283	0.0233	0.0050
CD (0.05)	0.16	0.055	0.030	0.015	0.007	0.085	0.070	0.10

4.3.10 Heavy metals

Available Cd and Pb were not detected in the soil

4.3.11 Microbial population

4.3.11.1 Bacteria

Bacterial population of the incubated soil varied significantly among the treatments due to the addition of organic fertilizers (Table 94). At 0 D and first week bacterial population recorded the highest for MC and later by F-TOF. In all the treatments the bacterial population increased from 0 D up to 24 W, with control as exception. Throughout the incubation highest value was recorded by MC.

Table 94. Bacterial population of the soil at different periods of incubation, log cfu g^{-1}

Treatments	Microbial count -Bacteria (log cfu g^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
$T_{1\ \text{Control}}$	2.83^{f}	4.38^{g}	5.60^{f}	5.85^{f}	6.20^{e}	5.95^{d}	5.30^{g}	6.11^{c}
$T_{2\ \text{Soil+FYM}}$	4.18^{d}	5.33^{f}	6.11^{d}	6.23^{c}	6.34^{d}	6.60^{b}	6.08^{f}	6.15^{c}
$T_{3\ \text{Soil+OC}}$	4.30^{c}	5.45^{e}	6.08^{e}	6.11^{e}	6.59^{c}	6.60^{b}	6.48^{d}	6.65^{b}
$T_{4\ \text{Soil+VC}}$	4.79^{b}	5.57^{b}	6.38^{b}	6.51^{a}	6.60^{c}	6.65^{a}	6.69^{b}	6.75^{a}
$T_{5\ \text{Soil+MC}}$	4.86^{a}	5.64^{a}	6.08^{e}	6.15^{d}	6.60^{c}	6.61^{b}	6.51^{c}	6.64^{b}
$T_{6\ \text{Soil+TOF}}$	3.70^{e}	5.48^{d}	6.28^{c}	6.34^{b}	6.38^{c}	6.51^{c}	6.11^{e}	6.18^{c}
$T_{7\ \text{Soil+F-TOF}}$	3.71^{e}	5.49^{c}	6.48^{a}	6.54^{a}	6.62^{a}	6.77^{a}	6.78^{a}	6.79^{a}
SEm±	0.005	0.002	0.002	0.010	0.005	0.028	0.010	0.005
CD (0.05)	0.015	0.005	0.007	0.030	0.015	0.085	0.030	0.085

4.3.11.2 Fungi

Fungal population of the incubated soil varied significantly between the treatments due to the addition of organic fertilizers (Table 95). Fungal count increased up to 8 W of incubation for all treatments and declined afterwards. Towards the end of incubation, again a rise in fungal population was noted for all treatment except control, compared to that of 20 W. During the incubation, the highest value for fungal count was maintained by F-TOF followed by VC and TOF.

Table 95. Fungal population of soil at different periods of incubation, log cfu g^{-1}

Treatments	Microbial count -Fungus (log cfu g^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
$T_{1\ \text{Control}}$	1.91^{d}	3.00^{g}	2.60^{f}	2.62^{e}	2.23^{d}	2.16^{b}	2.10^{c}	2.06^{e}
$T_{2\ \text{Soil+FYM}}$	2.91^{b}	3.67^{d}	2.94^{d}	2.98^{cd}	2.62^{c}	2.72^{b}	2.92^{a}	3.15^{d}
$T_{3\ \text{Soil+OC}}$	3.05^{ab}	3.08^{f}	2.91^{e}	2.95^{d}	2.32^{d}	2.83^{a}	2.89^{a}	3.18^{d}
$T_{4\ \text{Soil+VC}}$	3.14^{ab}	3.90^{c}	3.06^{b}	3.08^{b}	2.72^{b}	2.56^{c}	2.72^{b}	3.41^{b}
$T_{5\ \text{Soil+MC}}$	3.17^{a}	3.20^{e}	2.94^{d}	2.95^{d}	2.20^{d}	2.81^{a}	2.89^{a}	3.18^{d}
$T_{6\ \text{Soil+TOF}}$	2.21^{c}	3.93^{b}	3.02^{c}	3.04^{bc}	2.65^{bc}	2.45^{d}	2.69^{bc}	3.26^{c}
$T_{7\ \text{Soil+F-TOF}}$	2.24^{c}	4.04^{a}	3.16^{a}	3.19^{a}	2.83^{a}	2.84^{a}	2.90^{a}	3.32^{a}
SEm±	0.080	0.007	0.003	0.026	0.031	0.023	0.019	0.080
CD (0.05)	0.241	0.020	0.010	0.078	0.093	0.070	0.057	0.035

4.3.11.3 Actinomycetes

Actinomycetes population in the soil varied significantly among the treatments due to the addition of organic fertilizers (Table 96). Actinomycetes number increased during the first week and remained almost constant throughout the incubation for control, FYM and OC. For VC and MC a decrease was noticed at 4 W and 8 W and increase at 12 W and 16 W followed by a decline. Soils with F-TOF and TOF maintained a higher actinomycetes count throughout the incubation and it remained more or less constant.

Table 96. Actinomycetes population of the soil at different periods of incubation, log cfu g^{-1}

Treatments	Microbial count -Actinomycetes (log cfu g^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
$T_{1\ \mathrm{Control}}$	1.42^{e}	2.00^{g}	2.00^{d}	2.00^{e}	2.00^{f}	2.00^{f}	2.00^{e}	2.00^{d}
$T_{2\ \mathrm{Soil+FYM}}$	1.72^{d}	2.30^{f}	2.30^{c}	2.30^{c}	2.30^{d}	2.30^{d}	2.30^{c}	2.10^{c}
$T_{3\ \mathrm{Soil+OC}}$	2.12^{a}	2.70^{c}	2.48^{b}	2.48^{b}	2.48^{c}	2.48^{c}	2.48^{b}	2.30^{b}
$T_{4\ \mathrm{Soil+VC}}$	1.22^{f}	2.67^{d}	2.48^{b}	2.43^{b}	2.57^{b}	2.68^{b}	2.36^{c}	2.30^{b}
$T_{5\ \mathrm{Soil+MC}}$	1.70^{d}	2.48^{e}	2.48^{b}	2.10^{d}	2.15^{e}	2.21^{e}	2.12^{d}	2.08^{c}
$T_{6\ \mathrm{Soil+TOF}}$	2.00^{b}	2.78^{a}	2.60^{a}	2.78^{a}	2.78^{a}	2.78^{a}	2.78^{a}	2.48^{a}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	1.82^{c}	2.78^{a}	2.60^{a}	2.78^{a}	2.78^{a}	2.78^{a}	2.78^{a}	2.48^{a}
SEm±	0.010	0.023	0.002	0.018	0.028	0.022	0.025	0.010
CD (0.05)	0.030	0.070	0.007	0.055	0.083	0.065	0.076	0.062

4.3.29 Dehydrogenase activity

Dehydrogenase activity in the soil varied significantly among the treatments due to the addition of organic fertilizers (Table 97). At 0 D and 1 W, dehydrogenase activity was the highest for MC and afterwards F-TOF recorded the highest value. The lowest dehydrogenase activity was recorded with control.

Table 97. Dehydrogenase activity of the soil at different periods of incubation, µg TPF g^{-1} soil 24 hr^{-1}

Treatments	Dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1})							
	0 D	1 W	4 W	8 W	12 W	16 W	20 W	24 W
$T_{1\ \mathrm{Control}}$	7.23^{d}	7.99^{d}	8.23^{e}	7.91^{d}	7.89^{e}	7.77^{d}	7.56^{d}	7.23^{d}
$T_{2\ \mathrm{Soil+FYM}}$	13.42^{b}	16.25^{b}	21.35^{c}	24.25^{b}	26.14^{d}	29.45^{c}	31.21^{c}	32.19^{c}
$T_{3\ \mathrm{Soil+OC}}$	12.26^{bc}	18.55^{a}	24.25^{b}	25.21^{b}	29.56^{c}	32.46^{b}	33.56^{b}	33.98^{c}
$T_{4\ \mathrm{Soil+VC}}$	14.49^{b}	18.63^{a}	26.28^{b}	28.45^{a}	31.55^{b}	33.66^{b}	35.89^{a}	36.87^{b}
$T_{5\ \mathrm{Soil+MC}}$	16.71^{a}	19.21^{a}	21.68^{c}	23.65^{b}	28.99^{c}	32.48^{b}	33.84^{b}	35.45^{b}
$T_{6\ \mathrm{Soil+TOF}}$	11.74^{c}	13.27^{c}	19.46^{d}	21.14^{c}	25.67^{d}	28.96^{c}	31.58^{c}	32.89^{c}
$T_{7\ \mathrm{Soil+F\text{-}TOF}}$	11.74^{c}	14.14^{c}	29.68^{a}	30.25^{a}	33.66^{a}	35.89^{a}	37.54^{a}	38.75^{a}
SEm±	0.553	0.630	0.707	0.653	0.550	0.590	0.747	0.610
CD (0.05)	1.66	1.89	2.12	1.96	1.65	1.77	2.24	1.83

4.4 FIELD EXPERIMENTS

Field experiments on tomato-amaranthus cropping sequence were carried out two times during November 2018 to November 2019. The first crop of tomato was taken in the month of November 2018. Immediately after the harvest of tomato, the field was prepared for the succeeding crop of amaranthus. The same sequence was repeated once more without any time lag. In the field trial, the effect of different organic fertilizers on the growth, yield, quality, and nutrient uptake by crops, and nutrient availability in soil were studied.

Biometric characteristics of the plant, nutrient content in plant parts, nutrient uptake, quality parameters of edible portions, yield and yield attributes of tomato and amaranthusof both the cropping sequence are detailed below. The tomato and amaranthus of the first cropping sequence are designated as Tomato I and Amaranthus I and for second sequence as Tomato II and Amaranthus II respectively.

4.4.1 TOMATO

4.4.1.1 BIOMETRIC OBSERVATIONS

4.4.1.1.1 Plant height

Plant height of tomato differed significantly among the treatments during both the cropping sequences (Table 98). For both cropping sequences, the highest plant height was recorded by treatment T_7 (F-TOF + STBR). It was followed by treatments T_4 (VC + STBR) and T_5 (MC + STBR) in the first cropping sequence and by T_4 and T_6 (TOF +STBR) in the second cropping sequence.In second cropping sequence, the treatments such as T_3 (OC+STBR), T_4, T_5 and T_6 were statistically on par with the treatment T_7. For both the cropping sequences, the lowest plant height was recorded by the treatment T_9 (absolute control).

4.4.1.1.2 Number of primary branches

Number of primary branches of tomato varied significantly between the treatments (Table 98). For both the cropping sequences, number of primary branches was the highest for the treatment T_7 (F-TOF +STBR) followed by T_6 and T_4. For absolute control (T_9), there was only single primary branch for both the cropping sequences. Production of primary branches was comparatively less in FYM applied crop plants (T_1 and T_2) compared to other organic fertilizers.

4.4.1.1.3 Dry matter production

Treatments significantly influenced the dry matter content of shoot, fruit and root (Table 98)

4.4.1.1.3.1 Shoot

In the first cropping sequence, the highest shoot dry matter (82.60 g plant^{-1}) was recorded by treatment T_4 (VC + STBR), followed by T_7 (F-TOF + STBR) and T_6 (TOF +STBR). Also treatment T_7 was statistically on par with T_4 and treatments T_3 (OC + STBR), T_5 (MC +STBR) and T_6 were statistically on par with each other. For the second cropping sequence, the highest dry matter production (90.72 g plant^{-1}) was recorded by T_7 followed by T_4 and T_6. For both the cropping sequences, the lowest dry matter content was recorded by absolute control (T_9).

4.4.1.1.3.2 Fruit

The highest dry matter production (73 g plant^{-1}) was recorded by treatment T_4 (VC+STBR) followed by T_7 (F-TOF + STBR) and T_6 (TOF +STBR) for the first cropping sequence as in the case of shoot. In the second cropping sequence, treatment T_7 (79.4 g plant^{-1}) recorded highest value followed by T_4 and T_6 and they were statistically on par with each other. For both the cropping sequences, the dry matter

Table 98. Effect of organic fertilizer based treatments on biometric observations and dry matter production of tomato

Treatments	Biometric observations and dry matter production									
	Tomato I					Tomato II				
	Plant height (cm)	No. of primary branches per plant	Dry matter production (g plant^{-1})			Plant height (cm)	No. of primary branches per plant	Dry matter production (g plant^{-1})		
			Shoot	Fruit	Root			Shoot	Fruit	Root
T_1- FYM + NPK $_{POP}$	46.00^{f}	3.30^{g}	70.45^{d}	$62.3\ ^{c}$	2.47^{f}	48.56^{bc}	3.33^{f}	75.88^{c}	$66.4\ ^{c}$	2.81^{g}
T_2 - FYM + STBR	46.50^{e}	3.30^{g}	73.47^{cd}	$64.9\ ^{c}$	2.57^{e}	49.25^{bc}	3.33^{f}	78.29^{bc}	$68.5\ ^{c}$	2.90^{f}
T_3- OC + STBR	48.00^{d}	4.50^{e}	75.49^{bc}	66.7^{b}	2.64^{d}	51.23^{abc}	4.50^{e}	80.19^{bc}	$70.2\ ^{b}$	2.97^{e}
T_4- VC + STBR	50.00^{b}	6.33^{c}	82.60^{a}	73.0^{a}	2.89^{c}	54.23^{a}	5.33^{c}	89.54^{a}	$78.4\ ^{a}$	3.31^{b}
T_5- MC+ STBR	49.00^{c}	5.50^{d}	75.43^{bc}	66.7^{d}	2.64^{d}	52.63^{ab}	5.25^{d}	81.70^{b}	$71.5\ ^{b}$	3.02^{d}
T_6- TOF + STBR	48.00^{d}	$7.33\ ^{b}$	77.78^{bc}	$68.8\ ^{b}$	2.98^{b}	52.89^{ab}	6.33^{b}	88.65^{a}	$77.6\ ^{a}$	3.28^{c}
T_7- F-TOF + STBR	52.50^{a}	9.50^{a}	79.80^{ab}	$70.5\ ^{a}$	3.14^{a}	55.55^{a}	7.50^{a}	90.72^{a}	$79.4\ ^{a}$	3.36^{a}
T_8- F-TOF alone	34.00^{g}	4.25^{f}	33.04^{e}	$29.2\ ^{d}$	1.45^{g}	47.23^{c}	3.33^{f}	49.28^{d}	43.1^{d}	1.82^{h}
T_9- Absolute control	28.00^{h}	1.00^{h}	8.12^{f}	$7.2\ ^{e}$	0.28^{h}	26.32^{d}	1.00^{g}	5.88e	5.1 e	0.22i
SEm±	0.150	0.002	1.520	1.19	0.002	1.52	0.003	1.82	1.41	0.002
CD (0.05)	0.45	0.005	4.56	3.56	0.007	4.56	0.009	5.47	4.24	0.007

content in the absolute control was the lowest. The results followed the same pattern as that of shoot.

4.4.1.1.3.3 Root

The highest root dry matter was recorded in treatment T_7 (F-TOF + STBR) followed by T_6 (TOF +STBR) and T_4 (VC+STBR) in the first cropping sequence. In the second cropping sequence also T_7 recorded the highest value followed by T_4 and T_6. In both the cropping sequences, the lowest value was recorded by absolute control.

4.4.1.2 GROWTH ATTRIBUTES AND YIELD CHARACTERS

4.4.1.2.1 Days for first flowering

There was significant difference in the number of days taken for first flowering in tomato for different treatments (Table 99). In the first cropping sequence, the first flower was observed at 22.33 days after transplanting (DAT) for the treatment T_9 (absolute control). It was followed by treatment T_8 (F-TOF alone) and T_2 (FYM + STBR) where the first flower was observed at 26.25 and 29 DAT, respectively. The treatments T_7 (F-TOF +STBR) and T_4 (VC + STBR) flowered lately at 36.76 and 34.00 DAT, respectively. During the second cropping sequence also “days to flowering” showed the same trend as in the first sequence i.e. T_9 (20.33 DAT) < T_8 (24.50 DAT) < T_2 (27 DAT). For T_7, the first flower emergence was late (35.33 DAT). The first flowering was almost on same day for treatments such as T_3 (OC + STBR), T_4 (VC + STBR) and T_6 (TOF + STBR) i.e., 33.50, 33 and 33.33 DAT, respectively.

4.4.1.2.2 Days for 50 % flowering

There was significant difference in the number of days taken for 50 per cent flowering in tomato for different treatments (Table 99). In the first cropping sequence, 50 percent of flowering occurred first with the treatment T_9 (absolute control) at 34.64 DAT followed by T_8 (F-TOF alone) at 40.33 DAT and T_2 at 44.62 DAT. It followed the same pattern as that of "days for first flowering". For the treatments, T_7 (F-TOF + STBR) and T_8 (F-TOF alone), it took longer duration of 57.67 and 54.33 DAT, respectively for 50 % flowering. The treatments T_3 (OC +STBR), T_4 (VC +STBR) and T_5 (MC + STBR) were on par with each other for the number of days taken for 50 % flowering i.e., at 51.33, 52.33 and 50.67 DAT, respectively. In the second cropping sequence also the trend was same that the first 50 % of flowering. The treatments T_7 (51.45 DAT) and T_6 (49.33 DAT) took longer duration for flowering and the treatments T_3 and T_4 were on par with treatment T_6 (TOF + STBR) for the number of days taken for 50 % flowering.

4.4.1.2.3 Number of fruits per plant

Number of tomato fruits per plant varied significantly among the treatments (Table 99). For both the cropping sequence, the highest number of tomato fruits (58.50 and 60.50, respectively) was recorded by the treatment T_7 (F-TOF +STBR) followed by T_4 (VC + STBR) and T_6 (TOF + STBR). The lowest number of fruits was recorded by the absolute control (T_9) during both cropping sequences preceded by T_8 (F-TOF alone).

4.4.1.2.4 Fruit yield

Fruit yield was significantly influenced by the treatments (Table 99). For the first cropping sequence, the highest fruit yield per plant (1.475 kg plant^{-1}) was recorded by treatment T_4 (VC +STBR) followed by T_7 (F-TOF + STBR). For second cropping sequence, treatment T_7 recorded the highest yield (1.62 kg plant^{-1}) followed by T_4. For both the cropping sequence, the lowest fruit yield was recorded by absolute control.

Table 99. Effect of treatments on yield attributes and fruit yield of tomato

Treatments	Yield characters									
	Tomato I					Tomato II				
	Days to first flowering (DAT)	Days to 50% flowering (DAT)	Number of fruits per plant	Fruit yield per plant (kg)	Fruit yield (t ha^{-1})	Days to first flowering	Days to 50% flowering	Number of fruits per plant	Fruit yield per plant (kg)	Fruit yield (t ha-^{1})
T$_{1}$- FYM + NPK $_{POP}$	30.00^{d}	45.33^{bcd}	36.50^{f}	1.258^{e}	34.94^{f}	28.00^{cd}	41.33^{c}	39.33^{e}	1.355^{c}	37.64^{c}
T$_{2}$ - FYM + STBR	29.00^{d}	44.67^{cd}	38.33^{e}	1.312^{d}	36.44^{e}	27.00^{cd}	40.67^{c}	42.50^{de}	1.398^{bc}	38.83^{c}
T$_{3}$- OC + STBR	32.50^{bc}	51.33^{abc}	41.33^{d}	1.348^{cd}	37.4^{d}	33.50^{ab}	48.33^{ab}	46.33^{c}	1.432^{b}	39.78^{bc}
T$_{4}$- VC + STBR	34.00^{b}	52.33^{ab}	52.33^{b}	1.475^{a}	40.97^{a}	33.00^{ab}	48.33^{ab}	54.50^{b}	1.599^{a}	44.42^{a}
T$_{5}$- MC+ STBR	31.00^{cd}	50.67^{abc}	42.55^{d}	1.347^{cd}	37.4^{d}	30.00^{bc}	45.89^{b}	44.33^{cd}	1.459^{b}	40.53^{abc}
T$_{6}$- TOF + STBR	32.33^{bc}	54.33^{a}	44.75^{c}	1.389^{bc}	38.58^{c}	33.33^{ab}	49.33^{ab}	44.50^{cd}	1.583^{a}	43.97^{ab}
T$_{7}$- F-TOF + STBR	36.76^{a}	57.67^{a}	58.50^{a}	1.425^{b}	39.5^{b}	35.33^{a}	51.45^{a}	60.50^{a}	1.620^{a}	45.00^{a}
T$_{8}$- F-TOF alone	26.25^{e}	40.33^{de}	31.33^{g}	0.790^{f}	16.3^{g}	24.50^{de}	38.56^{c}	33.33^{f}	0.880^{d}	24.44^{d}
T$_{9}$- Absolute control	22.33^{f}	34.67^{e}	8.25^{h}	0.145^{g}	4.03^{h}	20.33^{e}	30.67^{d}	5.50^{g}	0.105^{e}	2.92^{e}
SEm±	0.693	2.43	0.597	0.015	0.031	1.52	1.16	1.13	0.023	1.52
CD (0.05)	2.08	7.29	1.79	0.046	0.092	4.56	3.48	3.40	0.068	4.56

4.4.1.3 QUALITY PARAMETERS

4.4.1.3.1 Lycopene

There was significant difference in the lycopene content of different treatments (Table 100). For both the cropping sequences, the highest lycopene content was recorded by treatment T_7 (F-TOF +STBR) and it was statistically on par with other treatments that have received different organic fertilizers. For both the cropping sequences, the lowest lycopene content was recorded with the absolute control (T_9).

4.4.1.3.2 TSS content

There was no significant difference in the TSS content of tomatoes of different treatments (Table 100).

4.4.1.3.3 Ascorbic acid content

Ascorbic acid content of different treatments varied significantly (Table 100). For the first cropping sequence, the highest ascorbic acid content was recorded by the treatment T_7 (F-TOF + STBR) and it statistically on par with other treatments, except absolute control

Table 100. Influence of treatments on quality parameters of tomato

Treatments	Quality parameters					
	Tomato I			Tomato II		
	Lycopene (µg g^{-1})	TSS (%)	Ascorbic acid (mg $100g^{-1}$)	Lycopene (µg g^{-1})	TSS (%)	Ascorbic acid (mg $100g^{-1}$)
T_1- FYM +NPK $_{POP}$	11.72 ^{ab}	4..75	25.28 ^{ab}	11.84 ^{ab}	4.65	26.08 ^{a}
T_2 - FYM + STBR	11.74 ^{ab}	4.79	25.39 ^{ab}	11.86 ^{ab}	4.69	26.19 ^{a}
T_3- OC + STBR	11.79 ^{ab}	4.89	25.65 ^{ab}	11.92 ^{ab}	4.75	26.85 ^{a}
T_4- VC + STBR	11.98 ^{ab}	5.10	25.94 ^{a}	12.05 ^{ab}	4.98	26.94 ^{a}
T_5- MC+ STBR	11.89 ^{ab}	4.91	25.42 ^{ab}	11.93 ^{ab}	4.89	26.42 ^{a}
T_6- TOF + STBR	11.86 ^{ab}	5.12	25.77 ^{ab}	11.91 ^{ab}	5.02	26.77 ^{a}
T_7- F-TOF+STBR	12.25 ^{a}	5.25	26.41 ^{a}	12.31 ^{a}	5.21	27.15 ^{a}
T_8- F-TOF alone	11.89 ^{ab}	4.69	24.69 ^{b}	11.90 ^{ab}	4.55	24.89 ^{b}
T_9-Absolutecontrol	11.63 ^{b}	4.51	23.21 ^{c}	11.66 ^{b}	4.45	21.88 ^{c}
SEm±	0.043	-	0.238	0.025	-	0.314
CD (0.05)	0.55	NS	1.24	0.49	NS	1.13

4.4.1.4 NUTRIENT CONCENTRATION IN DIFFERENT PLANT PARTS

4.4.1.4.1 Shoot

Treatment effects on macro and micronutrient concentrations in shoot were statistically significant and are presented in Table 101 and 102 respectively.

4.4.1.4.1.1 Macronutrients

4.4.1.4.1.1.1 Nitrogen

In the first cropping sequence, the highest N content (1.96 %) was recorded by the treatment T_7 (F-TOF + STBR) followed by T_8 and T_6. In the second cropping sequence, treatment T_5 (MC + STBR) recorded the highest content followed by T_7 and they were statistically on par with each other. In both the cropping sequences, the lowest N content was recorded with absolute control (T_9)

4.4.1.4.1.1.2 Phosphorus

In the first cropping sequence the highest P content in shoot (0.519 %) was recorded by treatment T_3 (OC + STBR) followed by T_5 (MC + STBR), T_2 (FYM + STBR) and T_7 (F-TOF + STBR) and they were statistically on par with each other. In second cropping sequence the highest P content in shoot (0.521 %) was recorded by treatment T_3 followed by T_7. In both the cropping sequences the lowest P content (0.264 and 0.201 %, respectively) was recorded with absolute control (T_9).

4.4.1.4.1.1.3 Potassium

For both the cropping sequences, the highest K content (1.73 and 1.88 %, respectively) was recorded by the treatment T_7 (F-TOF + STBR) followed by T_6 (TOF +STBR) and T_4 (VC + STBR) and the lowest value was recorded with the absolute control (T_9).

4.4.1.4.1.1.4 Calcium

For both the cropping sequences, the highest Ca content was recorded with the treatment T_7 (F-TOF + STBR) followed by T_6. In first cropping sequence the treatments T_3 (OC +STBR), T_4 (VC +STBR), T_5 (MC +STBR) and T_6 (TOF + STBR) were statistically on par with treatment T_7.While in the second cropping sequence, treatments T_5 and T_6 were statistically on par with T_7. In both the cropping sequences the lowest value was recorded with absolute control.

4.4.1.4.1.1.5 Magnesium

For the first cropping sequence the highest Mg content was recorded by treatment T_4 (VC +STBR) followed by T_7 (F-TOF + STBR) and T_6 (TOF + STBR). The treatments T_2 (FYM + STBR), T_5, T_6 and T_7 were statistically on par with the treatment T_4. In the second cropping sequence, the highest value was recorded by T_7

followed by T_6 and they were statistically on par with each other. In both the cropping sequences, the lowest value was recorded with absolute control (T_9)

4.4.1.4.1.1.6 Sulphur

There was significant difference in the sulphur content of tomato shoot of different treatments. In the first cropping sequence, the highest value (0.155 %) was recorded by treatment T_7 (F-TOF + STBR) followed by T_5 (MC + STBR). Also the treatments such as T_1 (FYM + NPK @ *POP), T_2 (FYM + STBR), T_5 and T_8 (TOF + STBR) were statistically on par with each other. For the second cropping sequence, treatments T_1 and T_2 recorded the highest value (0.198 %) and all the treatments except T_8 and T_9 were statistically on par with each other.

4.4.1.4.1.2 Micronutrients and heavy metals

4.4.1.4.1.2.1 Iron

For both the cropping sequences, the highest Fe content (2342 and 2398 mg kg^{-1}, respectively) was recorded with treatment T_5 (MC + STBR) followed by T_4 (VC + STBR). The lowest Fe content in the tomato shoot for both the cropping sequence was recorded by absolute control (T_9).

4.4.1.4.1.2.2 Manganese

For both the cropping sequences, the highest Mn content was recorded with treatment T_4 (VC + STBR). The lowest Mn content in the tomato shoot for both the cropping sequences was recorded by absolute control (T_9).

4.4.1.4.1.2.3 Zinc

For both the cropping sequences, the highest Zn content was recorded with treatment T_7 (F-TOF + STBR). The lowest Zn content in the tomato shoot for both the cropping sequences was recorded by absolute control (T_9).

Table 101. Macronutrient concentration in the tomato shoot as influenced by treatments, %

Treatments	Nutrient content in shoot (%)											
	Tomato I						Tomato II					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T_1- FYM + NPK $_{POP}$	1.74 ^{g}	0.486 ^{bc}	1.00 ^{f}	0.48^{bc}	0.184 ^{b}	0.132^{ab}	1.85 ^{cd}	0.514 ^{a}	1.06 ^{c}	0.56 ^{c}	0.172 ^{c}	0.198 ^{a}
T_2 - FYM + STBR	1.79 ^{d}	0.501 ^{ab}	0.99 ^{f}	0.47^{bc}	0.186^{ab}	0.133^{ab}	1.90 ^{bc}	0.507 ^{ab}	0.98 ^{c}	0.86 ^{ab}	0.168 ^{c}	0.198 ^{a}
T_3- OC + STBR	1.75 ^{fg}	0.519 ^{a}	1.40 ^{c}	0.56^{ab}	0.175 ^{c}	0.129 ^{b}	1.79 ^{d}	0.521 ^{a}	1.46 ^{b}	0.74 ^{b}	0.168 ^{c}	0.192 ^{a}
T_4- VC + STBR	1.77 ^{e}	0.465 ^{c}	1.45 ^{b}	0.57^{ab}	0.192 ^{a}	0.124 ^{b}	1.62 ^{e}	0.504 ^{ab}	1.58 ^{b}	0.54 ^{c}	0.192 ^{b}	0.184^{ab}
T_5- MC+ STBR	1.76 ^{ef}	0.516 ^{a}	1.37 ^{c}	0.59^{ab}	0.188^{ab}	0.148^{ab}	2.02 ^{a}	0.513 ^{ab}	1.38 ^{b}	0.90 ^{a}	0.168 ^{c}	0.178^{ab}
T_6- TOF + STBR	1.81 ^{c}	0.486 ^{bc}	1.47 ^{b}	0.64 ^{a}	0.189^{ab}	0.124 ^{b}	1.29 ^{f}	0.507 ^{ab}	1.58 ^{b}	0.92 ^{a}	0.212^{ab}	0.174^{ab}
T_7- F-TOF + STBR	1.96 ^{a}	0.498 ^{ab}	1.73 ^{a}	0.66 ^{a}	0.189^{ab}	0.155 ^{a}	1.96 ^{ab}	0.516 ^{a}	1.88 ^{a}	0.96 ^{a}	0.225 ^{a}	0.176^{ab}
T_8- F-TOF alone	1.84 ^{b}	0.48 ^{bc}	1.29 ^{d}	0.44^{bc}	0.174 ^{c}	0.146^{ab}	1.90 ^{bc}	0.498 ^{b}	1.40 ^{b}	0.56 ^{c}	0.192 ^{b}	0.158 ^{b}
T_9- Absolute control	1.18 ^{h}	0.264 ^{d}	1.13 ^{e}	0.39 c	0.139 ^{d}	0.065 ^{c}	1.18 ^{g}	0.201 ^{c}	0.90 ^{c}	0.36 ^{d}	0.120 ^{d}	0.050 ^{c}
SEm±	0.004	0.009	0.015	0.052	0.002	0.009	0.028	0.006	0.073	0.046	0.007	0.009
CD (0.05)	0.012	0.027	0.046	0.155	0.007	0.026	0.085	0.018	0.22	0.138	0.020	0.028

Table 102. Micronutrient concentration in the tomato shoot as influenced by treatments, mg kg^{-1}

Treatments	Nutrient content in shoot (mg kg^{-1})									
	Tomato I					Tomato II				
	Fe	Mn	Zn	Cu	B	Fe	Mn	Zn	Cu	B
T_1- FYM + NPK $_{POP}$	926.00 ^{g}	119.60 ^{c}	69.80 ^{d}	24.80 ^{bc}	14.50 ^{d}	1045 ^{g}	129.45 ^{b}	72.45 ^{e}	26.89 ^{bc}	12.21 ^{d}
T_2 - FYM + STBR	1113.20 ^{e}	127.60 ^{b}	60.00 ^{e}	22.40 ^{c}	14.30 ^{d}	1175 ^{f}	132.66 ^{b}	74.56 ^{de}	25.74 ^{bc}	12.41 ^{cd}
T_3- OC + STBR	1039.20 ^{f}	106.80 ^{d}	65.60 ^{de}	21.20 ^{c}	15.62^{bc}	1245 ^{e}	112.45 ^{c}	77.89 ^{d}	28.14 ^{b}	13.65 ^{b}
T_4- VC + STBR	2032.80 ^{b}	138.40 ^{a}	88.80 ^{b}	28.00 ^{a}	15.96^{ab}	2341 ^{b}	154.85 ^{a}	91.25 ^{b}	34.25 ^{a}	13.99 ^{b}
T_5- MC+ STBR	2342.00 ^{a}	122.40 ^{bc}	53.20 ^{f}	26.00 ^{a}	14.25 ^{d}	2398 ^{a}	131.45 ^{b}	66.59 ^{f}	27.89 ^{b}	12.49 ^{cd}
T_6- TOF + STBR	1276.00 ^{d}	98.00 ^{e}	75.20 ^{c}	20.40 ^{c}	14.89 ^{cd}	1389 ^{c}	89.56 ^{e}	81.24 ^{c}	24.25 ^{c}	12.75 ^{c}
T_7- F-TOF + STBR	937.60 ^{g}	103.60 ^{de}	99.60 ^{a}	24.80 ^{bc}	16.45 ^{a}	1041 ^{g}	104.56 ^{d}	112.56 ^{a}	27.45 ^{b}	15.60 ^{a}
T_8- F-TOF alone	1246.40 ^{c}	86.80 ^{f}	68.40 ^{d}	25.20 ^{b}	11.80 ^{e}	1335 ^{d}	77.12 ^{f}	69.89 ^{ef}	21.14 ^{c}	10.25 ^{e}
T_9- Absolute control	493.60 ^{f}	79.20 ^{g}	26.40 ^{g}	14.40 ^{d}	9.80 ^{f}	541 ^{h}	56.23 ^{g}	22.86 ^{g}	11.23 ^{d}	8.60 ^{f}
SEm±	8.56	2.24	1.96	0.83	0.271	9.48	1.93	1.42	1.18	0.136
CD (0.05)	25.67	6.72	5.89	2.48	0.814	28.45	5.78	4.27	3.55	0.409

4.5.1.4.1.2.4 Copper

For both the cropping sequences, the highest Cu content was recorded with treatment T_4 (VC + STBR). The lowest Cu content in the tomato shoot for both the cropping sequence was recorded by absolute control (T_9).

4.4.1.4.1.2.5 Boron

For both the cropping sequences, the highest B content (16.45 mg kg^{-1}) was recorded by the treatment T_7 (F-TOF + STBR) followed by T_4 and T_3. In the first cropping sequence the treatments T_7 and T_4 were statistically on par. While, in the second cropping sequence, the treatments T_4 and T_3 were statistically on par. The lowest B content in the tomato shoot for both the cropping sequence (9.80 ad 8.60 mg kg^{-1}, respectively) was recorded with absolute control (T_9).

4.4.1.4.1.2.6 Heavy Metals

Heavy metals Cd and Pb were not detected in tomato shoots.

4.4.1.4.2 Root

Macro and micronutrient contents in tomato root were significantly influenced by the treatments and presented in Table 103 and 104 respectively.

4.4.1.4.2.1 Macronutrients

4.4.1.4.2.1.1 Nitrogen

For both the cropping sequences, the highest value for N content was recorded by treatment T_7 (F-TOF +STBR) followed by T_6 (TOF + STBR) and the lowest value was recorded by absolute control (T_9). In the first cropping sequence, the treatments T_2 (FYM + STBR), T_3 (OC + STBR), T_4 (VC + STBR) and T_5 (MC + STBR) were statistically on par with each other. In the second cropping sequence, T_5 and T_7 were statistically on par with each other for their root nitrogen content.

4.4.1.4.2.1.2 Phosphorus

For the first cropping sequence, the highest P content in tomato root was recorded by treatment T_3 followed by T_5 and they were statistically on par. Similarly for the second cropping sequence, the highest P content was recorded with treatment T_4 followed by T_5 and T_3. The treatments from T_1 to T_7 were statistically on par with each other for their P content. For both the cropping sequences, the lowest P content in root was recorded with the absolute control (T_9).

4.4.1.4.2.1.3 Potassium

For the first cropping sequence, the highest K content (1.06 %) was recorded by treatment T_7 (F-TOF +STBR. It was followed by T_6 (TOF +STBR and T_4 (VC + STBR) and they were statistically on par with each other. In the second cropping sequence the highest value (0.78 %) was recorded with T_6 followed by T_7 and they were statistically on par with each other and the treatment T_4 was statistically on par with the treatment T_7. In both the cropping sequences, the lowest value was recorded with T_9 (absolute control).

4.4.1.4.2.1.4 Calcium

For both the cropping sequences, the highest value was recorded by treatment T_4. It was followed by T_7 and T_3 and they were statistically on par with each other. The lowest value for Ca content was recorded with absolute control.

4.4.1.4.2.1.5 Magnesium

For both the cropping sequence, the highest value (0.169 and 0.139%, respectively) was recorded by the treatment T_7 (F-TOF + STBR) followed by T_6 (TOF + STBR) and T_4 (VC +STBR). In the first cropping sequence, treatments T_7 and T_6 were statistically on par. Also the treatments such as T_3 (OC + STBR), T_4 and T_5 (MC +STBR) were statistically on par. In the second cropping sequence T_6 was on par with treatment T_4. In both the cropping sequences, the lowest value was recorded with absolute control.

4.4.1.4.2.1.6 Sulphur

In both the cropping sequences, the highest sulphur content was recorded by T_7. It was followed by T_5 and T_8 (F-TOF alone) in the first cropping sequence and they were statistically on par. While in the second cropping sequence, T_7 was followed by T_1 (FYM + NPK @* POP) and T_2 (FYM + STBR) and they were also statistically on par with each other. The lowest value was recorded with absolute control for both the cropping sequences.

4.4.1.4.2.2 Micronutrients and heavy metals

4.4.1.4.2.2.1 Iron

For both the cropping sequences the highest Fe content was recorded by treatment T_7 (F-TOF + STBR) followed by T_6 (TOF + STBR) and T_8 (F-TOF alone). For both the cropping sequence the lowest value was recorded with absolute control.

4.4.1.4.2.2.2 Manganese

For the first cropping sequences the highest Mn content was recorded by treatment T_6 (TOF + STBR) followed by T_7 (F-TOF + STBR). For the second cropping sequences the highest Mn content was recorded by treatment T_7 (F-TOF + STBR) followed by T_6 (TOF + STBR). For both the cropping sequence, the lowest value was recorded by absolute control.

4.4.1.4.2.2.3 Zinc

For both the cropping sequences the highest Zn content was recorded by treatment T_4 (VC + STBR) followed by T_5 (MC + STBR). For both the cropping sequence the lowest value was recorded by absolute control.

Table 103. Macronutrient concentration in the tomato root as influenced by treatments, %

Treatments	Nutrient content in root (%)											
	Tomato I						Tomato II					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T$_1$- FYM + NPK $_{POP}$	0.75^{c}	0.062^{de}	0.79^{c}	0.68^{c}	0.124^{c}	0.034^{c}	0.65^{h}	0.068^{ab}	0.59^{de}	0.56^{c}	0.104^{e}	0.030^{b}
T$_2$ - FYM + STBR	0.80^{bc}	0.067^{bc}	0.78^{c}	0.67^{cd}	0.126^{c}	0.035^{c}	0.70^{f}	0.074^{ab}	0.58^{e}	0.54^{cd}	0.106^{e}	0.031^{b}
T$_3$- OC + STBR	0.77^{bc}	0.073^{a}	0.80^{c}	0.76^{b}	0.135^{b}	0.032^{c}	0.67^{g}	0.077^{a}	0.63^{cde}	0.64^{b}	0.115^{d}	0.029^{bc}
T$_4$- VC + STBR	0.79^{bc}	0.055^{f}	0.90^{b}	0.83^{a}	0.142^{b}	0.027^{d}	0.74^{d}	0.082^{a}	0.70^{bc}	0.73^{a}	0.128^{b}	0.027^{cd}
T$_5$- MC+ STBR	0.78^{bc}	0.072^{ab}	0.74^{c}	0.59^{e}	0.138^{b}	0.050^{b}	0.72^{e}	0.077^{a}	0.66^{cd}	0.52^{de}	0.122^{c}	0.025^{d}
T$_6$- TOF + STBR	0.83^{b}	0.062^{de}	0.94^{b}	0.64^{d}	0.166^{a}	0.027^{d}	0.81^{b}	0.069^{ab}	0.78^{a}	0.54^{cd}	0.126^{b}	0.027^{cd}
T$_7$- F-TOF + STBR	0.98^{a}	0.066^{cd}	1.06^{a}	0.77^{b}	0.169^{a}	0.058^{a}	0.96^{a}	0.072^{ab}	0.76^{ab}	0.66^{b}	0.139^{a}	0.038^{a}
T$_8$- F-TOF alone	0.76^{c}	0.060^{e}	0.38^{d}	0.54^{f}	0.089^{d}	0.049^{b}	0.79^{c}	0.058^{b}	0.31^{f}	0.49^{e}	0.069^{f}	0.019^{e}
T$_9$- Absolute control	0.19^{d}	0.012^{g}	0.27^{e}	0.29^{g}	0.057^{e}	0.017^{e}	0.15^{i}	0.012^{c}	0.19^{g}	0.21^{f}	0.037^{g}	0.012^{f}
SEm±	0.021	0.002	0.024	0.010	0.003	0.001	0.006	0.006	0.025	0.012	0.001	0.001
CD (0.05)	0.064	0.005	0.073	0.031	0.008	0.004	0.019	0.018	0.074	0.036	0.003	0.003

Table 104. Micronutrient and Pb concentration in the tomato root as influenced by treatments, mg kg^{-1}

Treatments	Nutrient and Pb content in root (mg kg^{-1})											
	Tomato I						Tomato II					
	Fe	Mn	Zn	Cu	B	Pb	Fe	Mn	Zn	Cu	B	Pb
T$_1$- FYM + NPK$_{POP}$	4936.00^{d}	122.00^{b}	134.00^{c}	88.80^{a}	8.36^{b}	0.155	5115^{e}	115.12^{c}	125.25^{d}	84.56^{a}	6.48^{e}	0.075
T$_2$ - FYM + STBR	4100.00^{e}	110.60^{c}	117.60^{d}	80.40^{b}	8.40^{b}	0.160	4785^{f}	102.63^{d}	123.36^{d}	81.23^{a}	6.40^{e}	0.081
T$_3$- OC + STBR	3501.20^{g}	102.80^{d}	137.20^{bc}	70.40^{c}	7.54^{cd}	-	3789^{h}	98.75^{d}	142.35^{c}	69.85^{b}	6.64^{d}	-
T$_4$- VC + STBR	3852.80^{f}	112.40^{c}	180.00^{a}	51.20^{e}	8.88^{a}	-	4572^{g}	125.69^{b}	196.45^{a}	55.63^{cd}	7.48^{a}	-
T$_5$- MC+ STBR	4976.00^{d}	113.60^{c}	144.40^{b}	58.00^{de}	7.16^{de}	-	5178^{d}	119.89^{bc}	168.85^{b}	59.84^{c}	6.69^{cd}	-
T$_6$- TOF + STBR	6304.00^{b}	169.20^{a}	119.20^{d}	53.60^{e}	7.74^{c}	-	6678^{b}	134.89^{a}	135.96^{cd}	59.56^{c}	6.74^{c}	-
T$_7$- F-TOF + STBR	7128.00^{a}	123.20^{b}	122.00^{d}	61.60^{d}	8.50^{ab}	-	7584^{a}	137.45^{a}	141.12^{c}	68.56^{b}	7.36^{b}	-
T$_8$- F-TOF alone	6224.00^{c}	116.00^{c}	95.20^{e}	58.80^{d}	6.80^{e}	-	5896^{c}	104.25^{d}	114.31^{d}	47.56^{d}	4.56^{f}	-
T$_9$- Absolute control	2492.40^{h}	90.40^{e}	40.40^{f}	39.20^{f}	4.60^{f}	-	2214^{i}	77.45^{e}	35.62^{e}	28.96^{e}	2.90^{g}	-
SEm±	16.25	1.95	2.75	2.03	0.142	-	16.82	-	5.14	2.85	0.032	-
CD (0.05)	48.75	5.85	8.24	6.08	0.427	-	50.45	-	15.42	8.54	0.097	-

4.4.1.4.2.2 Micronutrients and heavy metals

4.4.1.4.2.2.1 Iron

For both the cropping sequences the highest Fe content was recorded by treatment T_7 (F-TOF + STBR) followed by T_6 (TOF + STBR) and T_8 (F-TOF alone). For both the cropping sequence the lowest value was recorded with absolute control.

4.4.1.4.2.2.4 Copper

For both the cropping sequences the highest Cu content was recorded by treatment T_1 (FYM + NPK @ *POP) followed by T_2 (FYM + STBR). For both the cropping sequence the lowest value was recorded by absolute control.

4.4.1.4.2.2.5 Boron

In the first cropping sequence the highest B content (8.88 mg kg^{-1}) was recorded by treatment T_4 (VC + STBR) followed by T_7 (F-TOF + STBR) and T_2 (FYM + STBR). The second cropping season the highest value was recorded with T_4 followed by T_7 and T_5 (MC +STBR). For both the cropping sequence the lowest value was recorded with absolute control.

4.4.1.4.2.2.6 Heavy metals

Cd was not detected in tomato roots. But Pb was detected in tomato roots in which FYM was given as the treatment. But the concentration was very low.

4.4.1.4.3 Fruit

Treatments had significantly influenced macro and micronutrient contents in fruit and are presented in Table 105 and 106 respectively.

4.4.1.4.3.1 Macronutrients

4.4.1.4.3.1.1 Nitrogen

In both the cropping sequences, the highest value (4.25 and 4.14, respectively) was recorded by the treatment T_4 (VC + STBR) followed by T_3 (OC + STBR) and T_7 (F-TOF + STBR) and they were statistically on par with each other for the first cropping sequence and not for the second cropping sequence. However, absolute control recorded the lowest N content in the fruit for both the cropping sequence.

4.4.1.4.3.1.2 Phosphorus

In the first cropping sequence, the highest P was recorded by the treatment T_4 and it was statistically on par with treatments such as T_1, T_2, T_3 and $T_{7.}$ In the second cropping sequence, the highest P content was recorded by treatment T_3 followed by T_4 and T_2. In both the cropping sequences, the lowest P content (0.232 and 0.212 %, respectively) was recorded with absolute control (T_9)

4.4.1.4.3.1.3 Potassium

In the first cropping sequence, the highest K content (2.66 %) was recorded by treatment T_4 (VC + STBR) followed by T_7 and T_3. But in the first cropping sequence all the treatments where statistically on par with each other for their K content except for T_8 (F-TOF alone) and T_9 (absolute control). In the second cropping sequence the highest value for K content was recorded with treatment T_4 followed by T_7 and T_3. In the second cropping sequence, the treatments T_1 (FYM +NPK @ *POP), T_3, T_5 (MC + STBR) and, T_7 were statistically on par with the treatment T_4. For both the cropping sequences the lowest value for K content was recorded by absolute control.

4.4.1.4.3.1.4 Calcium

In the first cropping sequence, the highest Ca content (0.32 %) was recorded by the treatment T_7. It was followed by treatments such as T_1, T_2 and T_4 and they were statistically on par with the treatment T_7. In the second cropping sequence, the highest Ca content (0.28 %) was recorded by the treatment T_7 followed by treatment T_4 and T_2 (FYM + STBR). For both the cropping sequences, the lowest value was recorded by the absolute control.

4.4.1.4.3.1.5 Magnesium

In both the cropping sequence, the highest Mg content (0.158 and 0.168 %, respectively) was recorded by treatment T_7 followed by T_6 (TOF + STBR) and T_4. The treatments T_1 (FYM + NPK @*POP), T_2, T_3 (OC + STBR), T_4, T_5 (MC + STBR) and T_6 were statistically on par with the treatment T_7. For both the cropping sequences, the lowest value was recorded by absolute control (T_9).

4.4.1.4.3.1.6 Sulphur

In both the cropping sequence, the highest value (0.194 and 0.196 %, respectively) was recorded with treatment T_5 followed by T_4 and T_3. In the first cropping sequence, the treatment T_5 and T_4 were statistically on par and in second cropping sequence, the treatments T_4 and T_3 were statistically on par. However, for both the cropping sequences, the lowest S content was recorded with absolute control

4.4.1.4.3.2 Micronutrients and heavy metals

4.4.1.4.3.2.1 Iron

For both the cropping sequences, highest Fe content in the tomato fruit was recorded with treatment T_7 (2017.20 and 2214 mg kg^{-1}, respectively) followed by T_6 and T_5. However, the lowest value for both the cropping sequences was recorded with absolute control (T_9).

Table 105: Macronutrient concentration in the tomato fruit as influenced by treatments, %

Treatments	Nutrient content in fruit (%)											
	Tomato I						Tomato II					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T_1- FYM + NPK $_{POP}$	3.84^{abcd}	0.466 ^{a}	2.58 ^{a}	0.29^{ab}	0.151 ^{ab}	0.162 ^{c}	3.58 ^{d}	0.454 ^{d}	2.63^{ab}	0.20 ^{c}	0.154 ^{b}	0.172 ^{d}
T_2 - FYM + STBR	3.78^{bcd}	0.459 ^{a}	2.55 ^{a}	0.29 ^{ab}	0.149 ^{ab}	0.160 ^{c}	3.58 ^{d}	0.462 ^{c}	2.58 ^{b}	0.21 ^{bc}	0.154 ^{b}	0.174 ^{cd}
T_3- OC + STBR	4.18^{ab}	0.464 ^{a}	2.61 ^{a}	0.25^{bcd}	0.147 ^{ab}	0.184 ^{b}	3.98 ^{b}	0.485 ^{a}	2.67^{ab}	0.20 ^{c}	0.144 ^{c}	0.189 ^{b}
T_4- VC + STBR	4.25^{a}	0.472 ^{a}	2.66 ^{a}	0.28^{abc}	0.151 ^{ab}	0.190^{ab}	4.14 ^{a}	0.477 ^{b}	2.72 ^{a}	0.24 ^{b}	0.156 ^{b}	0.188 ^{b}
T_5- MC+ STBR	3.68^{cd}	0.422 ^{b}	2.58 ^{a}	0.24 ^{cd}	0.148 ^{ab}	0.194 ^{a}	3.53 ^{d}	0.392 ^{h}	2.63^{ab}	0.20 ^{c}	0.144 ^{c}	0.196 ^{a}
T_6- TOF + STBR	3.66^{cd}	0.422 ^{b}	2.52 ^{a}	0.22 ^{de}	0.152 ^{ab}	0.152 ^{d}	3.47 ^{d}	0.442 ^{e}	2.58 ^{b}	0.19 ^{c}	0.166 ^{a}	0.172 ^{d}
T_7- F-TOF + STBR	3.94^{abc}	0.458 ^{a}	2.63 ^{a}	0.32 ^{a}	0.158 ^{a}	0.158 ^{cd}	3.70 ^{c}	0.431 ^{f}	2.67^{ab}	0.28 ^{a}	0.168 ^{a}	0.176 ^{c}
T_8- F-TOF alone	3.42^{d}	0.419 ^{b}	2.28 ^{b}	0.18 ^{e}	0.136 ^{b}	0.134 ^{e}	3.30 ^{e}	0.419 ^{g}	2.42 ^{c}	0.12 ^{d}	0.146 ^{c}	0.144 ^{e}
T_9- Absolute control	2.68^{e}	0.232 ^{c}	1.95 ^{c}	0.09 ^{f}	0.072 ^{c}	0.078 ^{f}	2.18 ^{f}	0.212 ^{i}	1.55 ^{d}	0.06 ^{e}	0.067 ^{d}	0.058 ^{f}
SEm±	0.153	0.005	0.051	0.014	0.006	0.003	0.038	0.002	0.031	0.012	0.001	0.001
CD (0.05)	0.46	0.016	0.153	0.043	0.018	0.008	0.113	0.007	0.093	0.037	0.004	0.003

Table 106. Micronutrient concentration in the tomato fruit as influenced by treatments, mg kg^{-1}

Treatments	Nutrient content in fruit (mg kg^{-1})									
	Tomato I					Tomato II				
	Fe	Mn	Zn	Cu	B	Fe	Mn	Zn	Cu	B
T_1- FYM + NPK $_{POP}$	941.20 ^{f}	85.20 ^{bc}	81.20 ^{a}	33.60 ^{a}	17.50^{bc}	1021 ^{f}	83.25 ^{c}	76.89 ^{ab}	29.62 ^{b}	15.21 ^{e}
T_2 - FYM + STBR	1051.20 ^{e}	84.80 ^{c}	71.20 ^{bc}	29.20 ^{b}	17.30 ^{c}	1189 ^{e}	86.23 ^{bc}	73.56 ^{b}	31.52 ^{a}	15.41 ^{d}
T_3- OC + STBR	870.00 ^{g}	90.00 ^{b}	65.60 ^{c}	28.00 ^{b}	17.62^{bc}	987 ^{g}	97.42 ^{a}	66.25 ^{c}	27.85 ^{b}	16.65 ^{b}
T_4- VC + STBR	1212.80 ^{d}	96.00 ^{a}	83.60 ^{a}	34.40 ^{a}	18.25 ^{a}	1345 ^{d}	95.41 ^{a}	79.89 ^{a}	33.42 ^{a}	17.48 ^{a}
T_5- MC+ STBR	1665.20 ^{c}	88.40 ^{b}	78.80 ^{ab}	27.60 ^{b}	17.78 ^{b}	1589 ^{c}	84.12 ^{bc}	72.36 ^{b}	24.26 ^{c}	16.49 ^{c}
T_6- TOF + STBR	1956.80 ^{b}	99.60 ^{a}	74.20 ^{b}	33.20 ^{a}	16.89 ^{d}	2147 ^{b}	89.56 ^{b}	73.62 ^{b}	29.56 ^{b}	14.75 ^{f}
T_7- F-TOF + STBR	2017.20 ^{a}	98.00 ^{a}	76.00 ^{b}	30.00 ^{b}	17.45^{bc}	2214 ^{a}	92.56 ^{ab}	74.45 ^{b}	31.56 ^{ab}	16.60^{bc}
T_8- F-TOF alone	697.60 ^{h}	82.40 ^{c}	63.20 ^{c}	21.60 ^{c}	13.80 ^{e}	789 ^{h}	71.25 ^{d}	71.56 ^{b}	18.59 ^{d}	12.25 ^{g}
T_9- Absolute control	580.80 ^{i}	75.60 ^{d}	28.40 ^{d}	9.60 ^{d}	11.60 ^{f}	446 ^{i}	69.86 ^{d}	25.48 ^{d}	8.56 ^{e}	7.88 ^{h}
SEm±	10.26	1.63	1.99	0.92	0.122	10.85	1.83	1.43	1.15	0.046
CD (0.05)	30.78	4.89	5.98	2.75	0.366	32.55	5.50	4.29	3.45	0.138

4.4.1.4.3.2.2 Manganese

In the first cropping sequence, highest Mn content in the tomato fruit was recorded by treatment T_6 (99.60 mg kg^{-1}) and it was statistically on par with treatments T_7 and T_4. For the second cropping sequence, the highest Mn content in the tomato fruit was recorded by treatment T_3 and it was statistically on par with treatment T_4. The lowest value for both the cropping sequence was recorded by absolute control.

4.4.1.4.3.2.3 Zinc

For both the cropping sequences, highest Zn content in the tomato fruit was recorded with treatment T_4 followed by T_7. However, the lowest value for both the cropping sequence was recorded with absolute control.

4.4.1.4.3.2.4 Copper

For both the cropping sequences, highest Cu content in the tomato fruit was recorded with treatment T_4. The lowest value for both the cropping sequence was recorded with absolute control.

4.4.1.4.3.2.5 Boron

For both the cropping sequences, highest B content in the tomato fruit was recorded by the treatment T_4 (18.25 and 17.48 mg kg^{-1}, respectively) followed by T_5 and T_3 in the first cropping sequence and followed by T_3 and T_5 in second cropping sequence. However, the lowest value for both the cropping sequence was recorded with absolute control.

4.4.1.4.3.2.6 Heavy metals

Cd and Pb were not detected in tomato fruits

4.4.1.5 NUTRIENT UPTAKE

4.4.1.5.1 Nitrogen

Total nitrogen uptake by tomato plants varied significantly among the treatments and also there was significant difference in the N uptake of different parts of tomato plant (Table 107). For both the cropping sequences, the highest total N uptake (135.40 and 139.54 kg ha^{-1}, respectively) and uptake by shoot and root were recorded by treatment T_7 (F-TOF + STBR). N uptake by the fruit was highest for the treatment T_4 (VC + STBR).

For both cropping sequences, the highest total N uptake and N uptake by shoot and root was in treatment $T_{7,}$ while T_4 for N uptake in fruit. For the cropping sequences, the lowest total N uptake (8.21 and 5.12 kg ha^{-1}, respectively) was recorded with absolute control (T_9).

Table 107. Influence of treatments on N uptake by tomato, kg ha^{-1}

Treatments	Uptake of N (kg ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T_1- FYM+ NPK $_{POP}$	34.05^{d}	5.15^{f}	66.5^{c}	105.7^{d}	38.99^{e}	5.07^{g}	68.20^{e}	112.26^{c}
T_2 - FYM + STBR	36.53^{c}	5.71^{de}	68.1^{c}	110.34^{c}	41.32^{c}	5.64^{e}	68.10^{e}	115.06^{c}
T_3- OC + STBR	36.70^{c}	5.65^{e}	77.2^{b}	119.5^{b}	39.87^{d}	5.53^{f}	77.60^{b}	123.00^{b}
T_4- VC + STBR	40.61^{b}	6.34^{c}	86.2^{a}	133.15^{a}	40.29^{d}	6.80^{c}	90.20^{a}	137.29^{a}
T_5- MC+ STBR	36.88^{c}	5.72^{d}	68.2^{c}	110.80^{c}	45.84^{b}	6.04^{d}	70.10^{d}	121.98^{b}
T_6- TOF + STBR	39.11^{b}	6.87^{b}	69.9^{c}	115.88^{b}	39.77^{f}	7.56^{b}	74.80^{c}	122.13^{b}
T_7- F-TOF + STBR	43.45^{a}	8.55^{a}	83.4^{a}	135.40^{a}	47.39^{a}	8.15^{a}	84.00^{b}	139.54^{a}
T_8- F-TOF alone	16.89^{e}	3.06^{g}	27.7^{d}	47.65^{e}	26.01^{g}	3.99^{h}	39.50^{f}	69.50^{d}
T_9-Absolute control	2.66^{f}	0.15^{h}	5.4^{e}	8.21^{f}	1.93 h	0.09i	3.10 g	5.12 e
SEm±	0.563	0.022	1.14	1.61	0.207	0.002	0.006	1.48
CD (0.05)	1.69	0.066	3.41	4.82	0.622	0.007	1.7	4.45

4.4.1.5.2 Phosphorus

Total P uptake by tomato plants varied significantly among the treatments and also there was significant difference in the P uptake of different parts of tomato plant

(Table 108). In both the cropping sequences, the highest P uptake (20.92 and 23.86 kg ha^{-1}, respectively) was by the treatment T_7 (F-TOF + STBR).

In the first cropping sequence, the highest P uptake in shoot and root was recorded by the treatment T_7 and for fruit it was by treatment T_4 (VC + STBR). In the case of total P uptake, the treatments such as T_3 (OC + STBR), T_4 and T_7 (F-TOF + STBR) were statistically on par with each other. In the second cropping sequence, the highest P uptake in tomato shoot was recorded by treatment T_7 and in root and fruit by treatment T_4. In the case of total P uptake in the second cropping sequence, treatments T_7 and T_4 were statistically on par with each other.

Table 108. Effect of treatments on P uptake by tomato, kg ha^{-1}

Treatments	Uptake of P (kg ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T_1- FYM+ NPK $_{POP}$	9.51^{c}	0.425^{g}	8.2^{cd}	18.24^{b}	10.89^{d}	0.531^{g}	8.40^{d}	19.82^{c}
T_2 - FYM + STBR	10.23^{b}	0.478^{e}	8.3^{cd}	19.01^{b}	11.04^{d}	0.596^{f}	8.80^{c}	20.44^{c}
T_3- OC + STBR	10.89^{ab}	0.535^{b}	8.6^{bc}	20.03^{a}	11.55^{c}	0.635^{d}	9.50^{b}	21.69^{b}
T_4- VC + STBR	10.68^{ab}	0.442^{f}	9.6^{a}	20.72^{a}	12.54^{b}	0.754^{a}	10.40^{a}	23.69^{a}
T_5- MC+ STBR	10.8^{ab}	0.528^{c}	7.8^{d}	19.13^{b}	11.64^{c}	0.646^{c}	7.80^{e}	20.09^{c}
T_6- TOF + STBR	10.5^{ab}	0.513^{d}	8.1^{cd}	19.11^{b}	12.48^{b}	0.629^{e}	9.50^{b}	22.61^{b}
T_7- F-TOF + STBR	11.04^{a}	0.576^{a}	9.3^{ab}	20.92^{a}	12.99^{a}	0.672^{b}	10.20^{a}	23.86^{a}
T_8- F-TOF alone	4.41^{d}	0.242^{h}	3.4^{e}	8.05^{c}	6.81^{e}	0.293^{h}	5.00^{f}	12.10^{d}
T_9-Absolute control	0.6 e	0.009^{i}	0.5^{f}	1.11^{d}	0.33^{f}	0.007^{i}	0.30^{g}	0.64^{e}
SEm±	0.230	0.002	0.2	0.307	0.138	0.002	0.001	0.320
CD (0.05)	0.69	0.005	0.60	0.920	0.414	0.006	0.3	0.960

4.4.1.5.3 Potassium

Total K uptake by tomato plants varied significantly among the treatments and also there was significant difference in the K uptake of different parts of tomato plant (Table 109). For both the cropping sequence, the highest total K uptake (99.07 and 113.35 kg ha^{-1}, respectively) as well as highest K uptake in shoot (38.39 and 47.38 kg ha^{-1}, respectively) and root (9.28 and 7.07 kg ha^{-1}, respectively) was recorded by treatment T_7 (F-TOF + STBR). K uptake in the fruit (54 and 59.3 kg ha^{-1}, respectively) was the highest by the treatment T_4 (VC + STBR). For both the cropping sequences, the highest total K uptake was for treatment T$_7$ followed by T$_4$. For both the cropping sequences, the lowest total K uptake was recorded by absolute control.

Table 109. Effect of treatments on K uptake by tomato, kg ha^{-1}

Treatments	Uptake of K (kg ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T$_1$-FYM+ NPK $_{POP}$	19.49^{g}	5.43 ^{f}	44.6 ^{d}	69.52^{e}	22.34 ^{e}	4.62 ^{f}	48.4 ^{g}	75.36 ^{d}
T$_2$ - FYM + STBR	20.16 ^{f}	5.54^{e}	45.9^{cd}	71.6 ^{e}	21.31 ^{f}	4.64 ^{e}	49.0 ^{f}	74.95 ^{d}
T$_3$- OC + STBR	29.32^{d}	5.84^{d}	48.3^{bc}	83.46^{d}	32.52 ^{c}	5.21 ^{d}	52.0 ^{e}	89.73 ^{c}
T$_4$- VC + STBR	33.27^{b}	7.23^{c}	54.0 ^{a}	94.50^{b}	39.30 ^{b}	6.44 ^{b}	59.3 ^{a}	105.04^{b}
T$_5$- MC+ STBR	28.71^{e}	5.43 ^{f}	47.8^{cd}	81.94^{d}	31.32 ^{d}	5.57 ^{c}	52.2 ^{d}	89.09 ^{c}
T$_6$- TOF + STBR	31.72^{c}	7.75^{b}	48.2^{bc}	87.67^{c}	38.91 ^{b}	7.06 ^{a}	55.5 ^{c}	101.47^{b}
T$_7$- F-TOF + STBR	38.39^{a}	9.28^{a}	51.4^{ab}	99.07^{a}	47.38 ^{a}	7.07 ^{a}	58.9 ^{b}	113.35^{a}
T$_8$- F-TOF alone	11.82^{h}	1.51^{g}	18.5 ^{e}	31.83^{f}	19.16 ^{g}	1.56 ^{g}	28.9 ^{h}	49.62 ^{f}
T$_9$-Absolute control	2.56 ^{i}	0.21^{h}	3.9 ^{f}	6.67 ^{g}	1.47 ^{h}	0.11 ^{h}	2.2 ^{i}	3.78 ^{g}
SEm±	0.017	0.003	1.10	1.06	0.284	0.005	0.10	2.11
CD (0.05)	0.052	0.009	3.30	3.02	0.853	0.014	0.21	6.03

4.4.1.5.4 Calcium

Total Ca uptake by tomato plants varied significantly among the treatments and also there was significant difference in the Ca uptake of different parts of tomato plant (Table 110). In the first cropping sequence, the highest total Ca uptake (27.03 kg ha^{-1}) as well as highest Ca uptake in different plant parts such as shoot (14.63 kg ha^{-1}), root (6.72 kg ha^{-1}) and fruit (5.68 kg ha^{-1}) was recorded with treatment T$_7$ (F-TOF + STBR). In second cropping season, highest total uptake and shoot uptake of Ca was recorded by treatment T$_7$. The highest uptake of Ca in root and fruit of tomato was recorded by treatment T$_4$ (VC + STBR). For both the cropping sequence, the lowest Ca uptake was recorded with absolute control (T$_9$).

Table 110. Effect of treatments on Ca uptake by tomato, kg ha^{-1}

Treatments	Uptake of Ca (kg ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T_1- FYM+ NPK $_{POP}$	9.39 ^{g}	4.67 ^{f}	5.02 ^{b}	19.08^{c}	11.80 ^{g}	4.371^{e}	3.69 ^{d}	19.86^{d}
T_2 - FYM + STBR	9.59 ^{f}	4.79 ^{e}	5.67 ^{a}	20.05^{c}	12.70 ^{f}	4.370^{e}	5.13^{ab}	22.20^{d}
T_3- OC + STBR	11.74 ^{e}	5.57 ^{c}	4.63 ^{c}	21.94^{bc}	16.48 ^{d}	5.280^{c}	3.90 ^{d}	25.66^{c}
T_4- VC + STBR	13.05 ^{c}	6.66 ^{b}	5.65 ^{a}	25.36^{ab}	13.43 ^{e}	6.712^{a}	5.23 ^{a}	25.37^{c}
T_5- MC+ STBR	12.36 ^{d}	4.33 ^{g}	4.45 ^{cd}	21.14^{bc}	20.43^{c}	4.362^{e}	3.97 ^{d}	28.76^{b}
T_6- TOF + STBR	13.83 ^{b}	5.30 ^{d}	4.20 ^{d}	23.33 ^{b}	22.66 ^{b}	4.920^{d}	4.10 ^{cd}	31.68^{b}
T_7- F-TOF + STBR	14.63 ^{a}	6.72 ^{a}	5.68 ^{a}	27.03 ^{a}	24.19 ^{a}	6.160^{b}	4.63 ^{bc}	34.98^{a}
T_8- F-TOF alone	4.04 ^{h}	2.18 ^{h}	1.46 ^{e}	7.68 ^{d}	7.67 ^{h}	2.477^{f}	1.44 ^{e}	11.59^{e}
T_9-Absolute control	0.88 ^{i}	0.23^{i}	0.18 ^{f}	1.29 ^{e}	0.59 ^{i}	0.128^{g}	0.09 f	0.808f
SEm±	0.065	0.017	0.11	0.96	0.022	0.017	0.22	0.191
CD (0.05)	0.194	0.051	0.33	2.9	0.067	0.052	0.61	3.25

4.4.1.5.5 Magnesium

Total Mg uptake by tomato plants varied significantly among the treatments and also there was significant difference in the Mg uptake of different parts of tomato plant (Table 111). In the first cropping sequence, the highest Mg uptake in the shoot (4.41 kg ha^{-1}) was recorded by the treatment T_4 (VC + STBR) followed by T_7 (F-TOF +STBR). The total Mg uptake and its uptake in root and fruit were highest in the treatment T_7. Similarly in second cropping sequence also, the highest total Mg uptake and highest uptake in shoot and root was recorded by treatment T_7. The Mg uptake in tomato fruit was highest with treatment T_6 followed by T_4. For both the cropping sequence, the lowest Mg uptake was recorded with absolute control (T_9).

Table 111. Magnesium uptake by tomato as influenced by treatments, kg ha^{-1}

Treatments	Uptake of Mg (kg ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T$_1$- FYM+ NPK $_{POP}$	3.60^{e}	0.85^{g}	2.61^{a}	7.06^{b}	3.63^{f}	0.81^{g}	3.10^{b}	7.54^{b}
T$_2$ - FYM + STBR	3.80^{d}	0.90^{f}	2.69^{a}	7.39^{b}	3.65^{f}	0.85^{f}	2.93^{b}	7.43^{b}
T$_3$- OC + STBR	3.67^{de}	0.99^{e}	2.72^{a}	7.38^{b}	3.74^{e}	0.95^{e}	2.81^{b}	7.50^{b}
T$_4$- VC + STBR	4.41^{a}	1.14^{c}	3.06^{a}	8.61^{a}	4.78^{c}	1.18^{b}	3.39^{a}	9.35^{a}
T$_5$- MC+ STBR	3.94^{c}	1.01^{d}	2.74^{a}	7.69^{b}	3.81^{d}	1.02^{d}	2.86^{b}	7.69^{b}
T$_6$- TOF + STBR	4.08^{b}	1.37^{b}	2.90^{a}	8.35^{a}	5.22^{b}	1.15^{c}	3.62^{a}	9.99^{a}
T$_7$- F-TOF + STBR	4.19^{b}	1.47^{a}	3.09^{a}	8.75^{a}	5.67^{a}	1.30^{a}	3.18^{b}	10.15^{a}
T$_8$- F-TOF alone	1.60^{f}	0.36^{h}	1.10^{b}	3.06^{c}	2.63^{g}	0.35^{h}	2.01^{c}	4.99^{c}
T$_9$-Absolute control	0.31^{g}	0.04^{i}	0.14^{c}	0.49^{d}	0.20^{h}	0.02^{i}	0.10^{d}	0.32^{d}
SEm±	0.046	0.002	0.24	0.31	0.018	0.001	0.15	0.63
CD (0.05)	0.138	0.007	0.72	0.93	0.054	0.003	0.42	1.90

4.4.1.5.6 Sulphur

Total S uptake by tomato plants varied significantly among the treatments and also there was significant difference in the S uptake of different parts of tomato plant (Table 112). In the first cropping sequence, the highest total uptake of S (7.24 kg ha^{-1}) as well as shoot and root uptake were recorded by treatment T$_7$. The highest uptake in fruit was recorded by treatment T$_4$ followed by treatment T$_5$ and T$_3$ and they were statistically on par with each other. In the case of total uptake treatment T$_7$ was followed by T$_5$. For second cropping sequence, the highest total S uptake (8.92 kg ha^{-1}) and highest uptake in root was recorded by the treatment T$_7$. The highest S uptake in shoot and fruit was recorded by treatment T$_4$.

Table 112. Sulphur uptake by tomato as influenced by treatments, kg ha^{-1}

Treatments	Uptake of S (kg ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T_1- FYM+ NPK $_{POP}$	2.58^{e}	0.233^{d}	2.80 ^{c}	5.62 ^{c}	4.17 ^{d}	0.234^{c}	3.17 ^{c}	7.57 ^{c}
T_2 - FYM + STBR	2.7 ^{d}	0.250^{c}	2.88 ^{c}	5.84 ^{c}	4.31 ^{c}	0.250 ^{b}	3.31 ^{bc}	7.87 ^{c}
T_3- OC + STBR	2.71^{d}	0.235^{d}	3.41 ^{ab}	6.36 ^{b}	4.28 ^{c}	0.239 ^{c}	3.69 ^{ab}	8.21 ^{b}
T_4- VC + STBR	2.85^{c}	0.217^{f}	3.85 ^{a}	6.92 ^{a}	4.44 ^{b}	0.248 ^{b}	4.09 ^{a}	8.78 ^{a}
T_5- MC+ STBR	3.10^{b}	0.367^{b}	3.59 ^{a}	7.06 ^{a}	4.04 ^{e}	0.210 ^{d}	3.89 ^{a}	8.14 ^{b}
T_6- TOF + STBR	2.68^{de}	0.224^{e}	2.90 ^{bc}	5.80 ^{c}	4.28 ^{c}	0.246 ^{b}	3.71 ^{ab}	8.24 ^{b}
T_7- F-TOF + STBR	3.44^{a}	0.506^{a}	3.29 ^{bc}	7.24 ^{a}	4.58 ^{a}	0.355 ^{a}	3.98 ^{a}	8.92 ^{a}
T_8- F-TOF alone	1.34^{f}	0.197^{g}	1.09 ^{d}	2.63 ^{d}	2.16 ^{f}	0.096 ^{e}	1.72 ^{d}	3.98 ^{d}
T_9-Absolute control	0.15^{g}	0.013^{h}	0. 16 ^{e}	0.32 ^{e}	0.08 ^{g}	0.007 ^{f}	0.08 ^{e}	0.17 ^{e}
SEm±	0.036	0.002	0.20	0.11	0.028	0.002	0.11	0.11
CD (0.05)	0.108	0.006	0.51	0.34	0.084	0.006	0.31	0.33

4.4.1.5.8 Iron

Total Fe uptake by tomato plants varied significantly among the treatments and also there was significant difference in the Fe uptake of different parts of tomato plant (Table 113). For both the cropping sequences, the highest total Fe uptake (8123 and 9246 g ha^{-1}) was recorded by the treatment T_4 (VC +STBR) followed by T_5. In the first cropping sequence the highest Fe uptake in tomato shoot was recorded with treatment T_5 and the highest Fe uptake in the fruit was recorded with treatment T_7 (F-TOF + STBR). Similarly in the second cropping sequence, the highest Fe uptake in shoot (5869 g ha^{-1}) was recorded by the treatment T_4 and the highest Fe uptake in the root (714 g ha^{-1}) and fruit (4922 g ha^{-1}) was recorded by the treatment T_7. In both the cropping sequences, the lowest Fe uptake was recorded by absolute control (T_9).

Table 113. Iron uptake by tomato as influenced by treatments, g ha^{-1}

Treatments	Uptake of Fe (g ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T$_1$-FYM+ NPK $_{POP}$	1825^{g}	341^{d}	1642^{f}	3809^{g}	2220^{g}	402^{d}	1898^{c}	4521^{g}
T$_2$ - FYM + STBR	2290^{d}	295^{e}	1910^{e}	4495^{e}	2576^{f}	389^{d}	2281^{c}	5245^{e}
T$_3$- OC + STBR	2197^{e}	259^{f}	1625^{f}	4080^{f}	2795^{d}	315^{e}	1940^{c}	5051^{f}
T$_4$- VC + STBR	4701^{b}	312^{e}	3110^{c}	8123^{a}	5869^{a}	424^{c}	2953^{b}	9246^{a}
T$_5$- MC+ STBR	4946^{a}	368^{c}	2479^{d}	7793^{b}	5486^{b}	438^{c}	3181^{b}	9105^{b}
T$_6$- TOF + STBR	2095^{f}	526^{b}	3770^{b}	6391^{d}	2644^{e}	613^{b}	4665^{a}	7923^{c}
T$_7$- F-TOF + STBR	2779^{c}	627^{a}	3982^{a}	7388^{c}	3448^{c}	714^{a}	4922^{a}	9083^{b}
T$_8$- F-TOF alone	1153^{h}	253^{f}	570^{g}	1976^{h}	1842^{h}	300^{e}	952^{d}	3095^{h}
T$_9$-Absolute control	112^{f}	20^{g}	117^{h}	249^{i}	89^{i}	14^{f}	64 ^{e}	167^{i}
SEm±	24.31	6.76	2.42	21.98	13.43	5.36	1.33	17.95
CD (0.05)	72.92	20.29	72.7	65.95	40.30	16.09	39.8	53.84

4.4.1.5.9 Manganese

Total Mn uptake by tomato plants varied significantly among the treatments and also there was significant difference in the Mn uptake of different parts of tomato plant (Table 114). In both the cropping sequences the highest total Mn uptake (525.41 and 609.32 g ha^{-1}) was recorded with the treatment T$_4$ followed by T$_5$. For both the cropping sequences the highest Mn uptakes in tomato shoot (320.09 and 388.23 g ha^{-1}, respectively) and fruit (196.22 and 209.44 g ha^{-1}, respectively) were recorded by treatment T$_4$. For the first cropping sequence, the highest Mn uptake in the root (14.12 g ha^{-1}) was recorded with the treatment T$_6$ and for the second cropping sequence highest value was recorded with the treatment T$_7$. For both the cropping sequence, the lowest Mn uptake was recorded with absolute control (T$_9$).

Table 114. Influence of treatments on Mn uptake by tomato, g ha^{-1}

Treatments	Uptake of Mn (g ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T$_1$-FYM+ NPK $_{POP}$	235.76^{cd}	8.44^{bc}	148.62^{c}	392.82^{d}	275.03^{c}	9.06^{bc}	154.78^{d}	438.87^{d}
T$_2$ - FYM+ STBR	242.49^{c}	7.92^{bc}	154.10^{c}	404.51^{d}	290.81^{b}	8.33^{cd}	165.39^{c}	464.53^{c}
T$_3$- OC + STBR	225.75^{d}	7.60^{cd}	168.08^{b}	401.43^{d}	252.49^{d}	8.21^{cd}	191.49^{b}	452.19^{c}
T$_4$- VC + STBR	320.09^{a}	9.10^{bc}	196.22^{a}	525.41^{a}	388.23^{a}	11.65^{ab}	209.44^{a}	609.32^{a}
T$_5$- MC+ STBR	258.51^{b}	8.40^{bc}	165.10^{b}	432.01^{b}	300.71^{b}	10.14^{abc}	168.41^{c}	479.26^{b}
T$_6$- TOF + STBR	213.43^{e}	14.12^{a}	191.87^{a}	419.42^{c}	222.31^{e}	12.39^{a}	194.60^{b}	429.30^{d}
T$_7$-F-TOF+ STBR	231.48^{d}	10.8^{b}	193.45^{a}	435.76^{b}	265.60^{c}	12.93^{a}	205.78^{a}	484.31^{b}
T$_8$- F-TOF alone	80.30^{f}	4.71^{d}	67.37^{d}	152.38^{e}	106.41^{f}	5.31^{d}	85.98^{e}	197.7^{e}
T$_9$-Absolute control	18.01^{g}	0.71^{e}	15.24^{e}	33.96^{f}	9.26^{g}	0.48^{e}	9.98^{f}	19.72^{f}
SEm±	2.73	0.99	3.1	5.36	3.64	1.04	3.2	5.33
CD (0.05)	8.18	2.98	9.2	15.87	10.91	3.11	9.6	16.00

4.4.1.5.10 Zinc

Total Zn uptake by tomato plants varied significantly among the treatments and also there was significant difference in the Zn uptake of different parts of tomato plant (Table 115). In both the cropping sequences the highest total Zn uptake (393.30 and 460.27 g ha^{-1}) was recorded by the treatment T$_7$ (F-TOF + STBR) followed by T$_4$. For both the cropping sequences the highest Zn uptake in tomato shoot was recorded with treatment T$_7$ followed by T$_4$ (VC + STBR). For both the cropping sequences, the highest Fe uptake in the root and fruit was recorded by treatment T$_4$. In both the cropping sequence, the lower most Zn uptake was recorded with absolute control (T$_9$).

Table 115. Zn uptake by tomato as affected by treatments, g ha^{-1}

Treatments	Uptake of Zn (g ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T_1-FYM+ NPK $_{POP}$	137.59^d	9.27^{bc}	141.65^g	288.51^c	153.93^{ef}	9.85^d	142.95^d	306.73^d
T_2 -FYM+ STBR	123.43^e	8.46^c	129.38^e	261.27^d	163.44^e	10.02^d	141.09^d	314.55^d
T_3- OC + STBR	138.66^d	10.14^b	122.51^f	271.31^d	174.89^d	11.84^{cd}	130.22^e	316.95^d
T_4- VC + STBR	205.38^b	14.57^a	170.88^a	390.83^a	228.77^b	18.21^a	174.78^a	421.76^b
T_5- MC+ STBR	112.36^f	10.67^b	147.17^d	270.2^d	152.33 ^{f}	14.28^b	144.86^d	311.47^d
T_6-TOF + STBR	163.77^c	9.95^b	142.94^c	316.66^b	201.65^c	12.49^{bc}	173.58^b	387.72^c
T_7-F-TOF+ STBR	222.55^a	10.73^b	160.02^b	393.30 ^{a}	285.92^a	13.28^{bc}	161.07^c	460.27^a
T_8- F-TOF alone	63.28^g	3.87^d	51.6 ^{h}	118.82^e	96.44^g	5.83^e	86.36^f	188.63^e
T_9-Absolute control	6.00^h	0.32^e	5.73 ^{i}	12.05^f	3.76^h	0.22 ^{f}	3.64^g	7.6 ^{f}
SEm±	2.67	0.48	0.01	4.23	3.18	0.75	0.02	1.56
CD (0.05)	8.02	1.44	3.2	12.6	9.53	2.26	5.9	14.69

4.4.1.5.11 Copper

Total Cu uptake by tomato plants varied significantly among the treatments and also there was significant difference in the Cu uptake of different parts of tomato plant (Table 116). In both the cropping sequences the highest total Cu uptake was recorded with the treatment T_4 followed by T_7. For both the cropping sequences the highest Cu uptakes in tomato shoot and fruit were recorded by treatment T_4. For both the cropping sequences, the highest Cu uptake in the root (6.14 and 6.65, respectively g ha^{-1}) was recorded with the treatment T_1 (FYM + NPK $_{POP}$). In both the cropping sequence, the lower most Cu uptake was recorded with absolute control (T_9).

Table 116. Cu uptake by tomato as affected by treatments, g ha^{-1}

Treatments	Uptake of Cu (g ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T$_1$-FYM+ NPK POP	48.89^{c}	6.14^{a}	58.61^{c}	113.64^{bc}	57.13^{cd}	6.65^{a}	55.07^{d}	118.85^{d}
T$_2$ -FYM+ STBR	46.08^{c}	5.79^{a}	53.06^{c}	104.93^{c}	56.43^{d}	6.60^{a}	60.46^{c}	123.49^{cd}
T$_3$- OC + STBR	44.81^{c}	5.20^{abc}	52.29^{d}	102.3^{c}	63.18^{bcd}	5.81^{ab}	54.74^{d}	123.73^{cd}
T$_4$- VC + STBR	64.76^{a}	4.14^{d}	70.31^{a}	139.21^{a}	85.87^{a}	5.16^{b}	73.36^{a}	164.39^{a}
T$_5$- MC+ STBR	54.91^{b}	4.29^{cd}	51.55^{d}	110.75^{c}	63.80^{bc}	5.06^{b}	48.57^{e}	117.43^{d}
T$_6$-TOF + STBR	44.43^{c}	4.47^{bcd}	63.96^{b}	112.86^{bc}	60.19^{cd}	5.47^{b}	64.23^{b}	129.89^{c}
T$_7$-F-TOF+ STBR	55.41^{b}	5.42^{ab}	59.22^{c}	120.05^{b}	69.73^{b}	6.45^{a}	70.16^{a}	146.34^{b}
T$_8$- F-TOF alone	23.31^{d}	2.39^{e}	17.66^{e}	43.36^{d}	29.17^{e}	2.42^{c}	22.43^{f}	54.02^{e}
T$_9$-Absolute control	3.27^{e}	0.31^{f}	1.94^{f}	5.52^{e}	1.85^{f}	0.18^{d}	1.22^{g}	3.25^{f}
SEm±	1.96	0.34	2.31	3.17	2.25	0.31	1.13	1.47
CD (0.05)	5.88	1.025	6.66	9.51	6.76	0.924	3.40	7.42

4.4.1.5.7 Boron

Total B uptake by tomato plants varied significantly among the treatments and also there was significant difference in the B uptake of different parts of tomato plant (Table 117). In both the cropping sequence the highest total B uptake (189.39 and 194.90 g ha^{-1}) was recorded by the treatment T$_7$ followed by T$_4$. In the first cropping sequence the highest B uptake in tomato shoot was recorded by the treatment T$_4$ and in root and fruit by treatment T$_7$. Similarly in the second cropping sequence, the highest B uptake in shoot and root was recorded by the treatment T$_7$ and in fruit by treatment T$_4$. In both the cropping season, the lower most B uptake was recorded by absolute control (T$_9$).

Table 117. Boron uptake by tomato as affected by treatments, g ha^{-1}

Treatments	Uptake of B (g ha^{-1})							
	Tomato I				Tomato II			
	Shoot	Root	Fruit	Total	Shoot	Root	Fruit	Total
T_1-FYM+ NPK $_{POP}$	28.38^{g}	0.583^{e}	120.10^{e}	149.06^{e}	25.74^{g}	0.506^{c}	118.7^{f}	144.95^{d}
T_2 -FYM+ STBR	29.18^{f}	0.600^{d}	123.50^{e}	153.28^{e}	26.99^{f}	0.516^{c}	124.1^{e}	151.61^{c}
T_3- OC + STBR	32.75^{c}	0.553^{f}	129.20^{d}	162.50^{d}	30.41^{d}	0.548^{bc}	137.4^{c}	168.36^{b}
T_4- VC + STBR	36.62^{a}	0.713^{b}	146.50^{b}	183.83^{b}	34.80^{b}	0.688^{a}	158.7^{a}	194.90^{a}
T_5- MC+ STBR	29.86^{e}	0.525^{g}	130.40^{d}	160.79^{d}	28.35^{e}	0.561^{bc}	138.3^{c}	167.21^{b}
T_6-TOF + STBR	32.17^{d}	0.641^{c}	139.80^{c}	172.61^{c}	31.40^{c}	0.614^{ab}	134.4^{d}	166.41^{b}
T_7-F-TOF+ STBR	36.46^{b}	0.729^{a}	152.20^{a}	189.39^{a}	41.31^{a}	0.687^{a}	154.9^{b}	196.19^{a}
T_8- F-TOF alone	10.83^{h}	0.274^{h}	55.60^{f}	66.70^{f}	14.03^{h}	0.231^{d}	61.9^{g}	76.16^{e}
T_9-Absolute control	2.21^{i}	0.036^{i}	9.0^{g}	11.25^{g}	1.40^{i}	0.018^{e}	4.8^{h}	6.22^{f}
SEm±	0.031	0.003	1.20	1.53	0.282	0.028	1.29	1.75
CD (0.05)	0.094	0.008	3.71	4.60	0.847	0.085	3.81	4.94

4.4.1.5.8 Heavy metals – Cd and Pb

For both the cropping sequences, uptake of Pb was detected only in the treatments that have received FYM as organic fertilizer and its presence was confined to root portion (Table 118). Cd was not detected in any of the plant parts.

Table 118. Effect of treatments on Pb uptake in tomato, mg ha^{-1}

Treatments	Pb uptake in roots (mg ha^{-1})	
	Tomato I	Tomato II
T_1-FYM + NPK $_{POP}$	10.63	5.85
T_2 - FYM + STBR	11.42	6.52
T_3- OC + STBR	-	-
T_4- VC + STBR	-	-
T_5- MC+ STBR	-	-
T_6- TOF + STBR	-	-
T_7- F-TOF + STBR	-	-
T_8- F-TOF alone	-	-
T_9- Absolute control	-	-
SEm±	-	-
CD (0.05)	-	-

4.4.2 AMARANTHUS

4.4.2.1 BIOMETRIC OBSERVATIONS

4.4.2.1.1 Plant height

The height of amaranthus plants varied significantly among the treatments (Table 119) and the highest plant height for both the cropping sequences (39 and 43.5 cm, respectively) was recorded by treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR) in the first cropping sequence and by T_6 (TOF + STBR) in the second cropping sequence. The treatments T_6, T_4, T_5 (MC +STBR) and T_3 (OC +STBR) were statistically on par with each other in the second cropping sequence. For both the cropping sequences, the lowest plant height was recorded by absolute control (T_9).

4.4.2.1.2 Number of primary branches per plant

The number of primary branches in amaranthus plants did not vary significantly among the treatments (Table 119).

4.4.2.1.3 Dry matter production

4.4.2.1.3.1 Shoot

There was significant difference in the shoot dry matter production of amaranthus by various treatments (Table 119). For both the cropping sequences, the highest shoot dry matter production (9.34 and 10.10 g plant^{-1}, respectively) was recorded by treatment T_7 (F-TOF + STBR). In the first cropping sequence, the treatment T_7 was followed by T_4 (VC + STBR) and they were statistically on par with each other. In the second cropping sequence, the treatment T_7 was followed by T_4 and T_5 (MC + STBR). For both the cropping sequences, the lowest shoot dry matter was recorded by absolute control (T_9).

4.4.1.1.3.2 Root

The root dry matter production of amaranthus varied significantly among the treatments (Table 119). For both the cropping sequences, the highest root dry matter was recorded (0.84 and 0.92 g plant^{-1}) by treatment T_7. In the first cropping sequence, the treatment T_7 was followed by T_8 (F-TOF alone) and T_6 (TOF + STBR) and these treatments were statistically on par with each other. In the second cropping sequence also, the same trend was followed. In both the cropping sequences, the lowest dry matter was recorded with absolute control (T_9)

4.4.1.2.4 Shoot yield

The shoot yield of amaranthus varied significantly among the treatments (Table 119). For the first cropping sequence the highest shoot yield (24.62 t ha^{-1}) was recorded by treatment T_7 followed by T_4 and they were statistically on par with each other. Also the treatments T_3 and T_5 were statistically on par with each other. In the second cropping sequence also the highest shoot yield was recorded by treatment T_7 and it was statistically on par with treatments T_4, T_5 and T_6.

Table 119. Effect of treatments on growth and yield of amaranthus

Treatments	Biometric observations and yield									
	Amaranthus I					Amaranthus II				
	Plant height (cm)	No. of primary branches per plant	Dry matter production (g plant^{-1})		Yield (t ha^{-1})	Plant height (cm)	No. of primary branches per plant	Dry matter production (g plant^{-1})		Yield (t ha^{-1})
			Shoot	Root				Shoot	Root	
T$_1$- FYM + NPK $_{POP}$	30.0 ^{g}	1	5.74 ^{d}	0.52 ^{c}	14.50 ^{d}	31.0 ^{d}	1	5.75 ^{e}	0.63 ^{c}	16.69 ^{c}
T$_2$ - FYM + STBR	32.0 ^{f}	1	6.10 ^{d}	0.55 ^{c}	15.50 ^{d}	33.0 ^{cd}	1	5.96 ^{de}	0.66 ^{c}	17.15 ^{c}
T$_3$- OC + STBR	32.5 ^{ef}	1	6.15 ^{d}	0.64 ^{b}	22.52 ^{b}	34.5 ^{bc}	1	6.15 ^{de}	0.67 ^{c}	22.63 ^{b}
T$_4$- VC + STBR	37.5 ^{ab}	2	8.96 ^{a}	0.68 ^{b}	24.21 ^{a}	36.5 ^{b}	1	8.89 ^{b}	0.70 ^{bc}	25.56 ^{ab}
T$_5$- MC+ STBR	34.0 ^{de}	2	8.81 ^{b}	0.53 ^{c}	22.41 ^{b}	35.0 ^{bc}	1	8.75 ^{c}	0.58 ^{b}	25.15 ^{ab}
T$_6$- TOF + STBR	36.0 ^{bc}	2	6.94 ^{c}	0.79 ^{a}	18.60 ^{c}	37.0 ^{b}	2	6.85 ^{cd}	0.76 ^{b}	24.97 ^{ab}
T$_7$- F-TOF + STBR	39.0 ^{a}	2	9.34 ^{a}	0.84 ^{a}	24.62 ^{a}	43.5 ^{a}	2	10.10 ^{a}	0.92 ^{a}	26.89 ^{a}
T$_8$- F-TOF alone	34.5 ^{cd}	1	5.03 ^{e}	0.81 ^{a}	7.68 ^{e}	34.5 ^{bc}	1	5.15 ^{e}	0.77 ^{b}	7.95 ^{d}
T$_9$- Absolute control	19.8 ^{h}	1	4.37 ^{f}	0.39 ^{d}	4.44 ^{f}	19.5 ^{e}	1	3.54 ^{f}	0.37 ^{d}	3.69 ^{e}
SEm±	0.560	-	0.148	0.03	0.356	0.920	-	0.337	0.03	1.09
CD (0.05)	1.68	NS	0.444	0.07	1.067	2.76	NS	1.01	0.08	3.28

4.4.2.2 QUALITY PARAMETERS

4.4.2.2.1 Crude fibre

There was significant difference in the crude fibre content of amaranthus of different treatments (Table 120). For both the cropping sequences the highest crude fibre content was recorded by treatment T_7 (F-TOF) and it was statistically on par with other treatments, except T_8 (F-TOF alone) and T_9 (absolute control). For both the cropping sequence, the lowest crude fibre content was recorded by the treatment T_9 (absolute control).

4.4.2.2.2 Nitrate content

Nitrate content in the amaranthus leaves significantly varied among the treatments (Table 120) and for both the cropping sequences the highest nitrate content (940.34 and 966.23 mg kg^{-1}, respectively) was recorded by the treatment T_4 (VC + STBR) and it was statistically on par with other treatments, except T_8 (F-TOF alone) and T_9 (absolute control). For both the cropping sequence, the lowest nitrate content was recorded by absolute control (T_9).

Table 120. Effect of treatments on quality parameters of amaranthus

Treatments	Quality parameters									
	Amaranthus I					Amaranthus II				
	Crude fibre (%)	Nitrate content (mg kg^{-1})	Ascorbic acid(mg 100g^{-1})	Carotene (µg 100g^{-1})	Oxalate content (%)	Crude fibre	Nitrate content (mg kg^{-1})	Ascorbic acid(mg 100g^{-1})	Carotene (µg 100g^{-1})	Oxalate content (%)
T_1-FYM + NPK $_{POP}$	5.34 ^{ab}	840.25 ^{ab}	27.16 ^{a}	2589 ^{a}	1.28 ^{c}	5.44 ^{ab}	872.36 ^{ab}	20.16 ^{a}	2645 ^{a}	1.14 ^{bc}
T_2 - FYM + STBR	5.40 ^{ab}	848.96 ^{ab}	28.21 ^{a}	2596 ^{a}	1.27 ^{c}	5.47 ^{ab}	880.85 ^{ab}	20.21 ^{a}	2676 ^{a}	1.12 ^{bc}
T_3- OC + STBR	5.72 ^{ab}	888.56 ^{ab}	29.33 ^{a}	2641 ^{a}	1.26 ^{c}	5.66 ^{ab}	937.25 ^{a}	20.33 ^{a}	2741 ^{a}	1.18 ^{bc}
T_4- VC + STBR	6.66 ^{ab}	940.34 ^{a}	31.48 ^{a}	2689 ^{a}	1.14 ^{c}	7.25 ^{a}	966.23 ^{a}	21.75 ^{a}	2789 ^{a}	1.12 ^{bc}
T_5- MC+ STBR	6.40 ^{ab}	894.67 ^{ab}	30.66 ^{a}	2645 ^{a}	1.25 ^{c}	6.97 ^{a}	939.56 ^{a}	20.66 ^{a}	2678^{a}	1.12 ^{bc}
T_6- TOF + STBR	5.92 ^{ab}	858.96 ^{ab}	30.75 ^{a}	2712 ^{a}	1.21 ^{c}	5.86 ^{ab}	886.74 ^{ab}	21.48 ^{a}	2798 ^{a}	1.08 ^{c}
T_7- F-TOF + STBR	7.22 ^{a}	913.56 ^{a}	32.65 ^{a}	2741 ^{a}	1.12 ^{c}	7.37 ^{a}	944.23 ^{a}	22.65 ^{a}	2841 ^{a}	1.08 ^{c}
T_8- F-TOF alone	5.06 ^{b}	776.34 ^{b}	21.35 ^{b}	2677 ^{a}	1.45 ^{b}	5.26 ^{ab}	796.58 ^{b}	20.35 ^{a}	2697 ^{a}	1.24 ^{b}
T_9- Absolute control	4.94 ^{b}	498.78 ^{c}	20.48 ^{b}	2154 ^{b}	1.89 ^{a}	3.91 ^{b}	365.56 ^{c}	18.64 ^{b}	1987 ^{a}	1.87 ^{a}
SEm±	0.74	36.76	1.18	83.22	0.061	0.76	42.69	0.84	82.71	0.051
CD (0.05)	2.092	120.29	4.54	229.65	0.18	2.184	125.08	2.54	218.13	0.15

4.4.2.2.3 Ascorbic acid

Ascorbic acid content in the amaranthus varied significantly among the treatments (Table 120). For both the cropping sequences, the highest ascorbic acid content was recorded with treatment T_7 followed by T_4 and T_6 (TOF + STBR) and they were statistically on par. For both the cropping sequences, the lowest ascorbic acid content was recorded with absolute control (T_9).

4.4.2.2.4 Carotene

There was significant difference in the carotene content of amaranthus of different treatments (Table 120). In both the cropping sequences, the highest carotene content (2741 and 2841 μg $100g^{-1}$) was recorded with the treatment T_7 (F-TOF +STBR) followed by T_6 (TOF + STBR) and T_4 (VC + STBR). For both the cropping sequences, the lowest carotene content was recorded with absolute control (T_9).

4.4.2.2.5 Oxalate content

There was significant difference in the oxalate content of amaranthus of different treatments (Table 120). For both the cropping sequences, the highest oxalate content (1.89 %) was recorded by treatment T_9 (absolute control). The lowest oxalate content (1.12 and 1.14 %, respectively) was recorded by treatment T_7 followed by T_4. In second cropping sequence, also the highest oxalate content was recorded with absolute control and the lowest value by the treatments T_6 and T_7. For both the cropping sequences, all the treatments that received organic fertilizers along with inorganic fertilizers were statistically on par with each other for their oxalate content.

4.4.2.3 NUTRIENT CONCENTRATION IN PLANT PARTS

4.4.2.3.1 Shoot

Macro and micronutrients contents in shoot varied significantly among the treatments and presented in Table 121 and 122, respectively.

4.5.2.3.1.1 Macronutrients

4.4.2.3.1.1.1 Nitrogen

For the first cropping sequence, the highest N content in shoot (3.68 %) was recorded by the treatment T_4 (VC + STBR) followed by T_7 (F-TOF + STBR) and T_5 (MC + STBR). In the second cropping sequence, the highest N content in shoot was recorded by treatment T_7 followed by T_4 and T_6 (TOF + STBR) and they were statistically on par with each other. In both the cropping sequences the lowest N content in shoot was recorded with absolute control.

4.4.2.3.1.1.2 Phosphorus

For the first cropping sequence, the highest P content in shoot (0.438 %) was recorded with treatment T_7 (F-TOF + STBR) followed by T_6 (TOF + STBR) and T_4 (VC + STBR) and these treatments were statistically on par with each other. For second cropping sequence, the highest P content (0.619 %) was recorded by treatment T_7 followed by T_4 and T_5 (MC + STBR). For both the cropping sequences, the lowest P was recorded by absolute control.

4.4.2.3.1.1.3 Potassium

For the first cropping sequence, the highest K content (1.72 %) was recorded by treatment T_7 followed by T_6 and T_4. In the second cropping sequence, the highest

K content was recorded with treatment T_4 (1.62 %) followed by T_7 and T_5. For both the cropping sequences, the lowest K content was recorded by absolute control (T_9).

4.4.2.3.1.1.4 Calcium

For the first cropping sequence, the highest Ca content was recorded by treatment T_4 (VC + STBR) followed by T_7 (F-TOF + STBR) and T_6 (TOF + STBR). For the second cropping sequence, the highest Ca content was recorded by treatment T_7 followed by T_4, T_6 and T_7 and these treatments were statistically on par with each other. For both the cropping sequences, the lowest Ca content was recorded by absolute control (T_9).

4.4.2.3.1.1.5 Magnesium

For the first cropping sequence, the highest Mg content (0.276 %) was recorded by treatments T_4 (VC + STBR) followed by T_7 and they were statistically on par with each other. It was followed by treatments T_5 (MC +STBR) and T_6 (TOF + STBR) and they were also statistically on par with each other. In the second cropping sequence, the highest Mg content (0.30 %) was recorded with treatment T_7 followed by T_4 and they were also statistically on par with each other. For both the cropping sequences, the lowest Mg content was recorded by absolute control (T_9).

4.4.2.3.1.1.6 Sulphur

For the first cropping sequence, the highest S content (0.322 %) was recorded by treatment T_5 (MC + STBR) followed by T_7 (F-TOF + STBR) and T_4 (VC + STBR). For the second cropping sequence, the highest S content (0.372 %) was recorded by treatment T_7 followed by T_5 and T_4. For both the cropping sequences, the lowest S content was recorded by absolute control (T_9).

4.4.2.3.1.2 Micronutrients and heavy metals

4.4.2.3.1.2.1 Iron

For both the cropping sequences, the highest Fe content was recorded by treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR). For both the cropping sequences, the lowest Fe content in shoot was recorded by absolute control (T_9).

4.4.2.3.1.2.2 Manganese

For both the cropping sequence, the highest Mn content (337.60 and 289.41 mg kg^{-1}, respectively) was recorded by treatment T_3 (OC + STBR) followed by T_2 in the first cropping sequence and by T_4 (VC + STBR) in the second cropping sequence. For both the cropping sequences, the lowest Mn content in shoot (98 and 84.56 mg kg^{-1}, respectively) was recorded by absolute control (T_9).

4.4.2.3.1.2.3 Zinc

For both the cropping sequence, the highest Zn content (166 and 178.25 mg kg^{-1}, respectively) was recorded by treatment T_3 (OC + STBR) followed by T_4 (VC + STBR) and T_5 (MC +STBR). For both the cropping sequences, the lowest Zn content in shoot (76 and 66.56 mg kg^{-1}, respectively) was recorded by absolute control (T_9).

4.4.2.3.1.2.4 Copper

For both the cropping sequence, the highest Cu content (37.20 and 35.45 mg kg^{-1}, respectively) was recorded by treatment T_3 (OC + STBR) followed by T_4 (VC + STBR). For both the cropping sequences, the lowest Cu content in shoot (17.20 and 14.56 mg kg^{-1}, respectively) was recorded by absolute control (T_9).

4.4.2.3.1.2.5 Boron

For the first cropping sequence, the highest B content (16 mg kg^{-1}) was recorded by treatment T_4 (VC + STBR) and T_7 (F-TOF + STBR) followed by T_3 (OC

+ STBR). For the second cropping sequence, the highest B content (17.40 mg kg^{-1}) was recorded by treatment T_4 followed by T_7 and T_3. For both the cropping sequences, the lowest B content in shoot was recorded by absolute control (T_9).

4.4.2.3.1.2.6 Heavy metals

Heavy metals Pb and Cd were not detected in the amaranthus shoot

4.4.2.3.2 Root

Macro and micronutrients contents in root varied significantly among the treatments and presented in Table 123 and 124, respectively.

4.4.2.3.2.1 Macronutrients

4.4.2.3.2.1.1 Nitrogen

For the first cropping sequence, the highest N content in root (2.09 %) was recorded by treatment T_4 (VC+ STBR) followed by T_5 (MC + STBR). Also the treatments such as T_4, T_5, T_7 (F-TOF + STBR) and T_3 (OC + STBR) were statistically on par with each other for their N content in the root. For the second cropping sequence, the highest N content (1.99 %) was recorded by treatment T_7 followed by T_4 and these treatments were statistically on par with each other. For both the cropping sequences, the lowest N content in root was recorded by absolute control (T_9).

4.4.2.3.2.1.2 Phosphorus

For the first cropping sequence the highest P content in root (0.198 %) was recorded by T_7 (VC + STBR) followed by T_5 and T_6. For the second cropping sequence, the highest P content in root (0.178 %) was recorded by treatment T_7 followed by T_5 and T_4 and also all the treatments except T_8 (F-TOF alone) and T_9

Table 121. Macronutrient concentration in the amaranthus shoot as influenced by treatments, %

Treatments	Nutrient content in shoot (%)											
	Amaranthus I						Amaranthus II					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T_1-FYM + NPK $_{POP}$	2.86^{c}	0.365^{c}	1.52^{cd}	0.62^{f}	0.204^{cde}	0.254^{cd}	3.05^{c}	0.55^{c}	1.34^{de}	0.80^{b}	0.216^{d}	0.312^{cd}
T_2 - FYM + STBR	2.84^{c}	0.369^{c}	1.59^{bc}	0.64^{f}	0.196^{de}	0.252^{cd}	2.97^{c}	0.551^{c}	1.32^{e}	0.80^{b}	0.240^{c}	0.314^{cd}
T_3- OC + STBR	2.97^{c}	0.371^{c}	1.43^{d}	0.69^{d}	0.228^{bc}	0.258^{cd}	3.14^{b}	0.562^{c}	1.46^{c}	0.76^{bc}	0.228^{cd}	0.332^{c}
T_4- VC + STBR	3.68^{a}	0.415^{ab}	1.63^{abc}	0.84^{a}	0.276^{a}	0.286^{bc}	3.75^{a}	0.596^{b}	1.62^{a}	1.04^{a}	0.288^{a}	0.368^{ab}
T_5- MC+ STBR	3.25^{b}	0.377^{bc}	1.61^{abc}	0.66^{e}	0.24^{b}	0.322^{a}	3.3^{b}	0.565^{c}	1.56^{b}	0.90^{ab}	0.264^{b}	0.370^{a}
T_6- TOF + STBR	3.02^{c}	0.435^{a}	1.69^{ab}	0.72^{c}	0.236^{b}	0.274^{bcd}	3.7^{a}	0.562^{c}	1.36^{d}	0.96^{ab}	0.269^{b}	0.344^{abc}
T_7- F-TOF + STBR	3.58^{a}	0.438^{a}	1.72^{a}	0.76^{b}	0.272^{a}	0.292^{ab}	3.81^{a}	0.619^{a}	1.58^{b}	1.08^{a}	0.300^{a}	0.372^{a}
T_8- F-TOF alone	2.97^{c}	0.331^{c}	1.43^{d}	0.54^{g}	0.216^{bcd}	0.24^{d}	2.84^{c}	0.535^{d}	1.21^{f}	0.68^{c}	0.216^{d}	0.284^{d}
T_9- Absolute control	2.3^{d}	0.269^{d}	1.05^{e}	0.36^{h}	0.18^{e}	0.174^{e}	2.46^{d}	0.473^{e}	0.94^{g}	0.34^{d}	0.144^{e}	0.184^{e}
SEm±	0.0667	0.0153	0.0407	0.0097	0.0093	0.0117	0.1237	0.0053	0.0123	0.071	0.0063	0.01
CD (0.05)	0.20	0.046	0.122	0.029	0.028	0.035	0.21	0.016	0.037	0.212	0.019	0.030

Table 122. Micronutrient concentration in the amaranthus shoot as influenced by treatments, mg kg^{-1}

Treatments	Nutrient content in shoot (mg kg^{-1})									
	Amaranthus I					Amaranthus II				
	B	Fe	Mn	Zn	Cu	B	Fe	Mn	Zn	Cu
T_1-FYM + NPK $_{POP}$	12.80^{c}	1487.2^{c}	176.80^{d}	105.2^{d}	20.80^{cd}	15.60^{c}	1584^{c}	189.25^{de}	112.32^{e}	25.45^{bc}
T_2 - FYM + STBR	12.60^{c}	1562.8^{b}	276.00^{b}	126.4^{c}	21.60^{cd}	15.20^{d}	1697^{b}	198.45^{d}	132.56^{d}	26.98^{bc}
T_3- OC + STBR	14.00^{b}	1376.4^{e}	337.60^{a}	166.0^{a}	37.20^{a}	15.72^{c}	1568^{c}	289.41^{a}	178.25^{a}	35.45^{a}
T_4- VC + STBR	16.00^{a}	1568.4^{b}	225.60^{c}	145.6^{b}	26.00^{b}	17.40^{a}	1678^{b}	274.56^{b}	158.26^{b}	29.56^{b}
T_5- MC+ STBR	12.40^{c}	1370.8^{e}	182.00^{d}	130.4^{c}	23.60^{c}	12.50^{e}	1463^{d}	215.78^{c}	142.36^{c}	25.63^{bc}
T_6- TOF + STBR	11.60^{d}	1420.8^{d}	100.80^{f}	89.2^{e}	25.20^{b}	12.10^{f}	1598^{c}	186.25^{e}	95.68^{f}	21.74^{c}
T_7- F-TOF + STBR	16.00^{a}	1929.2^{a}	135.60^{e}	92.8^{e}	23.60^{c}	16.40^{b}	1895^{a}	198.75^{d}	100.52^{f}	24.15^{c}
T_8- F-TOF alone	9.20^{e}	1364.0^{e}	105.20^{f}	75.2^{f}	24.00^{c}	10.80^{g}	1245^{e}	115.62^{f}	79.26^{g}	22.36^{c}
T_9- Absolute control	5.00^{f}	1164.8^{f}	98.00^{f}	76.0^{f}	17.20^{d}	4.40^{h}	1025^{f}	84.56^{g}	66.56^{h}	14.56^{d}
SEm±	0.226	15.58	4.12	2.09	1.52	0.115	18.56	3.86	2.85	1.42
CD (0.05)	0.673	46.75	12.36	6.28	4.55	0.337	55.69	11.58	8.55	4.25

(absolute control), were statistically on par with each other for the P content in the amaranthus root. For both the cropping sequences, the lowest P content in root was recorded by absolute control (T_9).

4.4.2.3.2.1.3 Potassium

For the first cropping sequence, the highest K content in root (0.83 %) was recorded by treatment T_4 (VC + STBR) followed by T_5 and T_7. In the second cropping sequence, the highest value (0.63 %) was recorded by treatment T_4 followed by T_5 and T_7. For both the cropping sequences, treatment T_4 and T_5 were statistically on par with each other and the lowest K content in root was recorded by absolute control (T_9).

4.4.2.3.2.1.4 Calcium

For the first cropping sequence, the highest Ca content in root (0.428 %) was recorded by treatment T_4 followed by T_7 (F-TOF + STBR) and T_6 (TOF + STBR). For the second cropping sequence, the highest Ca content (0.333 %) was recorded by treatment T_4 followed by T_6 and T_7 and also all the treatments except T_4 and T_9, were statistically on par with each other for their Ca content in the root. For both the cropping sequences, the lowest Ca content in root was recorded with absolute control (T_9).

4.4.2.3.2.1.5 Magnesium

For both the cropping sequences, the highest Mg content in root (0.116 and 104 %, respectively) was recorded by treatment T_4 followed by T_7 and T_6. In the second cropping sequence, all treatments except T_5 (MC + STBR) and T_9 (absolute control), were statistically on par with each other for their Mg content in the root. For both the cropping sequences, the lowest Mg content was recorded by absolute control.

4.4.2.3.2.1.6 Sulphur

In the first cropping sequence, the highest S content (0.092 %) was recorded by treatment T_7 (F-TOF + STBR) followed by T_4 and T_6. In the second cropping sequence, the highest S content was recorded by treatment T_7 (0.085 %) followed by T_6 (TOF + STBR) and T_5. For both the cropping sequences, the lowest S content was recorded by absolute control.

4.4.2.3.2.2 Micronutrients and heavy metals

4.4.2.3.2.2.1 Iron

In both the cropping sequences, the highest Fe content in amaranthus root (24070 and 18452 mg kg^{-1}, respectively) was recorded by treatment T_3 (OC + STBR) followed by T_5 (MC + STBR) and T_2 (FYM + STBR) in the first cropping sequence and by T_5 and T_4 (VC + STBR) in the second cropping sequence**.** For both the cropping sequences, the lowest Fe content was recorded by absolute control.

4.4.2.3.2.2.2 Manganese

In the first cropping sequence, the highest Mn content in amaranthus root (161.20 mg kg^{-1}**)** was recorded by treatment T_3 (OC + STBR) followed by T_5 (MC+ STBR). In the second cropping sequence, the highest Mn content in amaranthus root (189.75 mg kg^{-1}**)** was recorded by treatment T_5 (MC + STBR) followed by T_3 (OC+ STBR). For both the cropping sequences, the lowest Mn content was recorded by absolute control.

Table 123. Macronutrient concentration in the amaranthus root as influenced by treatments, %

Treatments	Nutrient content in root (%)											
	Amaranthus I						Amaranthus II					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T_1-FYM+NPK$_{POP}$	1.66^{c}	0.165^{c}	0.72^{c}	0.360^{ab}	0.094^{cde}	0.054^{de}	1.72^{d}	0.169^{a}	0.52^{d}	0.266^{b}	0.090^{ab}	0.044^{d}
T_2 -FYM + STBR	1.63^{c}	0.169^{bc}	0.73^{c}	0.366^{ab}	0.096^{cd}	0.052^{ef}	1.70^{d}	0.172^{a}	0.53^{cd}	0.268^{b}	0.090^{ab}	0.041^{e}
T_3- OC + STBR	1.96^{ab}	0.146^{d}	0.74^{bc}	0.368^{ab}	0.092^{cde}	0.056^{d}	1.89^{b}	0.166^{a}	0.54^{cd}	0.272^{b}	0.091^{ab}	0.046^{d}
T_4- VC + STBR	2.09^{a}	0.131^{e}	0.83^{a}	0.428^{a}	0.116^{a}	0.076^{b}	1.98^{a}	0.165^{a}	0.63^{a}	0.333^{a}	0.104^{a}	0.067^{c}
T_5- MC+ STBR	1.98^{a}	0.177^{b}	0.79^{ab}	0.344^{b}	0.090^{de}	0.072^{c}	1.79^{c}	0.169^{a}	0.59^{ab}	0.255^{b}	0.089^{b}	0.069^{bc}
T_6- TOF + STBR	1.72^{bc}	0.175^{bc}	0.72^{c}	0.372^{ab}	0.098^{c}	0.074^{bc}	1.81^{c}	0.164^{a}	0.52^{d}	0.276^{b}	0.092^{ab}	0.071^{b}
T_7-F-TO+ STBR	1.97^{ab}	0.198^{a}	0.77^{bc}	0.378^{ab}	0.108^{b}	0.092^{a}	1.99^{a}	0.178^{a}	0.57^{bc}	0.278^{b}	0.101^{ab}	0.085^{a}
T_8- F-TOF alone	1.16^{d}	0.132^{e}	0.63^{d}	0.266^{c}	0.088^{e}	0.050^{f}	1.26^{e}	0.129^{b}	0.43^{e}	0.266^{b}	0.074^{c}	0.046^{d}
T_9-Absolutecontrol	0.98^{d}	0.102^{f}	0.25^{e}	0.160^{d}	0.058^{f}	0.034^{g}	0.76^{f}	0.085^{c}	0.20^{f}	0.069^{c}	0.054^{d}	0.029^{f}
SEm±	0.086	0.003	0.017	0.0023	0.0023	0.001	0.007	0.0050	0.0150	0.0113	0.0047	0.001
CD (0.05)	0.257	0.010	0.052	0.069	0.007	0.003	0.021	0.015	0.045	0.034	0.014	0.003

Table 124. Micronutrient concentration in the amaranthus root as influenced by treatments, mg kg^{-1}

Treatments	Nutrient content in root (mg kg^{-1})									
	Amaranthus I					Amaranthus II				
	B	Fe	Mn	Zn	Cu	B	Fe	Mn	Zn	Cu
T_1-FYM + NPK $_{POP}$	5.80^{d}	13516^{e}	116.80^{c}	48.8^{d}	43.60^{d}	5.94^{cd}	8542^{g}	114.25^{d}	54.45^{e}	33.65^{d}
T_2 - FYM + STBR	5.75^{d}	17150^{c}	123.20^{c}	68.4^{c}	45.20^{d}	5.98^{cd}	9852^{e}	128.96^{c}	65.26^{d}	32.45^{d}
T_3- OC + STBR	6.15^{c}	24070^{a}	161.20^{a}	93.6^{a}	52.40^{c}	6.45^{bc}	18452^{a}	184.75^{a}	110.23^{a}	46.52^{c}
T_4- VC + STBR	7.89^{a}	16800^{d}	132.0^{b}	70.4^{c}	40.80^{de}	8.34^{a}	15682^{c}	178.52^{a}	78.28^{c}	41.63^{c}
T_5- MC+ STBR	7.40^{b}	20630^{b}	159.20^{a}	93.2^{a}	56.80^{bc}	7.20^{b}	17852^{b}	189.75^{a}	97.56^{b}	54.12^{b}
T_6- TOF + STBR	6.20^{c}	11960^{g}	109.20^{de}	50.0^{d}	60.00^{b}	6.00^{cd}	9854^{e}	124.78^{cd}	69.26^{c}	58.45^{ab}
T_7- F-TOF + STBR	7.40^{b}	12608^{f}	115.60^{cd}	84.8^{b}	67.20^{a}	7.15^{b}	11452^{d}	148.75^{b}	99.87^{b}	64.12^{a}
T_8- F-TOF alone	5.20^{e}	10964^{h}	116.80^{c}	63.6^{c}	56.80^{bc}	5.05^{d}	9152^{f}	115.63^{d}	71.45^{c}	42.13^{c}
T_9- Absolute control	4.20^{f}	8900^{i}	90.00^{e}	32.4^{e}	37.60^{e}	3.60^{e}	8145^{g}	94.56^{e}	22.95^{f}	29.45^{d}
SEm±	0.079	26.19	2.99	2.56	1.96	0.319	15.75	3.92	3.19	2.30
CD (0.05)	0.238	78.56	8.96	7.68	5.89	0.957	47.25	11.75	9.56	6.90

4.4.2.3.2.2.3 Zinc

In both the cropping sequences, the highest Zn content in amaranthus root (93.6 and 110.23 mg kg^{-1}, respectively) was recorded by treatment T_3 (OC + STBR) followed by T_5 (MC + STBR) in the first cropping sequence and by T_7 (F-TOF+ STBR) in the second cropping sequence**.** For both the cropping sequences, the lowest Fe content was recorded by absolute control.

4.4.2.3.2.2.4 Copper

In the both the cropping sequence, the highest Cu content in amaranthus root (67.20 and 64.12 mg kg^{-1}, respectively) was recorded by treatment T_7 (F-TOF + STBR) followed by T_6 (TOF + STBR)**.** For both the cropping sequences, the lowest Cu content was recorded by absolute control.

4.4.2.3.2.2.5 Boron

In the first cropping sequence, the highest B content in amaranthus root (7.89 mg kg^{-1}) was recorded by treatment T_4 (VC + STBR) followed by T_5 (MC + STBR) and T_7 (F-TOF + STBR). In second cropping sequence, the highest B content in amaranthus root was recorded by treatment T_4 followed by T_5 and T_7. For both the cropping sequences, the lowest B content was recorded by absolute control.

4.4.2.3.2.2.6 Heavy metals

Heavy metal contents of shoot and root were tested and Pb alone was detected and that too in root only. The application organic fertilizers resulted in accumulation Pb in roots of amaranthus (Table 125). Pb content was detected in the roots of all the treatments for both the cropping sequences. The highest Pb content in amaranthus root was with treatment T_1 (152 and 114 mg kg^{-1}, respectively) followed by T_2 and T_4 (VC+ STBR).

Table 125. Pb concentration in the roots of amaranthus, mg kg^{-1}

Treatments	Pb content in roots (mg kg^{-1})	
	Amaranthus I	Amaranthus II
T_1-FYM + NPK $_{POP}$	0.152 ^{a}	0.114 ^{a}
T_2 - FYM + STBR	0.143 ^{a}	0.109 ^{a}
T_3- OC + STBR	0.101 ^{b}	0.096 ^{a}
T_4- VC + STBR	0.114 ^{ab}	0.098 ^{a}
T_5- MC+ STBR	0.108 ^{ab}	0.096 ^{a}
T_6- TOF + STBR	0.091 ^{b}	0.086 ^{a}
T_7- F-TOF + STBR	0.089 ^{b}	0.073 ^{a}
T_8- F-TOF alone	0.086 ^{b}	0.083 ^{a}
T_9-Absolute control	0.022 ^{c}	0.016 ^{b}
SEm±	0.016	0.015
CD (0.05)	0.046	0.041

4.4.2.4 NUTRIENT UPTAKE

4.4.2.4.1 Nitrogen

Total N uptake by amaranthus plants varied significantly among the treatments and also there was significant difference in the N uptake by shoot and root of amaranthus (Table 126). For the first cropping sequence, the highest total N uptake (58.49 kg ha^{-1}) as well as uptake by shoot (55.73 kg ha^{-1}) and root (2.76 kg ha^{-1}) was recorded by the treatment T_7 (VC + STBR) followed by T_4 (F-TOF + STBR). The treatments T_4 and T_7 were statistically on par with each other for their total N uptake and N uptake by shoot and root. For the second cropping sequence, the highest total N uptake (62.10 kg ha^{-1}) as well as N uptake by shoot (59.31 kg ha^{-1}) and root (2.79 kg ha^{-1}) was recorded by treatment T_7 followed by treatment T_4 and they were statistically on par for total N uptake in the second cropping sequence also. For both the cropping sequences, the lowest total N uptake as well as N uptake by shoot and root was recorded by treatment T_9 (absolute control).

Table 126. Effect of treatments on N uptake by amaranthus, kg ha^{-1}

Treatments	Uptake of N (kg ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T_1-FYM+NPK$_{POP}$	27.36 ^{e}	1.44 ^{b}	28.80 ^{de}	29.18 ^{f}	1.49 ^{c}	30.67 ^{de}
T_2 - FYM + STBR	26.74 ^{e}	1.49 ^{b}	28.23 ^{de}	30.20 ^{ef}	1.56 ^{c}	31.75 ^{d}
T_3- OC + STBR	30.44 ^{d}	2.10 ^{a}	32.54 ^{cd}	32.19 ^{e}	2.02 ^{b}	34.20 ^{d}
T_4- VC + STBR	54.95 ^{a}	2.37 ^{a}	57.32 ^{a}	55.56 ^{b}	2.24 ^{b}	57.80 ^{a}
T_5- MC+ STBR	47.72 ^{b}	1.75 ^{b}	49.47 ^{b}	48.46 ^{c}	1.58 ^{c}	50.04 ^{b}
T_6- TOF + STBR	34.93 ^{c}	2.26 ^{a}	37.20 ^{c}	42.80 ^{d}	2.38 ^{a}	45.18 ^{c}
T_7-F-TOF+STBR	55.73 ^{a}	2.76 ^{a}	58.49 ^{a}	59.31 ^{a}	2.79 ^{a}	62.10 ^{a}
T_8- F-TOF alone	24.90 ^{f}	1.57 ^{b}	26.47 ^{e}	23.81 ^{g}	1.70 ^{c}	25.51 ^{e}
T_9-Absolutecontrol	16.75 ^{g}	0.64 ^{c}	17.39 ^{f}	17.92 ^{h}	0.49 ^{d}	18.41 ^{f}
SEm±	0.04	0.224	1.65	0.78	0.137	1.73
CD (0.05)	2.15	0.671	4.96	2.35	0.410	5.18

4.4.2.4.2 Phosphorus

Total P uptake by amaranthus varied significantly among the treatments and also there was significant difference in the P uptake by shoot and root (Table 127). For both the cropping sequences, the highest total P uptake (7.10 and 9.89 kg ha^{-1}, respectively) as well as uptake by shoot (6.82 and 9.64 kg ha^{-1}, respectively) and root (0.277 and 0.249 kg ha^{-1}) was recorded by the treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR). For both the cropping sequences, the total P uptake by treatment T_7 and T_4 were statistically on par with each other. For both the cropping sequences, the lowest total P uptake as well as P uptake by shoot and root was recorded by treatment T_9 (absolute control).

Table 127. Effect of treatments on P uptake by amaranthus, kg ha^{-1}

Treatments	Uptake of P (kg ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T_1-FYM + NPK $_{POP}$	3.49^{c}	0.143^{e}	3.63^{cd}	5.26^{d}	0.146^{c}	5.41^{de}
T_2 - FYM + STBR	3.75^{c}	0.155^{d}	3.91^{c}	5.60^{d}	0.158^{bc}	5.76^{cd}
T_3- OC + STBR	3.79^{c}	0.156^{d}	3.95^{c}	5.76^{d}	0.177^{bc}	5.94^{cd}
T_4- VC + STBR	6.20^{a}	0.148^{de}	6.35^{a}	8.90^{ab}	0.187^{b}	9.09^{a}
T_5- MC+ STBR	5.54^{b}	0.156^{d}	5.69^{b}	8.30^{b}	0.149^{bc}	8.45^{b}
T_6- TOF + STBR	5.03^{b}	0.230^{b}	5.26^{b}	6.50^{c}	0.216^{a}	6.72^{c}
T_7- F-TOF + STBR	6.82^{a}	0.277^{a}	7.10^{a}	9.64^{a}	0.249^{a}	9.89^{a}
T_8- F-TOF alone	2.77^{d}	0.178^{c}	2.95^{d}	4.49^{e}	0.174^{bc}	4.66^{e}
T_9- Absolute control	1.96^{e}	0.066^{f}	2.03^{e}	3.45^{f}	0.055^{d}	3.50^{f}
SEm±	0.216	0.004	0.296	0.09 g	0.015	0.38
CD (0.05)	0.641	0.012	0.890	0.776	0.039	1.14

4.4.2.4.3 Potassium

Total K uptake by amaranthus varied significantly among the treatments and also there was significant difference in the K uptake by shoot and root (Table 128). For both the cropping sequences, the highest total K uptake (27.85 and 25.39 kg ha^{-1}, respectively) as well as K uptake by shoot (26.78 and 24.60 kg ha^{-1}, respectively) and root (1.078 and 0.798 kg ha^{-1}) were recorded by the treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR). For the first cropping sequence, the total K uptake by treatment T_7 and T_4 were statistically on par. Also the treatment T_4 was statistically on par with the treatment T_5 (MC + STBR). For the second cropping sequence, the total K uptake by the treatments T_7, T_4 and T_5 were statistically on par with each other. For both the cropping sequences, the lowest total K uptake as well as K uptake by shoot and root were recorded by treatment T_9 (absolute control).

Table 128. Effect of treatments on K uptake by amaranthus, kg ha^{-1}

Treatments	Uptake of K (kg ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T_1-FYM + NPK $_{POP}$	14.54 ^{e}	0.624 ^{d}	15.17 ^{d}	12.82 ^{c}	0.451 ^{b}	13.27 ^{b}
T_2 - FYM + STBR	16.17 ^{d}	0.669 ^{cd}	16.83 ^{d}	13.42 ^{c}	0.486 ^{b}	13.91 ^{b}
T_3- OC + STBR	14.66 ^{de}	0.789 ^{c}	15.45 ^{d}	14.97 ^{bc}	0.576 ^{ab}	15.54 ^{b}
T_4- VC + STBR	24.34 ^{b}	0.941 ^{b}	25.28 ^{ab}	24.19 ^{a}	0.714 ^{a}	24.91 ^{a}
T_5- MC+ STBR	23.64 ^{b}	0.698 ^{c}	24.34 ^{b}	22.91 ^{a}	0.521 ^{b}	23.43 ^{a}
T_6- TOF + STBR	19.55 ^{c}	0.948 ^{b}	20.50 ^{c}	15.73 ^{b}	0.685 ^{a}	16.42 ^{b}
T_7- F-TOF + STBR	26.78 ^{a}	1.078 ^{a}	27.85 ^{a}	24.60 ^{a}	0.798 ^{a}	25.39 ^{a}
T_8- F-TOF alone	11.99 ^{f}	0.851 ^{bc}	12.84 ^{e}	10.14 ^{d}	0.581 ^{ab}	10.72 ^{c}
T_9- Absolute control	7.65 ^{g}	0.163 ^{e}	7.81 ^{f}	6.85 ^{e}	0.130 ^{c}	6.98 ^{d}
SEm±	0.518	0.041	0.968	0.58	0.088	1.16
CD (0.05)	1.54	0.123	2.90	1.70	0.265	3.49

4.4.2.4.4 Calcium

Total Ca uptake by amaranthus varied significantly among the treatments and also there was significant difference in the Ca uptake by shoot and root (Table 129). For the first cropping sequence, the highest total Ca uptake (13.03 kg ha^{-1}) as well as uptake by shoot (12.54 kg ha^{-1}) and root (0.485 kg ha^{-1}) was recorded by the treatment T_4 (VC + STBR) followed by T_7 (F-TOF + STBR). The treatments T_4 and T_7 were statistically on par with each other for their total Ca uptake and Ca uptake by shoot. For the second cropping sequence, the highest total Ca uptake (17.20 kg ha^{-1}) as well as N uptake by shoot (16.81 kg ha^{-1}) and root (0.389 kg ha^{-1}) was recorded by treatment T_7 followed by treatment T_4. Also, the treatments T_7 and T_8 were statistically on par with each other for their total Ca uptake and Ca uptake by root. For both the cropping sequences, the lowest total Ca uptake as well as Ca uptake by shoot and root was recorded by treatment T_9 (absolute control).

Table 129. Effect of treatments on Ca uptake by amaranthus, kg ha^{-1}

Treatments	Uptake of Ca (kg ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T_1-FYM + NPK $_{POP}$	5.93 ^{e}	0.312 ^{de}	6.24 ^{cd}	7.65 ^{e}	0.231 ^{c}	7.88 ^{d}
T_2 - FYM + STBR	6.51 ^{de}	0.336 ^{d}	6.84 ^{cd}	8.13 ^{e}	0.246 ^{b}	8.38 ^{d}
T_3- OC + STBR	7.07 ^{d}	0.393 ^{c}	7.47 ^{c}	7.79 ^{e}	0.290 ^{b}	8.08 ^{d}
T_4- VC + STBR	12.54 ^{a}	0.485 ^{b}	13.03 ^{a}	15.53 ^{b}	0.377 ^{a}	15.91^{a}
T_5- MC+ STBR	9.69 ^{b}	0.304 ^{e}	9.99 ^{b}	13.22 ^{c}	0.225 ^{c}	13.44 ^{b}
T_6- TOF + STBR	8.33 ^{c}	0.490 ^{b}	8.82 ^{b}	11.10 ^{d}	0.363 ^{a}	11.47 ^{c}
T_7- F-TOF + STBR	11.83 ^{a}	0.529 ^{a}	12.36 ^{a}	16.81 ^{a}	0.389 ^{a}	17.20 ^{a}
T_8- F-TOF alone	4.53 ^{f}	0.359 ^{d}	4.89 ^{d}	5.70 ^{f}	0.359 ^{a}	6.06 ^{e}
T_9- Absolute control	2.62 ^{g}	0.104 ^{f}	2.73 ^{e}	3.64 ^{g}	0.045 ^{d}	3.69 ^{f}
SEm±	0.27	0.01	0.767	0.384	0.02	0.47
CD (0.05)	0.81	0.027	2.30	1.13	0.054	1.41

4.4.2.4.5 Magnesium

Total Mg uptake by amaranthus varied significantly among the treatments and also there was significant difference in the Mg uptake by shoot and root (Table 130). For both the cropping sequences, the highest total Mg uptake (4.45 and 4.81 kg ha^{-1}, respectively) as well as Mg uptake by shoot (4.30 and 4.67 kg ha^{-1}, respectively) and root (0.1512 and 0.1414 kg ha^{-1}, respectively) were recorded by the treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR). For the first cropping sequence, the highest total Mg uptake as well as Mg uptake by shoot and root of treatments T_7 and T_4 were statistically on par. For the second cropping sequence, the total Mg uptake by the treatments T_7, T_4 and T_5 (MC +STBR) were statistically on par with each other. For both the cropping sequences, the lowest total Mg uptake as well as Mg uptake by shoot and root was recorded by treatment T_9 (absolute control).

Table 130. Influence of treatments on Mg uptake by amaranthus, kg ha^{-1}

Treatments	Uptake of Mg (kg ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T_1-FYM + NPK POP	1.95^{d}	0.0815^{c}	2.03^{d}	2.07^{d}	0.0780^{b}	2.14^{c}
T_2 - FYM + STBR	1.99^{d}	0.0898^{c}	2.08^{d}	2.44^{d}	0.0825^{b}	2.52^{c}
T_3- OC + STBR	2.34^{cd}	0.0981^{bc}	2.44^{cd}	2.34^{d}	0.0971^{b}	2.43^{c}
T_4- VC + STBR	4.12^{a}	0.1315^{a}	4.25^{a}	4.30^{a}	0.1179^{a}	4.42^{a}
T_5- MC+ STBR	3.52^{b}	0.0795^{c}	3.60^{b}	3.88^{b}	0.0786^{b}	3.96^{a}
T_6- TOF + STBR	2.73^{c}	0.1264^{a}	2.86^{c}	3.11^{c}	0.1211^{a}	3.23^{b}
T_7- F-TOF + STBR	4.30^{a}	0.1512^{a}	4.45^{a}	4.67^{a}	0.1414^{a}	4.81^{a}
T_8- F-TOF alone	1.81^{d}	0.1188^{b}	1.93^{c}	1.81^{d}	0.0999^{b}	1.91^{d}
T_9- Absolute control	1.31^{e}	0.0377^{d}	1.35^{e}	1.05^{e}	0.0351^{c}	1.08^{e}
SEm±	0.200	0.010	0.238	0.246	0.010	0.198
CD (0.05)	0.601	0.028	0.714	0.739	0.027	0.596

4.4.2.4.6 Sulphur

Total S uptake by amaranthus varied significantly among the treatments and also there was significant difference in the S uptake by shoot and root (Table 131). For the first cropping sequence, the highest total sulphur uptake (4.79 kg ha^{-1}) and S uptake by shoot (4.73 kg ha^{-1}) was recorded by the treatment T_5 (MC + STBR) and the highest S uptake in root (0.1288 kg ha^{-1}) was recorded by treatment T_7 (F-TOF + STBR). Also the treatments such as T_5, T_7 and T_4 (VC +STBR) were statistically on par with each other for their total sulphur uptake. For the second cropping sequence, the highest total sulphur uptake (5.91 kg ha^{-1}) and S uptake by shoot (5.79 kg ha^{-1}) and root (0.1190 kg ha^{-1}) were recorded by the treatment T_7 and for total S uptake, the treatments such as T_7, T_4 and T_5 were statistically on par with each other. For both the cropping sequences, the lowest total S uptake as well as S uptake by shoot and root were recorded by treatment T_9 (absolute control).

Table 131. Effect of treatments on S uptake by amaranthus, kg ha^{-1}

Treatments	Uptake of S (kg ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T_1-FYM + NPK $_{POP}$	2.43 ^{cd}	0.0468 ^{c}	2.48 ^{bc}	2.98 ^{c}	0.0381 ^{c}	3.02 ^{c}
T_2 - FYM + STBR	2.56 ^{c}	0.0477 ^{c}	2.61 ^{bc}	3.19 ^{c}	0.0376 ^{c}	3.23 ^{c}
T_3- OC + STBR	2.64 ^{c}	0.0597 ^{bc}	2.70 ^{bc}	3.40 ^{c}	0.0491 ^{b}	3.45 ^{bc}
T_4- VC + STBR	4.27 ^{a}	0.0861 ^{b}	4.36 ^{a}	5.50 ^{a}	0.0759 ^{b}	5.57 ^{a}
T_5- MC+ STBR	4.73 ^{a}	0.0636 ^{bc}	4.79 ^{a}	5.43 ^{a}	0.0610 ^{b}	5.49 ^{a}
T_6- TOF + STBR	3.17 ^{b}	0.0974 ^{a}	3.27 ^{b}	3.98 ^{b}	0.0935 ^{a}	4.07 ^{b}
T_7- F-TOF + STBR	4.55 ^{a}	0.1288 ^{a}	4.67 ^{a}	5.79 ^{a}	0.1190 ^{a}	5.91 ^{a}
T_8- F-TOF alone	2.01 ^{d}	0.0675 ^{bc}	2.08 ^{c}	2.38 ^{d}	0.0621 ^{b}	2.44 ^{d}
T_9- Absolute control	1.27 ^{e}	0.0221 ^{c}	1.29 ^{d}	1.34 ^{e}	0.0189 ^{c}	1.36 ^{e}
SEm±	0.174	0.012	0.366	0.163	0.009	0.237
CD (0.05)	0.513	0.034	0.879	0.489	0.027	0.712

4.4.2.4.8 Iron

Total Fe uptake by amaranthus varied significantly among the treatments and also there was significant difference in the Fe uptake by shoot and root (Table 132). For the cropping sequences, the highest total Fe uptake as well as uptake by shoot were recorded by the treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR). For both the cropping sequences, the highest Fe uptake by root was recorded by the treatment T_3 (OC + STBR) For both the cropping sequences, the lowest total Fe uptake as well as Fe uptake by shoot and root was recorded by treatment T_9 (absolute control).

Table 132. Fe uptake of amaranthus as affected by treatments, g ha^{-1}

Treatments	Uptake of Fe (g ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T$_1$-FYM+ NPK $_{POP}$	1425.60^{f}	1173.73 ^{g}	2599.33 ^{h}	1521.04 ^{g}	898.70 ^{h}	2419.74^{g}
T$_2$ - FYM + STBR	1592.02^{e}	1575.23 ^{e}	3167.25 ^{f}	1689.06 ^{e}	1085.89^{g}	2774.95 ^{f}
T$_3$- OC + STBR	1413.63^{f}	2572.60 ^{a}	3986.23 ^{c}	1610.41 ^{f}	2064.59 ^{a}	3675.01^{d}
T$_4$- VC + STBR	2346.83^{b}	1907.81 ^{b}	4254.64 ^{b}	2491.21 ^{b}	1833.23^{b}	4324.43^{b}
T$_5$- MC+ STBR	2016.82^{c}	1825.96 ^{c}	3842.78 ^{d}	2137.81 ^{c}	1729.14^{d}	3866.95 ^{c}
T$_6$- TOF + STBR	1646.68^{d}	1577.88 ^{e}	3224.56 ^{e}	1828.03 ^{d}	1250.67 ^{e}	3078.70 ^{e}
T$_7$- F-TOF+ STBR	3009.13^{a}	1768.65 ^{d}	4777.78 ^{a}	3196.30 ^{a}	1759.49 ^{c}	4955.78 ^{a}
T$_8$- F-TOF alone	1145.77^{g}	1483.10 ^{f}	2628.87 ^{g}	1070.76 ^{h}	1176.86 ^{f}	2247.62^{h}
T$_9$-Absolute control	850.06 ^{h}	579.66 ^{h}	1429.72 ^{i}	605.96 ^{i}	503.28 ^{i}	1109.24 ^{i}
SEm±	12.34	6.45	3.65	17.64	4.02	11.71
CD (0.05)	37.01	19.35	10.95	52.92	12.07	35.12

4.4.2.4.11 Manganese

Total Mn uptake by amaranthus varied significantly among the treatments and also there was significant difference in the Mn uptake by shoot and root (Table 133). For the first cropping sequence, the highest total Mn uptake, shoot uptake and root uptake were recorded by the treatment T$_3$ (OC + STBR). For the second cropping sequence, the highest total Mn uptake (428.49 g ha^{-1}) and Mn uptake by shoot (407.62 g ha^{-1}) was recorded by the treatment T$_4$ and highest root uptake was recorded by treatment T$_7$ (F-TOF+ STBR). For the cropping sequences, the lowest total Mn uptake as well as uptake by shoot and root was recorded by absolute control.

Table 133. Mn uptake of amaranthus I and II as affected by treatments, g ha^{-1}

Treatments	Uptake of Mn (g ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T$_1$-FYM +NPK $_{POP}$	169.48 ^{e}	7.89 ^{f}	177.36 ^{d}	181.73 ^{f}	12.02 ^{d}	193.75 ^{e}
T$_2$ - FYM + STBR	281.16 ^{b}	11.32 ^{e}	292.48 ^{b}	197.52 ^{ef}	14.21 ^{cd}	211.74 ^{de}
T$_3$- OC + STBR	346.73 ^{a}	17.23 ^{a}	363.96 ^{a}	297.24 ^{d}	20.67 ^{ab}	317.91 ^{c}
T$_4$- VC + STBR	337.57 ^{a}	14.99 ^{c}	352.56 ^{a}	407.62 ^{a}	20.87 ^{ab}	428.49 ^{a}
T$_5$- MC+ STBR	267.77 ^{c}	14.09 ^{d}	281.86 ^{b}	315.31 ^{c}	18.38 ^{b}	333.69 ^{c}
T$_6$- TOF + STBR	116.83 ^{f}	14.41 ^{cd}	131.23 ^{e}	213.06 ^{e}	15.84 ^{c}	228.90 ^{d}
T$_7$- F-TOF +STBR	211.51 ^{d}	16.22 ^{b}	227.72 ^{c}	335.23 ^{b}	22.85 ^{a}	358.09 ^{b}
T$_8$- F-TOF alone	88.37 ^{g}	15.80 ^{b}	104.17 ^{f}	99.44 ^{g}	14.87 ^{c}	114.31 ^{f}
T$_9$- Absolute control	71.52 ^{h}	6.64 ^{g}	78.16 ^{g}	49.99 ^{h}	5.84 ^{e}	55.83 ^{g}
SEm±	4.19	0.21	8.03	5.48	0.84	6.73
CD (0.05)	12.58	0.636	24.10	16.44	2.52	20.18

4.4.1.5.10 Zinc

Total Zn uptake by amaranthus varied significantly among the treatments and also there was significant difference in the Zn uptake by shoot and root (Table 134). For both the cropping sequences, the highest total Zn uptake (246.64 and 264.89 g ha^{-1}, respectively) as well as uptake by shoot and root were recorded by the treatment T$_7$ (F-TOF + STBR) followed by T$_5$ (MC + STBR). For the cropping sequences, the lowest total Zn uptake as well as uptake by shoot and root was recorded by absolute control (T$_9$).

Table 134. Zn uptake of amaranthus as affected by treatments, g ha^{-1}

Treatments	Uptake of Zn (g ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T$_1$-FYM + NPK $_{POP}$	100.84 ^{e}	4.24 ^{h}	105.08 ^{f}	107.86 ^{f}	5.73 ^{d}	113.58 ^{e}
T$_2$ - FYM + STBR	128.76 ^{d}	6.28 ^{g}	135.05 ^{e}	131.94 ^{e}	7.19 ^{cd}	139.13 ^{d}
T$_3$- OC + STBR	170.49 ^{c}	10.00 ^{b}	180.49 ^{d}	183.07 ^{d}	12.33 ^{ab}	195.41 ^{c}
T$_4$- VC + STBR	217.86 ^{a}	7.99 ^{e}	225.86 ^{b}	234.96 ^{b}	9.15 ^{bc}	244.11 ^{b}
T$_5$- MC+ STBR	191.85 ^{b}	8.28 ^{d}	200.14 ^{c}	208.02 ^{c}	9.45 ^{bc}	217.47 ^{c}
T$_6$- TOF + STBR	103.38 ^{e}	6.60 ^{f}	109.98 ^{f}	109.45 ^{f}	8.79 ^{cd}	118.24 ^{e}
T$_7$- F-TOF + STBR	234.74 ^{a}	11.90 ^{a}	246.64 ^{a}	249.55 ^{a}	15.34 ^{a}	264.89 ^{a}
T$_8$- F-TOF alone	63.17 ^{f}	8.60 ^{c}	71.77 ^{g}	68.17 ^{g}	9.19 ^{bc}	77.36 ^{f}
T$_9$- Absolute control	55.46 ^{f}	2.11 ^{i}	57.57 ^{h}	39.35 ^{h}	1.42 ^{e}	40.77 ^{g}
SEm±	6.71	0.04	5.86	3.64	1.12	3.30
CD (0.05)	20.12	0.129	17.58	10.91	3.37	9.91

4.4.2.4.11 Copper

Total Cu uptake by amaranthus varied significantly among the treatments and also there was significant difference in the Cu uptake by shoot and root (Table 135). For the cropping sequences, the highest total Cu uptake as well as uptake by root was recorded by the treatment T$_7$ (F-TOF+ STBR). For both the cropping sequences, the highest Cu uptake by shoot (38.90 and 43.89 g ha^{-1}, respectively) was recorded by the treatment T$_4$ (VC + STBR). For the cropping sequences, the lowest total Cu uptake as well as uptake by shoot and root was recorded by absolute control (T$_9$).

Table 135. Cu uptake of amaranthus as affected by treatments, g ha^{-1}

Treatments	Uptake of Cu (g ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T_1-FYM + NPK $_{POP}$	19.56 ^{d}	3.79 ^{h}	23.34 ^{h}	24.44 ^{e}	3.54 ^{e}	27.98 ^{de}
T_2 - FYM + STBR	30.15 ^{c}	4.15 ^{g}	34.31 ^{f}	26.85 ^{d}	3.58 ^{e}	30.43 ^{de}
T_3- OC + STBR	38.21 ^{a}	5.60 ^{d}	43.81 ^{b}	36.41 ^{c}	5.21 ^{cd}	41.61 ^{c}
T_4- VC + STBR	38.90 ^{a}	4.63 ^{f}	43.54 ^{c}	43.89 ^{a}	4.87 ^{d}	48.75 ^{ab}
T_5- MC+ STBR	34.72 ^{b}	5.03 ^{e}	39.75 ^{d}	37.45 ^{c}	5.24 ^{cd}	42.69 ^{bc}
T_6- TOF + STBR	29.21 ^{c}	7.92 ^{b}	37.12 ^{e}	24.87 ^{e}	7.42 ^{b}	32.29 ^{d}
T_7- F-TOF + STBR	36.81 ^{ab}	9.43 ^{a}	46.24 ^{a}	40.73 ^{b}	9.85 ^{a}	50.59 ^{a}
T_8- F-TOF alone	20.16 ^{d}	7.68 ^{c}	27.84 ^{g}	19.23 ^{f}	5.42 ^{c}	24.65 ^{e}
T_9- Absolute control	12.55 ^{e}	2.45 ^{i}	15.00 ^{i}	8.61 ^{g}	1.82 ^{f}	10.43 ^{f}
SEm±	1.16	0.05	0.07	0.60	0.15	2.24
CD (0.05)	3.47	0.162	0.211	1.79	0.448	6.73

4.4.2.4.7 Boron

Total B uptake by amaranthus varied significantly among the treatments and also there was significant difference in the B uptake by shoot and root (Table 136). For both the cropping sequences, the highest total B uptake (38.91 and 43.39 g ha^{-1}, respectively) as well as uptake by shoot (37.36 and 41.41 g ha^{-1}, respectively) and root (1.554 and 1.984 g ha^{-1}) were recorded by the treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR) in the first cropping sequence. In the second cropping sequence, for total B uptake and B uptake by shoot, treatment T_7 was followed by T_4. For B uptake by root, treatment T_7 was followed by treatment T_5 (MC + STBR) and it was statistically on par with the treatment T_4. For both the cropping sequences, the lowest total B uptake as well as B uptake by shoot and root was recorded by treatment T_9 (absolute control).

Table 136. B uptake of amaranthus as affected by treatments, g ha^{-1}

Treatments	Uptake of B (g ha^{-1})					
	Amaranthus I			Amaranthus II		
	Shoot	Root	Total	Shoot	Root	Total
T_1-FYM + NPK $_{POP}$	18.37^{d}	0.754^{d}	19.12^{ef}	22.43^{e}	0.936^{d}	23.37^{ef}
T_2 - FYM + STBR	19.22^{cd}	0.791^{cd}	20.01^{e}	22.65^{e}	0.987^{cd}	23.64^{e}
T_3- OC + STBR	30.84^{b}	1.215^{b}	32.06^{c}	24.17^{d}	1.097^{c}	25.27^{d}
T_4- VC + STBR	35.84^{a}	1.598^{a}	37.44^{b}	31.76^{b}	1.668^{b}	33.43^{b}
T_5- MC+ STBR	21.51^{c}	1.147^{b}	22.66^{d}	27.97^{c}	1.764^{b}	29.73^{c}
T_6- TOF + STBR	17.17^{d}	0.822^{c}	17.99^{f}	20.72^{f}	1.125^{c}	21.85^{f}
T_7- F-TOF + STBR	37.36^{a}	1.554^{a}	38.91^{a}	41.41^{a}	1.984^{a}	43.39^{a}
T_8- F-TOF alone	11.57^{e}	0.585^{e}	12.16^{g}	14.18^{g}	0.732^{e}	14.91^{g}
T_9- Absolute control	5.46^{f}	0.410^{f}	5.87^{h}	3.89^{h}	0.351^{f}	4.24^{h}
SEm±	0.946	0.0186	0.446	0.356	0.051	0.53
CD (0.05)	2.84	0.055	1.34	1.067	0.153	1.59

4.4.2.4.12 Heavy metal- Lead (Pb)

For amaranthus during both the cropping sequences, the highest Pb uptake (Table 137) was from treatments T_1 (13.17 and 11.97 mg ha^{-1}) and T_2 (13.11 and 11.99 mg ha^{-1}) followed by T_4 (VC +STBR). For amaranthus, all the treatments showed uptake of Pb by roots.

Table 137. Effect of treatments on Pb uptake by amaranthus, mg ha^{-1}

Treatments	Pb uptake in roots (mg ha^{-1})	
	Amaranthus I	Amaranthus II
T_1-FYM + NPK $_{POP}$	13.17^{a}	11.97^{a}
T_2 - FYM + STBR	13.11^{a}	11.99^{a}
T_3- OC + STBR	10.77^{b}	10.72^{b}
T_4- VC + STBR	12.92^{a}	11.43^{a}
T_5- MC+ STBR	9.54^{b}	9.28^{c}
T_6- TOF + STBR	11.98^{ab}	10.89^{b}
T_7- F-TOF + STBR	12.46^{ab}	11.19^{a}
T_8- F-TOF alone	11.61^{ab}	10.65^{b}
T_9- Absolute control	1.43^{c}	0.99^{d}
SEm±	0.85	0.35
CD (0.05)	2.55	1.05

4.4.3 SOIL PROPERTIES

The soil samples collected before planting and harvest of each crop were analysed for its physical, chemical and biological properties and the results are presented below.

4.4.3.1 PHYSICAL PROPERTIES

4.4.3.1.1 Bulk density

Bulk density of the soil at the time of planting varied from 1.41 to 1.43 Mg m^{-3} and did not differ significantly between the treatments. But after the first crop of tomato, there was a noticeable decrease in the bulk density of treatments which have received organic fertilizers and it lasts up to the end of the cropping sequence (Table 138). The lowest bulk density of 1.28 Mg m^{-3} was recorded by the treatment T_8 where F-TOF alone was applied. The highest bulk density was recorded for absolute control (T_9) where bulk density showed an increase from the initial values. All treatments, which received organic fertilizers, exhibited a sharp decline in their bulk density from their initial values. Three treatments T_4, T_6 and T_7 which received organic fertilizers VC, TOF and F-TOF, respectively, recorded the bulk density of 1.29 Mg m^{-3} at the end of the cropping sequence.

4.4.3.1.2. Water holding capacity

The water holding capacity (WHC) of initial soil did not vary significantly among the treatments, but varied significantly in the post-harvest soil (Table 138). Throughout the cropping sequences, the highest WHC was recorded for the treatment T_7 (F-TOF + STBR) followed by T_8 (F-TOF alone) and they were statistically on par with each other. The absolute control (T_9) recorded the lowest values for WHC and it was slightly higher than its initial value. In the absolute control, WHC decreased after the first cropping sequence and the lowest value (21.36 %) was recorded at the end of the second cropping sequence while all the treatments that received organic fertilizers recorded a higher WHC than their initial values.

4.4.3.2 ELECTROCHEMICAL PROPERTIES

4.4.3.2.1 pH

pH of the soil after the harvest of each crop varied significantly among the treatments (Table 139). For all the four crops, pH of post-harvest soil was the highest for treatment T_8 (F-TOF alone) followed by T_6 (TOF + STBR) and T_7 (F-TOF + STBR). The lowest pH was recorded with absolute control and it exhibited a decreasing trend after each crop. For organic fertilizer applied treatments the pH of the post harvest soil increased upto the third crop and declined later. While, the thermochemical organic fertilizer applied treatments (T_6, T_7 and T_8) showed a declining trend in pH after the second crop and they maintained a slightly acidic to near neutral pH (6.33 to 7.11) throughout the cropping sequence. While, treatments received organic fertilizers other than thermochemical organic fertilizer showed a decrease in pH to acidic range towards the end of the cropping sequence.

Table 138. Effect of organic fertilizer application on bulk density (Mg m^{-3}) and water holding capacity (%) of soil under tomato-amaranthus cropping sequence

Treatments	Physical properties									
	Bulk density (Mg m^{-3})					Water holding capacity (WHC) (%)				
		After harvest				Initial	After harvest			
	Initial	Tomato I	Amaranthus I	TomatoII	Amaranthus II		Tomato I	Amaranthus I	Tomato II	Amaranthus II
T$_1$- FYM + NPK $_{POP}$	1.41	1.35^{bc}	1.34 ^{b}	1.34^{bc}	1.33 ^{b}	21.25	23.17 ^{d}	23.95 ^{g}	25.12 ^{d}	26.04 ^{f}
T$_2$ - FYM + STBR	1.42	1.35^{bc}	1.34 ^{b}	1.34^{bc}	1.33 ^{b}	21.45	23.95 ^{d}	24.45 ^{f}	25.36 ^{d}	25.32 ^{g}
T$_3$- OC + STBR	1.41	1.35 ^{bc}	1.32^{bcd}	1.31^{bcd}	1.31 ^{c}	19.99	25.68 ^{c}	26.22 ^{e}	27.99 ^{c}	28.05 ^{d}
T$_4$- VC + STBR	1.43	1.32^{cd}	1.34 ^{b}	1.29 ^{d}	1.29 ^{d}	20.13	27.84 ^{b}	28.21 ^{c}	29.68 ^{b}	29.13 ^{c}
T$_5$- MC+ STBR	1.42	1.36 ^{b}	1.33 ^{bc}	1.35 ^{b}	1.32 ^{bc}	21.54	26.99^{bc}	27.42 ^{d}	27.45 ^{c}	27.27 ^{e}
T$_6$- TOF + STBR	1.42	1.31^{d}	1.30 ^{de}	1.29 ^{d}	1.29 ^{d}	21.23	27.85 ^{b}	29.89 ^{b}	29.99^{ab}	30.11 ^{b}
T$_7$- F-TOF + STBR	1.41	1.32^{cd}	1.31 ^{cd}	1.30 ^{cd}	1.29 ^{d}	20.45	29.50 ^{a}	30.31 ^{a}	30.89 ^{a}	31.02 ^{a}
T$_8$- F-TOF alone	1.43	1.31 ^{d}	1.31 ^{e}	1.30 ^{cd}	1.29 ^{d}	21.23	29.48 ^{a}	30.02 ^{ab}	30.32^{ab}	30.52 ^{b}
T$_9$- Absolute control	1.44	1.45 ^{a}	1.48 ^{a}	1.46 ^{a}	1.44 ^{a}	20.96	21.60 ^{e}	21.99 ^{h}	21.46 ^{e}	21.35 ^{h}
SEm±	-	0.012	0.008	0.015	0.005	-	0.477	0.099	0.304	0.146
CD (0.05)	NS	0.036	0.023	0.046	0.016	NS	1.43	0.296	0.913	0.439

4.4.3.2.2 EC

The EC of the post-harvest soil varied significantly among treatments after each crop (Table 139). For all the four crops, the EC of post-harvest soil recorded the highest value (0.54, 0.23, 0.30 and 0.33 dS m^{-1}, respectively) with treatment T_7 (F-TOF + STBR) and the lowest value with T_9 (absolute control) and it was lower than the initial value. After the first crop of tomato and after the second cropping sequence, EC of treatment T_4 (VC + STBR) was on par with T_7. While, after the second crop (amaranthus), EC of T_6 (TOF + STBR) was on par with T_7. EC of the soil increased after the first crop of tomato followed by a decrease and an increase by the end of second cropping sequence, except for treatment T_8.

4.4.3.3 SOIL CARBON POOLS

4.4.3.3.1 Total organic carbon

Total organic carbon of post-harvest soil differed significantly between the treatments, even though there was no significant difference initially (Table 140). The TOC of the soil increased than its initial value for all treatments except for absolute control (T_9). The highest value for TOC was recorded by the treatment T_7 (F-TOF + STBR) and followed by T_6 (TOF + STBR) and T_8 (F-TOF alone) and they were on par with each other. The lowest value was recorded by the treatment T_9 (absolute control) and it declined after each crop and lowest value was recorded at the end of the second cropping sequence.

Table 139. Effect of organic fertilizer application on pH and EC (dS m^{-1}) of soil under tomato-amaranthus cropping sequence

Treatments	Electrochemical properties									
	pH					EC (dS m^{-1})				
	Initial	After harvest				Initial	After harvest			
		Tomato I	Amaranthus I	Tomato II	Amaranthus II		Tomato I	Amaranthus I	Tomato II	Amaranthus II
T$_1$- FYM + NPK $_{POP}$	5.31	6.22^{d}	6.35 ^{d}	6.48^{d}	5.25 ^{g}	0.22	0.21 ^{de}	0.14 ^{c}	0.16 ^{b}	0.23 ^{b}
T$_2$ - FYM + STBR	5.30	6.24^{d}	6.33 ^{d}	6.52^{d}	5.26 ^{g}	0.21	0.20 ^{e}	0.15 ^{c}	0.16 ^{b}	0.24 ^{b}
T$_3$- OC + STBR	5.31	6.45^{c}	6.54 ^{c}	6.68 ^{c}	5.41 ^{f}	0.20	0.35 ^{bc}	0.10 ^{c}	0.18 ^{b}	0.20 ^{b}
T$_4$- VC + STBR	5.32	6.38 ^{e}	6.36 ^{d}	6.65^{c}	5.56 ^{e}	0.22	0.46 ^{ab}	0.10 ^{c}	0.28 ^{a}	0.26 ^{a}
T$_5$- MC+ STBR	5.32	6.48^{c}	6.26 ^{d}	6.72 ^{b}	5.70 ^{d}	0.21	0.39 ^{bc}	0.11 ^{c}	0.24 ^{a}	0.29 ^{a}
T$_6$- TOF + STBR	5.30	6.86^{a}	7.11 ^{b}	6.94^{a}	6.46^{b}	0.23	0.34 ^{bcd}	0.21 ^{a}	0.21 ^{a}	0.30 ^{a}
T$_7$- F-TOF + STBR	5.33	6.67^{b}	7.02 ^{b}	6.86 ^{a}	6.33^{c}	0.21	0.54^{a}	0.23 ^{a}	0.30^{a}	0.33 ^{a}
T$_8$- F-TOF alone	5.30	6.96 ^{a}	7.35^{a}	6.95 ^{a}	6.64 ^{a}	0.23	0.28^{cde}	0.18^{ab}	0.11 ^{g}	0.16 ^{c}
T$_9$- Absolute control	5.32	5.42 ^{e}	5.32 ^{e}	5.23 ^{e}	5.13 ^{h}	0.21	0.15 ^{e}	0.06 ^{d}	0.06^{c}	0.08 ^{d}
SEm±		0.047	0.033	0.040	0.037		0.043	0.017	0.037	0.023
CD (0.05)	NS	0.14	0.10	0.12	0.11	NS	0.13	0.05	0.11	0.07

4.4.3.3.2 Water soluble organic carbon

Water soluble organic carbon (WSOC) of post harvest soil differed significantly between the treatments (Table 140). Water soluble organic carbon in the post-harvest soil recorded highest value with treatment T_4 (VC +STBR). It was followed by the treatment T_5 (MC+ STBR) after the first crop of tomato and by T_3 (OC+ STBR) after the subsequent crops. Water soluble organic carbon in the post-harvest soil increased in the first cropping sequence and declined in the second cropping system, except absolute control (T_9). In T_9, WSOC declined after each crop and lowest value was recorded at the end of the second cropping sequence. However, WSOC content of all treatments increased than their initial value in all the treatments which have received organic fertilizers.

4.4.3.3.3 Labile carbon

Labile carbon in the post harvest soil varied significantly between the treatments (Table 141). The highest value for labile carbon was recorded with T_7 (F-TOF+ STBR) and it was followed by treatments T_6 (TOF + STBR) and T_4 (VC + STBR). The lowest value for labile carbon was recorded with absolute control and declined after each crop and lowest value was recorded after the fourth crop of amaranthus. All treatments exhibited an increase in their labile carbon content than the initial value, except absolute control (T_9). In case of labile carbon, the highest value during the cropping sequence was recorded after the third crop (tomato 2) and declined afterwards.

4.4.3.3.4 Microbial biomass carbon

Microbial biomass carbon (MBC) of post harvest soil varied significantly among the treatments (Table 141). The highest value for microbial biomass carbon was recorded with T_7 (F-TOF + STBR) followed by T_4 (VC + STBR). The lowest value was recorded with absolute control (T_9) and it decreased after each crop. All treatments, except absolute control, MBC increased than their initial values. Similar

Table 140. Effect of organic fertilizer application on TOC (%) and WSOC (mg kg^{-1}) of soil under tomato-amaranthus cropping sequence

Treatments	TOC (%)					WSOC (mg kg^{-1})				
	Initial	After harvest				After harvest				
		Tomato I	Amaranthus I	Tomato II	Amaranthus II	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII
T$_1$- FYM + NPK $_{POP}$	1.31	1.54 ^{c}	1.55 ^{c}	1.56 ^{e}	1.56 ^{d}	9.95	23.60 ^{d}	36.00 ^{e}	31.90 ^{d}	22.80 ^{e}
T$_2$ - FYM + STBR	1.30	1.55 ^{c}	1.56 ^{c}	1.58 ^{e}	1.59 ^{d}	9.87	24.60 ^{d}	37.25 ^{e}	31.00 ^{d}	22.20 ^{e}
T$_3$- OC + STBR	1.31	1.70 ^{b}	1.72 ^{b}	1.75 ^{cd}	1.76 ^{c}	9.66	26.00 ^{c}	48.60 ^{b}	43.50 ^{b}	36.40 ^{b}
T$_4$- VC + STBR	1.30	1.75 ^{b}	1.73 ^{b}	1.79 ^{c}	1.81 ^{c}	10.03	34.80 ^{a}	59.40 ^{a}	48.60 ^{a}	48.00 ^{a}
T$_5$- MC+ STBR	1.30	1.69 ^{b}	1.72 ^{b}	1.73 ^{d}	1.80 ^{c}	9.85	29.60 ^{b}	38.00 ^{d}	31.80 ^{d}	17.00 ^{f}
T$_6$- TOF + STBR	1.29	1.95 ^{a}	1.97 ^{a}	1.98 ^{a}	1.99 ^{a}	9.55	20.40 ^{h}	40.20 ^{d}	37.80 ^{c}	33.00 ^{c}
T$_7$- F-TOF + STBR	1.30	1.96 ^{a}	1.98 ^{a}	2.01 ^{a}	2.01 ^{a}	10.11	23.80 ^{d}	43.20 ^{c}	36.00 ^{c}	28.80 ^{d}
T$_8$- F-TOF alone	1.31	1.89 ^{a}	1.90 ^{a}	1.94 ^{a}	1.95 ^{a}	9.57	21.60 ^{e}	39.60 ^{d}	31.20 ^{d}	33.60 ^{c}
T$_9$- Absolute control	1.29	1.20 ^{d}	1.15 ^{d}	1.04 ^{f}	0.98 ^{e}	10.02	9.40 ^{f}	6.80 ^{f}	6.50 ^{e}	6.00 ^{g}
SEm±	-	0.037	0.040	0.020	0.027	-	0.443	0.750	0.983	0.847
CD (0.05)	NS	0.11	0.12	0.06	0.08	NS	1.33	2.25	2.95	2.54

Table 141. Effect of organic fertilizer application on labile carbon and MBC of soil under tomato-amaranthus cropping sequence, mg kg^{-1}

Treatments	Labile carbon(mg kg^{-1})					Microbial biomass carbon (mg kg^{-1})				
	Initial	After harvest				Initial	After harvest			
		Tomato I	Amaranthus I	Tomato II	Amaranthus II		Tomato I	Amaranthus I	Tomato II	Amaranthus II
T$_1$- FYM + NPK $_{POP}$	689.25	876.38 ^{d}	745.88 ^{e}	1120.50 ^{e}	699.75^{g}	21.28	26.29 ^{cd}	20.88 ^{b}	33.62 ^{d}	21.31 ^{d}
T$_2$ - FYM + STBR	696.56	991.13 ^{b}	749.25 ^{e}	1135.25 ^{e}	703.13 ^{g}	20.56	29.73 ^{b}	20.98 ^{b}	34.36 ^{c}	21.69 ^{d}
T$_3$- OC + STBR	689.56	744.75 ^{g}	810.00 ^{d}	1236.38 ^{c}	784.13 ^{e}	21.89	22.34 ^{e}	23.22 ^{a}	37.09 ^{b}	23.96 ^{b}
T$_4$- VC + STBR	694.21	929.25 ^{c}	837.00 ^{c}	1263.38 ^{b}	902.25 ^{c}	21.45	37.67 ^{a}	23.44 ^{a}	39.79^{a}	26.62 ^{a}
T$_5$- MC+ STBR	692.25	826.88 ^{e}	740.25 ^{e}	1243.13 ^{c}	748.13 ^{f}	19.66	24.81 ^{d}	22.73 ^{a}	37.29 ^{b}	21.95 ^{cd}
T$_6$- TOF + STBR	695.24	1255.50^{a}	861.75 ^{b}	1326.38 ^{a}	950.63 ^{b}	20.55	27.88 ^{bc}	22.68 ^{a}	37.90 ^{b}	24.69 ^{b}
T$_7$- F-TOF + STBR	694.55	1269.00^{a}	969.75 ^{a}	1335.38 ^{a}	994.50 ^{a}	21.24	38.07 ^{a}	24.13 ^{a}	40.06 ^{a}	27.85 ^{a}
T$_8$- F-TOF alone	697.26	992.25 ^{b}	829.13 ^{c}	1198.13 ^{d}	832.50 ^{d}	19.86	29.77 ^{b}	20.15 ^{b}	35.94 ^{c}	23.26^{bc}
T$_9$- Absolute control	689.29	651.50 ^{f}	550.13 ^{f}	511.50 ^{h}	466.88 ^{h}	20.14	22.55 ^{h}	15.40 ^{c}	19.85 ^{e}	13.07 ^{e}
SEm±		5.37	6.11	6.38	5.22		0.800	0.660	0.613	0.483
CD (0.05)	NS	16.10	18.33	19.14	15.66	NS	2.40	1.98	1.84	1.45

to labile carbon, MBC recorded the highest value during the second cropping sequence, i.e. after the third crop of tomato.

4.4.3.3.5 Recalcitrant organic carbon

Recalcitrant organic carbon (ROC) of the post harvest soil varied significantly between the treatments even though there was no significant difference initially (Table 142). There was a noticeable increase in the ROC content of the post harvest soil and it gradually increased after each crop except with treatment T_9 (absolute control). For absolute control, ROC declined after each crop and the lowest value was recorded after Amaranthus II. Among the treatments, highest ROC was recorded by T_7 (1.72 %) after the 3rd crop. By the end of second cropping sequence, ROC slightly declined for treatments such as T_4 (VC + STBR), T_6 (TOF + STBR), T_7 (F- TOF + STBR) and T_8 (F-TOF alone).

Table 142. Effect of organic fertilizer application on ROC of soil under tomato-amaranthus cropping sequence, %

Treatments	ROC (%)				
	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II
T_1- FYM + NPK $_{POP}$	0.87	0.95 ^{c}	0.97 ^{c}	1.27 ^{c}	1.32 ^{c}
T_2 - FYM + STBR	0.87	0.96 ^{c}	0.98 ^{c}	1.30 ^{c}	1.34 ^{c}
T_3- OC + STBR	0.86	1.19 ^{b}	1.30 ^{d}	1.43 ^{b}	1.47 ^{b}
T_4- VC + STBR	0.86	1.05 ^{c}	1.40 ^{a}	1.52 ^{b}	1.42 ^{b}
T_5- MC+ STBR	0.87	1.18 ^{b}	1.30 ^{b}	1.39^{f}	1.49 ^{b}
T_6- TOF + STBR	0.87	1.23 ^{b}	1.37 ^{a}	1.60 ^{a}	1.56 ^{a}
T_7- F-TOF + STBR	0.85	1.51 ^{a}	1.43 ^{a}	1.72 ^{a}	1.63 ^{a}
T_8- F-TOF alone	0.86	1.31^{b}	1.40 ^{a}	1.56 ^{b}	1.48 ^{b}
T_9- Absolute control	0.87	0.80 ^{d}	0.74 ^{d}	0.64 ^{d}	0.59 ^{d}
SEm±	-	0.05	0.04	0.05	0.03
CD (0.05)	NS	0.14	0.12	0.15	0.10

4.4.3.4 SOIL NITROGEN POOLS

4.4.2.4.1 Ammonical N

NH_4-N content of the initial soil did not differ significantly, but differed after the application of organic fertilizers (Table 143). For all the treatments except absolute control, NH_4-N content of the post harvest soil was higher than their initial value for the first cropping sequence (Tomato-Amaranthus). But it declined after 3rd crop (tomato II) and again increased after the 4th crop. After the first crop highest value (86.60 mg kg^{-1}) was recorded by treatment T_7 (F- TOF + STBR) followed by T_4 (VC + STBR) and T_3 (OC+ STBR). After the 2nd crop (amaranthus I), the highest value (67.20 mg kg^{-1}) was recorded by T_5 (MC+ STBR) followed by T_4, T_7 and T_8 (F- TOF alone). After the 3rd crop (tomato II) the highest value was recorded by T_5 (50.40 mg kg^{-1}) followed by T_7 and T_4. After the 4th crop (amaranthus II), the highest value (90.80 mg kg^{-1}) was recorded with T_7 followed by T_6 (TOF + STBR), T_8 and T_4. The lowest value for NH_4-N was recorded by absolute control (T_9) and declined after the each crop and the lowest was recorded after amaranthus II.

4.4.3.4.2 Nitrate- N

NO_3-N content of the initial soil had no significant difference (Table 143). But with the application of organic fertilizers there was significant difference among treatments. NO_3-N content in the post harvest soil increased than their initial value for all the treatments. But in absolute control (T_9), there was a decline in nitrate content after each crop and the lowest value (12.40 mg kg^{-1}) was recorded after second crop of amaranthus. After the first crop of tomato and at the end of second cropping sequence, the highest value was recorded with treatment T_7 (F-TOF + STBR). The highest value for NO_3-N after amaranthus I and tomato II was recorded by treatment T_5 (MC+ STBR) and T_4 (VC + STBR), respectively.

4.4.3.4.3 Organic N

Organic N content in the initial soils were almost uniform, but varied significantly in the post-harvest soil (Table 144). Organic N content of the post harvest soil increased than their initial value for all the treatment except treatment T_9 (absolute control). The organic N content increased gradually after each crop and the highest value recorded by the end of second cropping sequence. But for absolute control, it decreased after each crop and the lowest value (762.40 mg kg^{-1}) was recorded after amaranthus II. After the first crop of tomato, the highest value (1713.80 mg kg^{-1}) for organic N was recorded for treatment T_5 (MC + STBR) and after third crop, highest value (1900.60 mg kg^{-1}) was for the treatment T_4 (VC + STBR). After the first and second cropping sequence, the highest values were recorded for treatment T_7.

4.4.3.4.4 Total N

Total N of the initial soil did not differed significantly, but differed after the imposition of the treatments (Table 144). There was build up of total N in the soil after each crop and the highest values were recorded at the end of the second cropping sequence. But in absolute control (T_9) there was a decline in total N content after the each crop. Highest value for total N (1904, 2072 and 2224 mg kg^{-1} respectively) was recorded by treatment T_7 (F- TOF + STBR) and followed by T_4 (VC+ STBR) after the first, second and third crop. While after the third crop, the highest value for total N (1989 mg kg^{-1}) was recorded with T_4 followed by T_7. Throughout the cropping sequence the lowest total N content was recorded with absolute control.

Table 143. Effect of organic fertilizer application on NH$_4$-N and NO$_3$-N content of soil under tomato-amaranthus cropping sequence, mg kg^{-1}

Treatments	NH$_4$-N (mg kg^{-1})					NO$_3$-N (mg kg^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII
T$_1$- FYM + NPK $_{POP}$	52.36	61.60^{e}	54.40^{c}	31.20^{e}	46.56^{d}	32.55	44.80^{g}	61.60^{c}	38.60^{d}	56.20^{d}
T$_2$ - FYM + STBR	52.36	67.20^{d}	56.00^{c}	29.30^{e}	47.68^{d}	31.78	49.80^{f}	56.00^{d}	39.20^{d}	58.40^{d}
T$_3$- OC + STBR	50.48	78.40^{b}	56.00^{c}	34.90^{d}	48.80^{d}	31.78	62.70^{d}	61.60^{c}	44.30^{b}	50.80^{e}
T$_4$- VC + STBR	52.36	84.00^{a}	61.60^{b}	39.20^{c}	62.80^{c}	32.55	78.40^{b}	67.20^{b}	49.20^{a}	88.56^{b}
T$_5$- MC+ STBR	50.48	75.20^{b}	67.20^{a}	50.40^{a}	51.60^{d}	32.55	56.00^{e}	72.80^{a}	39.20^{d}	80.80^{b}
T$_6$- TOF + STBR	52.36	70.50^{c}	56.00^{c}	39.20^{c}	74.00^{b}	31.78	70.40^{c}	67.20^{b}	40.60^{c}	75.60^{c}
T$_7$- F-TOF + STBR	51.42	86.60^{a}	61.60^{b}	44.80^{b}	90.80^{a}	31.78	89.60^{a}	56.00^{d}	44.80^{b}	98.20^{a}
T$_8$- F-TOF alone	52.36	56.60^{f}	61.60^{b}	28.00^{e}	62.80^{c}	32.55	39.20^{h}	46.00^{d}	22.40^{e}	36.40^{f}
T$_9$- Absolute control	52.36	44.80^{g}	39.20^{d}	16.80^{f}	12.40^{e}	32.55	28.00^{i}	24.80^{e}	16.80^{f}	12.40^{g}
SEm±		1.65	1.44	1.17	1.68		1.85	1.46	1.32	1.50
CD (0.05)	NS	4.94	4.32	3.52	5.05	NS	5.55	4.37	3.96	4.51

Table 144. Effect of organic fertilizer application on organic N and total N content of soil under tomato-amaranthus cropping sequence, mg kg^{-1}

Treatments	Organic N (mg kg^{-1})					Total N (mg kg^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII
T_1- FYM + NPK $_{POP}$	1020	1349.60^f	1680.00 ^{e}	1545.2 ^{g}	1680.24 ^{g}	1109	1456 ^{f}	1792 ^{e}	1615.00^g	1832.0 ^{g}
T_2 - FYM + STBR	1018	1381.00^e	1652.00 ^{f}	1575.5 ^{f}	1763.12 ^{f}	1109	1498 ^{e}	1764 ^{f}	1644.00^f	1944.0 ^{f}
T_3- OC + STBR	1020	1426.90^d	1722.40 ^{d}	1645.8 ^{e}	1912.40 ^{d}	1112	1568 ^{d}	1840 ^{d}	1725.00^e	2072.0 ^{d}
T_4- VC + STBR	1020	1693.60^b	1897.20 ^{b}	1900.6 ^{a}	2010.40 ^{b}	1109	1856 ^{b}	2026 ^{b}	1966.00^a	2156.0 ^{b}
T_5- MC+ STBR	1018	1713.80^a	1764.00 ^{c}	1806.4 ^{c}	1920.8 ^{d}	1112	1845 ^{b}	1904 ^{c}	1896.00^c	2083.2 ^{d}
T_6- TOF + STBR	1020	1671.10^c	1892.80 ^{b}	1776.2 ^{d}	1938.40^c	1108	1812 ^{c}	2016 ^{b}	1856.00^d	2112.0 ^{c}
T_7- F-TOF + STBR	1018	1727.80^a	1954.40 ^{a}	1876.4 ^{b}	2044.80 ^{a}	1109	1904 ^{a}	2072 ^{a}	1986.00^a	2224.0 ^{a}
T_8- F-TOF alone	1020	1304.20^g	1898.40 ^{b}	1472.6 ^{h}	1868.80 ^{e}	1112	1400 ^{g}	2016 ^{b}	1523.00^h	2020.0 ^{e}
T_9- Absolute control	1020	991.20 ^{h}	872.00 ^{g}	821.4 ^{i}	762.40 ^{h}	1112	1064 ^{h}	1456 ^{g}	855.00^i	1192.0 ^{h}
SEm±	-	6.14	3.10	5.07	3.92	-	6.53	3.34	5.85	4.39
CD (0.05)	NS	18.43	9.29	15.22	11.75	NS	19.59	10.03	17.55	13.17

4.4.3.4.4 Total N

Total N of the initial soil did not differed significantly, but differed after the imposition of the treatments (Table 144). There was build up of total N in the soil after each crop and the highest values were recorded at the end of the second cropping sequence. But in absolute control (T_9) there was a decline in total N content after the each crop. Highest value for total N (1904, 2072 and 2224 mg kg^{-1} respectively) was recorded by treatment T_7 (F- TOF + STBR) and followed by T_4 (VC+ STBR) after the first, second and third crop. While after the third crop, the highest value for total N (1989 mg kg^{-1}) was recorded with T_4 followed by T_7. Throughout the cropping sequence the lowest total N content was recorded with absolute control.

4.4.3.5 SOIL AVAILABLE NUTRIENTS AND HEAVY METALS

4.4.3.5.1 Available P

Available P in the initial soil did not differ significantly. But for the post harvest soil, there was significant difference between the treatments (Table 145). For all treatments that received organic fertilizer recorded a higher value for available P than their initial value. While, for absolute control the value declined than their initial value after each crop and lowest value (60.42 kg ha^{-1}) was recorded at the end of second cropping sequence. In the post harvest soil, the highest value for available P was recorded with treatment T_4 (VC + STBR) followed by T_5 (MC+ STBR). For the treatment T_8 (F- TOF alone) the available P content decreased than its initial after the 4th crop (amaranthus II).

4.4.3.5.2 Available K

Available K of initial soil was almost uniform and did not differ significantly. But the available K of post harvest soil differed significantly among the treatments (Table 145). In the post harvest soil of all the four crops, the highest value

Table 145. Effect of organic fertilizer application on available P and K of soil under tomato-amaranthus cropping sequence, kg ha^{-1}

Treatments	Available P (kg ha^{-1})					Available K (kg ha^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II
T$_1$- FYM + NPK $_{POP}$	85.49	112.50^{c}	97.53 ^{b}	106.74 ^{b}	104.61 ^{c}	386	332 ^{e}	88.80 ^{e}	112 ^{e}	173.60 ^{e}
T$_2$ - FYM + STBR	84.99	111.83^{c}	97.80 ^{b}	106.01 ^{b}	105.00 ^{c}	387	327 ^{e}	84.00 ^{e}	100.8 ^{f}	168.00 ^{e}
T$_3$- OC + STBR	85.66	122.47^{b}	96.04 ^{b}	105.17 ^{b}	98.18 ^{d}	388	372 ^{d}	89.60 ^{e}	100.8 ^{f}	229.60 ^{c}
T$_4$- VC + STBR	85.34	134.29 ^{a}	104.50 ^{a}	116.98 ^{a}	120.85 ^{a}	390	424 ^{c}	106.40 ^{c}	123.2 ^{d}	246.40 ^{b}
T$_5$- MC+ STBR	86.24	125.83^{b}	101.81 ^{a}	109.09 ^{b}	107.97 ^{b}	386	428 ^{c}	117.60 ^{b}	179.2 ^{b}	201.60 ^{d}
T$_6$- TOF + STBR	85..66	111.89^{c}	87.14 ^{g}	88.09^{c}	87.86 ^{e}	388	456 ^{b}	126.00 ^{a}	179.2 ^{b}	218.40 ^{c}
T$_7$- F-TOF + STBR	84.79	122.64 ^{b}	94.86 ^{b}	95.09^{c}	89.90 ^{e}	385	596 ^{a}	132.40 ^{a}	201.6 ^{a}	280.00 ^{a}
T$_8$- F-TOF alone	85.66	99.40^{d}	99.90 ^{a}	80.42^{d}	68.21 ^{f}	389	256 ^{f}	95.60 ^{d}	168 ^{c}	151.20 ^{h}
T$_9$- Absolute control	85.66	81.76^{e}	78.56 ^{c}	76.89^{d}	60.42 ^{g}	390	164 ^{g}	74.40 ^{f}	67.2 ^{g}	57.20 ^{f}
SEm±	-	1.21	1.57	2.43	0.76	-	2.36	2.21	1.44	5.40
CD (0.05)	NS	3.64	4.71	7.29	2.28	NS	7.08	6.62	4.33	16.19

Table 146. Effect of organic fertilizer application on available Ca and Mg of soil under tomato-amaranthus cropping sequence, mg kg^{-1}

	Available Ca (mg kg^{-1})					Available Mg (mg kg^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II
T_1- FYM + NPK $_{POP}$	506	600^{c}	290^{e}	390^{g}	330^{f}	63	69^{ef}	147^{c}	72^{e}	102^{e}
T_2 - FYM + STBR	509	595^{c}	290^{e}	415^{f}	330^{f}	63	66^{f}	144^{c}	75^{c}	104^{e}
T_3- OC + STBR	505	600^{c}	295^{de}	545^{e}	340^{e}	63	78^{cd}	168^{a}	81^{c}	108^{d}
T_4- VC + STBR	506	590^{c}	300^{cd}	630^{b}	360^{d}	63	144^{a}	174^{a}	93^{b}	132^{b}
T_5- MC+ STBR	505	580^{d}	305^{bc}	570^{d}	320^{g}	64	81^{b}c	154^{b}	90^{b}	114^{c}
T_6- TOF + STBR	509	700^{b}	310^{ab}	590^{c}	480^{b}	65	75^{cde}	150^{b}	90^{b}	128^{b}
T_7- F-TOF + STBR	505	795^{a}	315^{a}	650^{a}	500^{a}	65	87^{b}	156^{b}	111^{a}	144^{a}
T_8- F-TOF alone	508	570^{d}	270^{f}	345^{h}	420^{c}	65	78^{cd}	150 b	81^{c}	84^{f}
T_9- Absolute control	506	485^{e}	135^{g}	295^{i}	140^{h}	65	62^{def}	60^{d}	59^{f}	55^{g}
SEm±	-	5.24	2.13	3.34	2.24	-	2.13	2.88	2.58	1.74
CD (0.05)	NS	15.73	6.38	10.03	6.72	NS	6.38	8.65	7.73	5.23

for available K was recorded by the treatment T_7 (F-TOF + STBR) and lowest with absolute control (T_9). Available K in the post harvest soil after the first crop of tomato was higher than the initial value for all the treatments, except for T_8 (F-TOF alone) and T_9. For the absolute control the available K decreased after each crop and lowest was recorded after amaranthus II.

4.4.3.5.3 Available Ca

Available Ca in the initial soil did not differed significantly. But in the post harvest soil, the available Ca varied significantly among the treatments (Table 146). For both the cropping sequences, the highest value was recorded with treatment T_7 (F- TOF + STBR) and the lowest value with absolute control (T_9). After the first crop of tomato, available Ca in the soil increased than the initial values, and then decreased after the second crop amaranthus. The trend was same in the second cropping sequence also.

4.4.3.5.4 Available Mg

Available Mg of post harvest soil varied significantly among the treatments (Table 146). In the post harvest soil of both the-cropping sequences, the available Mg was higher than their initial value, except for absolute control. Available Mg in the soil slightly increased after the first crop of tomato and noticeably increased after the second crop for all treatments that received organic fertilizers. The trend was same for second cropping sequence also. In the absolute control the available Mg decreased after each crop and lowest was recorded at the end of second cropping sequences. The highest value for available Mg (144 and 174 mg kg^{-1}) was recorded by the treatment T_4 (VC + STBR) after the first cropping sequence and for the second cropping sequence, the highest value (111 and 144 mg kg^{-1}, respectively) was recorded by the treatment T_7 (F-TOF + STBR).

4.4.3.5.5 Available S

Available S of initial soil did not differ significantly (Table 147). But there was significant difference in the post harvest soil of different treatments. In the absolute control, there was drastic reduction in the available S of the soil after the harvest of each crop and the lowest value was recorded with absolute control. After the first crop of tomato, the highest value (27.25 mg kg^{-1}) was recorded with treatment T_4 (VC + STBR) followed by T_5 (MC +STBR) and T_7 (F-TOF + STBR) and they were statistically on par with each other. After the second crop, the highest value was recorded with treatment T_5 (17.50 mg kg^{-1}) followed by T_4 and T_7 and they were also on par. In the second cropping sequence, after the harvest of tomato the highest value (11.25 mg kg^{-1}) was recorded with the treatment T_7. It was followed by treatments T_4, T_5 and T_6 and they were on par with each other. By the end of second cropping sequence, the highest value for available S (13.50 mg kg^{-1}) was recorded with treatment T_4 followed by T_7 and T_5.

Table 147. Effect of organic fertilizer application on soil available sulphur under tomato-amaranthus cropping sequence, mg kg^{-1}

Treatments	Available S (mg kg^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II
T_1- FYM + NPK $_{POP}$	10.67	17.75 ^{d}	12.00 ^{c}	6.25 ^{c}	9.50 ^{d}
T_2 - FYM + STBR	10.56	19.75 ^{d}	13.00 ^{c}	6.00 ^{c}	9.00 ^{d}
T_3- OC + STBR	11.56	24.50 ^{c}	15.00 ^{b}	6.00^{c}	11.50 ^{c}
T_4- VC + STBR	11.36	27.25 ^{a}	16.50 ^{a}	7.75 ^{b}	13.50 ^{a}
T_5- MC+ STBR	11.96	26.25 ^{a}	17.50 ^{a}	11.25 ^{a}	12.00 ^{b}
T_6- TOF + STBR	10.99	21.00 ^{b}	15.50 ^{b}	7.50 ^{b}	11.00 ^{c}
T_7- F-TOF + STBR	11.25	25.50 ^{a}	16.00 ^{a}	7.75 ^{b}	12.50 ^{a}
T_8- F-TOF alone	11.85	18.25 ^{d}	10.50 ^{d}	5.75 ^{c}	8.50 ^{d}
T_9- Absolute control	11.25	10.50 ^{e}	7.50 ^{e}	3.25 ^{d}	5.00 ^{e}
SEm±	-	0.88	0.58	0.41	0.37
CD (0.05)	NS	2.64	1.75	1.23	1.12

4.4.3.5.6 Available Fe

All the treatments that received organic fertilizers recorded higher values for available Fe than their initial values and were significantly different (Table 148). For absolute control, the value declined than their initial value after each crop and lowest value (6.09 mg kg^{-1}) was recorded at the end of second cropping sequence. In the post-harvest soil, the highest value for available Fe was recorded by treatment T_3 (OC + STBR) after the first crop (tomato) of the first and second cropping sequences and by treatment T_4 (VC + STBR) after the second crop (amaranthus) of the first and second cropping sequences.

4.4.3.5.7 Available Mn

Available Mn content in the initial soil did not differ significantly. But for the post-harvest soil, there was significant difference between the treatments (Table 148). For all treatments that received organic fertilizers recorded a higher value for available Mn than their initial value. While, for absolute control, the value declined than their initial value after each crop and lowest value (0.98 mg kg^{-1}) was recorded at the end of second cropping sequence. In the post-harvest soil, the highest value for available Mn was recorded by treatment T_4 (VC + STBR) after the first cropping sequence and by treatment T_5 (MC + STBR) at the end of second cropping sequence.

4.4.3.5.8 Available Zn

Available Zn content in the initial soil did not differ significantly. But for the post-harvest soil, there was significant difference between the treatments (Table 149). For all treatments that received organic fertilizers recorded a higher value for available Zn than their initial value. While, for absolute control, the value declined than their initial value after each crop and the lowest value (0.39 mg kg^{-1}) was recorded at the end of second cropping sequence. For both the cropping sequences, the highest value for available Zn was recorded by treatment T_7 (F-TOF + STBR).

Table 148. Effect of organic fertilizer application on available Fe and Mn of soil under tomato-amaranthus cropping sequence, mg kg^{-1}

Treatments	Available Fe (mg kg^{-1})					Available Mn (mg kg^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II
T_1- FYM + NPK_{POP}	6.88	13.86^{bc}	10.36^{bc}	11.52^{c}	10.56^{b}	3.72	4.42^{d}	5.15^{b}	5.27^{bcd}	5.04 bcd
T_2 - FYM + STBR	6.88	13.70^{bc}	10.14^{c}	$12..15^{c}$	10.33^{bc}	3.74	4.82^{b}	5.06^{b}	5.33^{bc}	4.99 cd
T_3- OC + STBR	6.87	16.49^{a}	11.58^{abc}	15.47^{a}	9.45^{d}	3.72	5.29^{a}	4.63^{c}	5.41^{b}	5.25 ab
T_4- VC + STBR	6.84	13.37^{c}	12.52^{a}	13.14^{b}	11.45^{a}	3.74	4.53^{cd}	5.30^{a}	5.87^{a}	5.17 abc
T_5- MC+ STBR	6.86	10.81^{d}	11.64^{ab}	9.75^{d}	9.56^{cd}	3.72	3.76^{e}	3.31^{f}	4.96^{cde}	5.31 a
T_6- TOF + STBR	6.88	14.80^{b}	10.86^{bc}	9.47^{d}	9.12^{d}	3.72	4.30^{d}	4.44^{d}	4.89^{e}	4.79 de
T_7- F-TOF + STBR	6.84	10.25^{d}	11.26^{abc}	9.86^{d}	10.45^{b}	3.76	4.76^{bc}	3.97^{e}	4.94^{de}	4.89 d
T_8- F-TOF alone	6.87	7.34^{e}	7.99^{d}	8.45^{e}	8.11^{e}	3.72	4.78^{bc}	4.50^{d}	4.66^{e}	4.58 e
T_9- Absolute control	6.88	6.82^{e}	6.76^{d}	6.14^{f}	6.09^{f}	3.74	3.65^{e}	2.59^{g}	2.15^{f}	2.09 f
SEm±	-	0.453	0.48	0.227	0.288	-	0.093	0.039	0.102	0.075
CD (0.05)	NS	1.36	1.44	0.682	0.864	NS	0.280	0.118	0.306	0.225

Table 149. Effect of organic fertilizer application on available Zn and Cu of soil under tomato-amaranthus cropping sequence, mg kg^{-1}

Treatments	Available Zn (mg kg^{-1})					Available Cu (mg kg^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II
T$_1$- FYM + NPK $_{POP}$	0.96	1.35^{c}	1.22^{e}	1.18^{ef}	1.21^{e}	2.05	5.32^{c}	2.34^{a}	2.98^{a}	2.45^{c}
T$_2$ - FYM + STBR	0.96	1.83^{b}	1.24^{e}	1.12^{f}	1.15^{f}	2.06	6.91^{a}	1.99^{b}	2.56^{d}	2.74^{b}
T$_3$- OC + STBR	0.95	1.48^{c}	1.49^{c}	1.34^{cd}	1.39^{c}	2.07	2.87^{f}	1.94^{bc}	2.85^{b}	2.45^{c}
T$_4$- VC + STBR	0.95	1.46^{c}	1.68^{b}	1.49^{b}	1.51^{b}	2.06	2.07^{g}	1.96^{b}	2.69^{c}	2.85^{a}
T$_5$- MC+ STBR	0.96	1.36^{c}	1.25^{e}	1.15^{ef}	1.19^{ef}	2.06	1.92^{h}	1.70^{d}	2.55^{d}	2.22^{d}
T$_6$- TOF + STBR	0.96	1.40^{c}	1.50^{c}	1.45^{bc}	1.52^{b}	2.07	3.93^{e}	1.50^{e}	2.21^{f}	1.96^{f}
T$_7$- F-TOF + STBR	0.95	2.89^{a}	1.78^{a}	1.69^{a}	1.71^{a}	2.06	5.58^{b}	1.85^{c}	2.45^{e}	2.10^{e}
T$_8$- F-TOF alone	0.95	1.08^{d}	1.39^{d}	1.24^{de}	1.29^{d}	2.07	4.59^{d}	1.53^{e}	1.89^{g}	1.71^{g}
T$_9$- Absolute control	0.96	0.88^{e}	0.58^{f}	0.45^{g}	0.39^{g}	2.05	1.80^{i}	1.28^{f}	1.14^{h}	0.98^{h}
SEm±	-	0.046	0.029	0.038	0.015	-	0.026	0.033	0.251	0.027
CD (0.05)	NS	0.138	0.086	0.115	0.045	NS	0.079	0.099	0.754	0.081

4.4.3.5.9 Available Cu

Available Cu content in the initial soil did not differ significantly. But for the post-harvest soil, there was significant difference between the treatments (Table 149). For all treatments that received organic fertilizers recorded a higher value for available Cu than their initial value. While, for absolute control, the value declined than their initial value after each crop and the lowest value (2.09 mg kg^{-1}) was recorded at the end of second cropping sequence. In the post-harvest soil, the highest value for available Cu was recorded by treatment T_2 (FYM + NPK $_{POP}$) after the first cropping sequence and by treatment T_4 (VC + STBR) at the end of second cropping sequence.

4.4.3.5.10 Available B

Available B in the initial soil was almost uniform and did not differ significantly (Table 150). But in the post harvest soil, available B significantly varied among the treatments. For both cropping sequences, the highest value for available B (0.396, 0.456, 0.284 and 0.324 mg kg^{-1}) was recorded by the treatment T_7 (F-TOF +STBR) followed by T_4 (VC +STBR) and T_5. For T_7, T_4 and T_5, the trend was similar during the cropping sequence, the available B increased in the first cropping sequence and slightly decreased after second tomato crop and slightly increased after the second amaranthus crop. The lowest value was recorded with the absolute control and it decreased after the harvest of each crop (0.104, 0.040, 0.084 and 0.029 mg kg^{-1}, respectively).

Table 150. Effect of organic fertilizer application on soil available boron under tomato-amaranthus cropping sequence, mg kg^{-1}

Treatments	Available B (mg kg^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII
T_1- FYM + NPK $_{POP}$	0.113	0.108 ^{f}	0.160 ^{g}	0.112^{e}	0.136 ^{f}
T_2 - FYM + STBR	0.113	0.108 ^{f}	0.168 ^{fg}	0.112^{e}	0.128 ^{g}
T_3- OC + STBR	0.113	0.186 ^{d}	0.216 ^{e}	0.192 ^{c}	0.198 ^{d}
T_4- VC + STBR	0.112	0.286 ^{b}	0.328 ^{b}	0.228 ^{b}	0.220 ^{b}
T_5- MC+ STBR	0.110	0.216 ^{c}	0.264 ^{c}	0.196 ^{c}	0.206 ^{c}
T_6- TOF + STBR	0.113	0.140 ^{e}	0.240 ^{d}	0.122 ^{d}	0.198 ^{d}
T_7- F-TOF + STBR	0112	0.396 ^{a}	0.456 ^{a}	0.284 ^{a}	0.324 ^{a}
T_8- F-TOF alone	0.112	0.296 ^{b}	0.184 ^{f}	0.234 ^{b}	0.179 ^{e}
T_9- Absolute control	0.112	0.104 ^{g}	0.040 ^{h}	0.084 ^{h}	0.029 ^{h}
SEm±	-	0.005	0.008	0.005	0.002
CD (0.05)	`NS	0.016	0.023	0.014	0.005

4.4.3.5.11 Heavy metals - Cd and Pb

Among the heavy metals Cd and Pb, available Cd was not detected in soil and hence data on available Pb alone is presented. For both the cropping sequences, the availability of Pb was detected in the post-harvest soil (Table 151). But the amount was trace and did not vary significantly among the treatments.

Table 151. Effect of organic fertilizer application on available Pb of soil under tomato-amaranthus cropping sequence

Treatments	Available Pb (mg kg^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II
T_1- FYM + NPK $_{POP}$	0.007	0.022	0.012	0.028	0.010
T_2 - FYM + STBR	0.007	0.025	0.018	0.034	0.015
T_3- OC + STBR	0.007	0.021	0.017	0.031	0.013
T_4- VC + STBR	0.007	0.024	0.014	0.026	0.009
T_5- MC+ STBR	0.007	0.020	0.010	0.021	0.006
T_6- TOF + STBR	0.007	0.045	0.021	0.049	0.015
T_7- F-TOF + STBR	0.007	0.059	0.033	0.062	0.017
T_8- F-TOF alone	0.007	0.049	0.028	0.051	0.010
T_9- Absolute control	0.007	0.006	0.005	0.005	0.004
SEm±	-	-	-	-	-
CD (0.05)	NS	NS	NS	NS	NS

4.4.3.6 BIOLOGICAL PROPERTIES OF SOIL

4.4.3.6.1 Bacteria

Bacterial population in the initial soil did not differ significantly. But the bacterial population in the post harvest soil differed significantly among the treatments (Table 152). After the first crop of tomato, highest bacterial population was recorded with treatment T_7 followed by T_4, T_3 and T_6 and they were on par with each other. After the second crop of amaranthus, highest value for bacterial population in post harvest soil was recorded by treatment T_7 (F-TOF + STBR) followed by T_6 and T_3. In the second cropping sequence, after the tomato, the highest value was recorded with treatment T_5 followed by T_4. In the end of the second cropping season, the highest bacterial population was recorded with T_4 (6.41 log cfu g^{-1}) followed by T_7. The lowest population was recorded with absolute control (T_9) and it declined after the harvest of each crop.

4.4.3.6.2 Fungi

Fungal population of initial soil did not differ significantly, but varied significantly in the post-harvest soil (Table 152). In the first cropping sequence, the highest fungal population was recorded with treatment T_5 (MC + STBR) followed by T_4. In the second cropping sequence, the highest value was recorded with T_4 followed by T_7. The lowest fungal population was recorded with the absolute control (T_9), where it declined after each crop.

Table 152. Effect of organic fertilizer application on bacterial and fungal population of soil under tomato-amaranthus cropping sequence

Treatments	Microbial count (log cfu g^{-1})									
	Bacteria					Fungus				
	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II	Initial	Tomato I	Amaranthus I	Tomato II	Amaranthus II
T$_1$- FYM + NPK $_{POP}$	5.87	5.98^{b}	5.94^{f}	6.10^{f}	6.00^{g}	3.13	3.41^{f}	2.05^{f}	4.11^{f}	2.93^{e}
T$_2$ - FYM + STBR	5.88	5.95^{bc}	5.93^{g}	6.11^{e}	6.04^{f}	3.14	3.42^{e}	1.98^{h}	4.19^{e}	3.04^{cd}
T$_3$- OC + STBR	5.87	6.18^{a}	6.09^{c}	6.32^{c}	6.18^{c}	3.12	3.50^{c}	2.04^{g}	4.04^{g}	3.04^{cd}
T$_4$- VC + STBR	5.87	6.19^{a}	6.04^{d}	6.45^{b}	6.41^{a}	3.13	3.61^{b}	2.41^{b}	4.28^{a}	3.14^{a}
T$_5$- MC+ STBR	5.88	5.90^{c}	6.04^{d}	6.46^{a}	6.13^{e}	3.12	3.66^{a}	2.44^{a}	4.24^{c}	3.06^{bc}
T$_6$- TOF + STBR	5.87	6.18^{a}	6.25^{b}	6.32^{c}	6.15^{d}	3.13	3.45^{d}	2.35^{c}	4.24^{c}	3.02^{d}
T$_7$- F-TOF + STBR	5.88	6.20^{a}	6.29^{a}	6.25^{d}	6.27^{b}	3.12	3.45^{d}	2.25^{d}	4.26^{b}	3.07^{b}
T$_8$- F-TOF alone	5.87	5.95^{bc}	5.98^{e}	6.10^{f}	6.01^{g}	3.14	3.45^{d}	2.16^{e}	4.23^{d}	3.02^{d}
T$_9$- Absolute control	5.87	5.89^{d}	5.84^{h}	5.65^{e}	5.54^{h}	3.13	3.12^{g}	1.95^{i}	3.69^{h}	2.39^{f}
SEm±	-	0.026	0.002	0.002	0.005		0.002	0.003	0.002	0.008
CD (0.05)	NS	0.079	0.005	0.007	0.016	NS	0.007	0.008	0.006	0.023

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4.4.3.6.3 Actinomycetes

Population of actinomycetes in the initial soil did not differ significantly, but differed significantly in the post harvest soil between the treatments (Table 153). The highest actinomycetes population was recorded by the treatment T$_5$ (MC + STBR) after the tomato I and II. After the amaranthus I, highest value (1.54 log cfu g^{-1}) was recorded by treatment T$_4$ (VC + STBR). At the end of the second cropping sequence all the treatments except absolute control, were statistically on par with each other for actinomycetes population. The lowest value was recorded by absolute control and the population decreased after each crop.

Table 153. Effect of organic fertilizer application on actinomycetes population of soil under tomato-amaranthus cropping sequences

Treatments	Microbial count (log cfu g^{-1})				
	Actinomycetes				
	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII
T$_1$- FYM + NPK$_{POP}$	2.02	2.74^{f}	1.15^{d}	2.39^{e}	4.06^{a}
T$_2$ - FYM + STBR	2.02	2.72^{g}	1.15^{d}	2.39^{e}	4.04^{a}
T$_3$- OC + STBR	2.02	3.18^{b}	1.24^{c}	2.60^{b}	3.87^{a}
T$_4$- VC + STBR	2.01	3.14^{c}	1.54^{a}	2.54^{c}	4.00^{a}
T$_5$- MC+ STBR	2.01	3.30^{a}	1.39^{b}	2.65^{a}	3.98^{a}
T$_6$- TOF + STBR	2.00	2.77^{e}	1.00^{e}	2.48^{d}	3.95^{a}
T$_7$- F-TOF + STBR	2.02	2.84^{d}	1.15^{d}	2.54^{c}	4.14^{a}
T$_8$- F-TOF alone	2.01	2.65^{h}	1.15^{d}	2.30^{f}	4.02^{a}
T$_9$- Absolute control	2.00	2.15^{i}	1.00^{e}	2.00^{g}	3.00^{b}
SEm±	-	0.001	0.002	0.003	0.101
CD (0.05)	NS	0.004	0.005	0.008	0.302

4.4.3.6.4 Dehydrogenase activity

Dehydrogenase activity in the initial soil did not differ significantly, but varied significantly in the post-harvest soil (Table 154). After the first crop of tomato, the highest value for dehydrogenase activity (42.23 µg TPF g^{-1} soil 24 hr^{-1}) was recorded by the treatment T$_7$ (F-TOF + STBR) followed by T$_4$ (VC + STBR) and T$_8$

(F-TOF alone). After amaranthus crop of first cropping sequence highest value for dehydrogenase activity was recorded with the treatment T_4 (54.75 µg TPF g^{-1} soil 24 hr^{-1}) followed by treatment T_5 and they were statistically on par with each other. The treatments such as T_1 (FYM + NPK_{POP}), T_2 (FYM +STBR), T_3 (OC + STBR) and T_7 were on par with each other for their dehydrogenase activity. In the second cropping sequence after harvest of tomato, the highest value was recorded by treatment T_4 (50.69 µg TPF g^{-1} soil 24 hr^{-1}) followed by T_7, and they were statistically on par with each other. At the end of the second cropping sequence, the highest value was recorded with treatments T_7 (65.23 µg TPF g^{-1} soil 24 hr^{-1}) and treatments T_6 and T_8 were on par with T_7.

Table 154. Effect of organic fertilizer application on dehydrogenase activity of soil under tomato-amaranthus cropping sequence, µg TPF g^{-1} soil 24 hr^{-1}

Treatments	Dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1})				
	Initial	Tomato I	Amaranthus I	Tomato II	AmaranthusII
T_1- FYM + NPK_{POP}	22.36	34.55 ^{cd}	49.89 ^{bc}	47.89^{c}	50.67 ^{c}
T_2 - FYM + STBR	22.78	36.08 ^{bcd}	49.26 ^{bc}	48.21^{c}	55.47 ^{b}
T_3- OC + STBR	22.66	36.66 ^{bcd}	49.96 ^{bc}	49.52 ^{b}	55.47 ^{b}
T_4- VC + STBR	22.41	37.43 ^{b}	54.75 ^{a}	50.69 ^{a}	56.43 ^{b}
T_5- MC+ STBR	22.75	34.17 ^{d}	52.62 ^{ab}	49.56 ^{b}	53.74 ^{bc}
T_6- TOF + STBR	22.33	36.28 ^{bcd}	49.39 ^{c}	48.29 ^{c}	63.72 ^{a}
T_7- F-TOF + STBR	22.47	42.23 ^{a}	50.66 ^{bc}	49.96 ^{ab}	65.23 ^{a}
T_8- F-TOF alone	22.80	37.24 ^{bc}	42.45 ^{d}	39.55^{d}	61.26 ^{a}
T_9- Absolute control	22.46	23.42 ^{e}	16.28 ^{e}	18.08^{e}	14.34 ^{d}
SEm±	-	0.910	1.137	0.304	1.400
CD (0.05)	NS	2.73	3.41	0.913	4.20

4.4.3.7 CARBON STOCK OF THE SOIL OF TOMATO-AMARANTHUS CROPPING SEQUENCE

Carbon stock of post-harvest soil at a depth of 0-15 cm differed significantly among the treatments, though there was no significant difference initially (Table 155). The carbon stock in the post-harvest soil increased than the initial value and throughout the cropping sequence, the highest value was recorded by the treatment T_7 (F-TOF + STBR) followed by T_6 (TOF + STBR) and T_8 (F-TOF alone) and they were statistically on par with each other. The lowest value for carbon stock of post-harvest soil at a depth of 0-15 cm was recorded with the absolute control (T_9) and it decreased after the each crop and the lowest value was recorded at the end of second cropping sequence. But application of organic fertilizers has increased the carbon stock of the soil after each crop.

Carbon stock at the depth 15-30 cm depth did not differ significantly for the treatments received different organic fertilizers (Table 156). Though, the increase in carbon stock was very low compared to 0-15 cm depth, it also followed the same trend. The highest carbon stock in the post-harvest soil at a depth of 15-30 cm was recorded with the treatments T_6, T_7 and T_8 where thermochemical organic fertilizers was used as soil amendments. The lowest value for carbon stock at 15-30 cm was recorded with absolute control and it decreased after the each crop and the lowest value was recorded at the end of the second cropping sequence.

Table 155. Effect of organic fertilizer application on soil carbon stock at 0-15 cm depth under tomato - amaranthus cropping sequence, Mg ha^{-1}

Treatments	Carbon stock at 0-15 cm depth (Mg ha^{-1})				
	Initial	After harvest			
		Cropping sequence 1		Cropping sequence 2	
		Tomato-I	Amaranthus-I	Tomato-II	Amaranthus-II
T_1- FYM + NPK $_{POP}$	24.94	24.95 ^{c}	24.99 ^{d}	25.08 ^{c}	25.15 ^{c}
T_2 - FYM + STBR	24.94	25.11 ^{bc}	25.08 ^{d}	25.14 ^{c}	25.18 ^{c}
T_3- OC + STBR	24.94	25.54 ^{b}	25.74 ^{c}	26.11 ^{b}	26.25 ^{b}
T_4- VC + STBR	24.94	25.62 ^{b}	25.78 ^{c}	26.20 ^{b}	26.31 ^{b}
T_5- MC+ STBR	24.94	25.58 ^{b}	25.65 ^{c}	25.83 ^{b}	25.97 ^{b}
T_6- TOF + STBR	24.94	26.65 ^{a}	26.94 ^{a}	27.32 ^{a}	27.44 ^{a}
T_7- F-TOF + STBR	24.94	26.66 ^{a}	26.96 ^{a}	27.38 ^{a}	27.49 ^{a}
T_8- F-TOF alone	24.94	26.60 ^{a}	26.90 ^{b}	27.29 ^{a}	27.40 ^{a}
T_9- Absolute control	24.94	24.88 ^{c}	24.42 ^{c}	23.82 ^{d}	23.45 ^{d}
SEm±	-	0.16	0.18	0.21	0.25
CD (0.05)	NS	0.50	0.54	0.64	0.75

Table 156. Effect of organic fertilizer application on soil carbon stock at 15-30 cm depth under tomato - amaranthus cropping sequence, Mg ha^{-1}

Treatments	Carbon stock at 15-30 cm cm depth (Mg ha^{-1})				
	Initial	After harvest			
		Cropping sequence 1		Cropping sequence 2	
		Tomato-I	Amaranthus-I	Tomato-II	Amaranthus-II
T_1- FYM + NPK $_{POP}$	11.40	11.43 ^{a}	11.45 ^{a}	11.47 ^{a}	11.49 ^{a}
T_2 - FYM + STBR	11.41	11.43 ^{a}	11.45 ^{a}	11.47 ^{a}	11.49 ^{a}
T_3- OC + STBR	11.42	11.47 ^{a}	11.48 ^{a}	11.50 ^{a}	11.51 ^{a}
T_4- VC + STBR	11.40	11.51 ^{a}	11.53 ^{a}	11.56 ^{a}	11.58 ^{a}
T_5- MC+ STBR	11.41	11.50 ^{a}	11.51 ^{a}	11.53 ^{a}	11.56 ^{a}
T_6- TOF + STBR	11.42	11.54 ^{a}	11.56 ^{a}	11.58 ^{a}	11.60 ^{a}
T_7- F-TOF + STBR	11.40	11.55 ^{a}	11.56 ^{a}	11.59 ^{a}	11.60 ^{a}
T_8- F-TOF alone	11.40	11.53 ^{a}	11.55 ^{a}	11.56 ^{a}	11.59 ^{a}
T_9- Absolute control	11.41	11.39 ^{b}	11.36 ^{b}	11.35 ^{b}	11.32 ^{b}
SEm±	-	0.036	0.043	0.033	0.036
CD (0.05)	NS	0.11	0.13	0.010	0.11

4.5 CORRELATION STUDIES

4.5.1 Correlation between the growth and yield of crops with soil properties

The correlation between the yield and dry matter production of tomato and amaranthus with different soil properties were more significant during the second cropping sequence. The data on Tomato II and amaranthus II are presented in tables 157 to 161

The yield and dry matter production of tomato during the second cropping sequence were significantly and positively correlated with WSOC, MBC, TOC, labile carbon and total N content of soil (Table 157). The correlation with WSOC and MBC were significant at 1 % level.

Table 157. Correlation matrix for yield of tomato with soil carbon pools and nitrogen

	TOC	WSOC	LC	MBC	ROC	TOTAL N	DMP	Yield
TOC	1.000							
WSOC	0.714*	1.000						
LC	0.936**	0.776*	1.000					
MBC	0.805**	0.892**	0.856**	1.000				
ROC	0.929**	0.793*	0.866**	0.812**	1.000			
TOTAL N	0.960**	0.818**	0.930**	0.837**	0.947*	1.000		
DMP	0.719*	0.848**	0.778*	0.957**	0.662^{NS}	0.758*	1.000	
yield	0.719*	0.848**	0.778*	0.957**	0.662^{NS}	0.758*	1.000	1.000

** = Significant at 1% level * = Significant at 5% level

The yield and DMP of amaranthus were significantly and positively correlated with labile carbon, MBC, TOC, WSOC, ROC and total N of soil (Table 158). The correlation with labile carbon, MBC and total N were significant at 1 % level.

Table 158.Correlation matrix for yield of amaranthus with soil carbon pools and nitrogen

	TOC	WSOC	LC	MBC	ROC	TOTAL N	DMP	Yield
TOC	1.000							
WSOC	0.773*	1.000						
LC	0.938**	0.886**	1.000					
MBC	0.923**	0.917**	0.988**	1.000				
ROC	0.988**	0.829**	0.966**	0.962**	1.000			
TOTAL N	0.843**	0.883**	0.953**	0.970**	0.896**	1.000		
DMP	0.689*	0.668*	0.799**	0.806**	0.744*	0.887**	1.000	
YIELD	0.683*	0.789*	0.804**	0.824**	0.713*	0.923**	0.877**	1.000

** = Significant at 1% level * = Significant at 5% level

The correlation matrix presented in Table 159 revealed that yield of tomato and dry matter production of tomato were significantly and positively correlated with soil available Ca, Mg, S, Fe, Zn and B.

The correlation matrix presented in Table 160 revealed that yield and dry matter production of amaranthus were significantly and positively correlated with soil available Ca, Mg, S, Mn, Zn and B. Ca, Mg and Zn showed significant correlation at 1 % level.

Table 159. Correlation analysis between yield of tomato and available nutrients in soil

	Av P	Av K	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Zn	Av Cu	Av B	DMP	Yield
Av P	1.000											
Av K	0.221^{NS}	1.000										
Av Ca	0.714*	0.654^{NS}	1.000									
Av Mg	0.824**	0.514^{NS}	0.945**	1.000								
Av S	0.576^{NS}	0.758*	0.839**	0.795**	1.000							
Av Fe	0.622^{NS}	0.579^{NS}	0.830**	0.829**	0.945**	1.000						
Av Mn	0.617^{NS}	-0.005^{NS}	0.638^{NS}	0.719*	0.297	0.494^{NS}	1.000					
Av Zn	0.613^{NS}	0.708*	0.870**	0.895**	0.765*	0.759*	0.593^{NS}	1.000				
Av Cu	0.614^{NS}	-0.054^{NS}	0.569^{NS}	0.585^{NS}	0.345^{NS}	0.581^{NS}	0.734*	0.401^{NS}	1.000			
Av B	0.483^{NS}	0.845**	0.722*	0.682*	0.794*	0.724*	0.233^{NS}	0.880**	0.268^{NS}	1.000		
DMP	0.637^{NS}	0.658^{NS}	0.965**	0.900**	0.898**	0.923**	0.625^{NS}	0.854**	0.607^{NS}	0.751*	1.000	
Yield	0.634^{NS}	0.659^{NS}	0.964**	0.898**	0.899**	0.925**	0.623^{NS}	0.853**	0.606^{NS}	0.752*	1.000	1.000

Av = Available ** = Significant at 1% level * = Significant at 5% level

Table 160. Correlation analysis between yield of amaranthus and available nutrients in soil

	Av P	Av K	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Zn	Av Cu	Av B	DMP	Yield
Av P	1.000											
Av K	-0.047^{NS}	1.000										
Av Ca	0.524^{NS}	0.582^{NS}	1.000									
Av Mg	0.294^{NS}	0.828**	0.877**	1.000								
Av S	0.559^{NS}	0.693*	0.713*	0.678*	1.000							
Av Fe	0.785*	-0.175^{NS}	0.447^{NS}	0.214^{NS}	0.201^{NS}	1.000						
Av Mn	0.777*	0.337^{NS}	0.601^{NS}	0.551^{NS}	0.558^{NS}	0.797*	1.000					
Av Zn	0.422^{NS}	0.686*	0.804**	0.883**	0.543^{NS}	0.511^{NS}	0.808**	1.000				
Av Cu	0.925**	-0.004^{NS}	0.497^{NS}	0.335^{NS}	0.430^{NS}	0.859**	0.903**	0.571^{NS}	1.000			
Av B	0.184^{NS}	0.645^{NS}	0.584^{NS}	0.810**	0.456^{NS}	0.200^{NS}	0.427^{NS}	0.700*	0.200^{NS}	1.000		
DMP	0.541^{NS}	0.705^{NS}	0.906**	0.944**	0.792*	0.308^{NS}	0.711*	0.808**	0.503^{NS}	0.729*	1.000	
Yield	0.662^{NS}	0.536^{NS}	0.957**	0.805**	0.770*	0.565^{NS}	0.729*	0.805**	0.651^{NS}	0.724*	0.877**	1.000

Av = Available ** = Significant at 1% level * = Significant at 5% level

4.5.2 Relationship between nutrient uptake and soil characteristics

Labile carbon, WSOC, MBC and total N content of the soil were significantly and positively correlated to the uptake of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B (Table 161). For TOC the correlation with Mn, Cu, and B were not significant while ROC was significantly and positively correlated to almost all the nutrients.

Table 161. Correlation matrix for nutrient uptake of tomato with soil carbon and nitrogen

	TOC	WSOC	LC	MBC	ROC	Total N
N	0.737*	0.887**	0.909**	0.920**	0.815**	0.966**
P	0.744*	0.893**	0.912**	0.915**	0.819**	0.955**
K	0.791*	0.878**	0.912**	0.926**	0.851**	0.976**
Ca	0.759*	0.757*	0.872**	0.864**	0.804**	0.937**
Mg	0.807**	0.856**	0.921**	0.919**	0.864**	0.962**
S	0.691*	0.861**	0.884**	0.887**	0.771*	0.945**
Fe	0.703*	0.740*	0.809**	0.844**	0.751*	0.939**
Mn	0.584 ^{NS}	0.865**	0.805**	0.839**	0.682*	0.914**
Zn	0.773*	0.857**	0.890**	0.908**	0.843**	0.957**
Cu	0.649 ^{NS}	0.878**	0.835**	0.862**	0.740*	0.929**
B	0.697^{NS}	0.872**	0.872**	0.892**	0.777*	0.958**

** = Significant at 1% level * = Significant at 5% level

Labile carbon, MBC and total N content of the soil were significantly and positively correlated to the uptake of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B while WSOC was significantly and positively correlated to the uptake of K, S, Fe, Mn, Zn, Cu and B only (Table 162).

Table 162. Correlation matrix for nutrient uptake of amaranthus with soil carbon and nitrogen

	TOC	WSOC	LC	MBC	ROC	Total N
N	0.694 *	0.656 ^{NS}	0.696*	0.757*	0.693*	0.856**
P	0.688 *	0.644 ^{NS}	0.691*	0.758*	0.678*	0.857**
K	0.697*	0.672*	0.693*	0.764*	0.660 ^{NS}	0.864**
Ca	0.681 *	0.646 ^{NS}	0.691*	0.755*	0.688*	0.855**
Mg	0.683 *	0.654 ^{NS}	0.712*	0.775*	0.706*	0.869**
S	0.671 *	0.676*	0.732*	0.791*	0.697*	0.890**
Fe	0.701*	0.773*	0.783*	0.844**	0.764*	0.899**
Mn	0.548 ^{NS}	0.810**	0.701*	0.778*	0.628 ^{NS}	0.859**
Zn	0.698*	0.708*	0.668*	0.747*	0.623 ^{NS}	0.826**
Cu	0.691*	0.827**	0.803**	0.866**	0.761*	0.915**
B	0.682 *	0.717*	0.771*	0.822**	0.746*	0.891**

** = Significant at 1% level * = Significant at 5% level

Table 163. Correlation analysis between nutrient uptake by tomato and available nutrients in soil

	Av P	Av K	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Zn	Av Cu	Av B
N	0.669*	0.637 ^{NS}	0.954**	0.907**	0.904**	0.941**	0.619 ^{NS}	0.862**	0.642 ^{NS}	0.777*
P	0.632 ^{NS}	0.624 ^{NS}	0.956**	0.904**	0.882**	0.926**	0.655 ^{NS}	0.863**	0.637 ^{NS}	0.748*
K	0.568 ^{NS}	0.758*	0.928**	0.871**	0.927**	0.930**	0.528 ^{NS}	0.903**	0.508 ^{NS}	0.852**
Ca	0.439 ^{NS}	0.813**	0.893**	0.775*	0.929**	0.880**	0.360 ^{NS}	0.820**	0.402 ^{NS}	0.829**
Mg	0.545 ^{NS}	0.750*	0.942**	0.859**	0.874**	0.880**	0.593 ^{NS}	0.890**	0.522 ^{NS}	0.807**
S	0.634 ^{NS}	0.606 ^{NS}	0.943**	0.881**	0.898**	0.942**	0.613 ^{NS}	0.816**	0.657 ^{NS}	0.729*
Fe	0.555 ^{NS}	0.844**	0.818**	0.742*	0.960**	0.890**	0.295 ^{NS}	0.785*	0.313 ^{NS}	0.864**
Mn	0.698*	0.523 ^{NS}	0.874**	0.855**	0.887**	0.966**	0.640 ^{NS}	0.772*	0.691 ^{NS}	0.704*
Zn	0.563 ^{NS}	0.733*	0.913**	0.847**	0.874**	0.896**	0.584 ^{NS}	0.906**	0.552 ^{NS}	0.858**
Cu	0.621 ^{NS}	0.592 ^{NS}	0.889**	0.852**	0.879**	0.952**	0.649 ^{NS}	0.833**	0.659 ^{NS}	0.759*
B	0.622 ^{NS}	0.655 ^{NS}	0.917**	0.869**	0.926**	0.963**	0.565 ^{NS}	0.849**	0.612 ^{NS}	0.800**

Av = Available ** = Significant at 1% level * = Significant at 5% level

Table 164. Correlation analysis between nutrient uptake by amaranthus and available nutrients in soil

	Av P	Av K	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Zn	Av Cu	Av B
N	0.515 ^{NS}	0.656 ^{NS}	0.942**	0.922**	0.751*	0.281 ^{NS}	0.558 ^{NS}	0.781*	0.470 ^{NS}	0.655 ^{NS}
P	0.570 ^{NS}	0.638 ^{NS}	0.918**	0.913**	0.778*	0.311 ^{NS}	0.577 ^{NS}	0.761*	0.508 ^{NS}	0.687*
K	0.634 ^{NS}	0.600 ^{NS}	0.916**	0.880**	0.814**	0.364 ^{NS}	0.609 ^{NS}	0.739*	0.550 ^{NS}	0.681*
Ca	0.537 ^{NS}	0.648 ^{NS}	0.920**	0.915**	0.751*	0.277 ^{NS}	0.570 ^{NS}	0.775*	0.495 ^{NS}	0.653 ^{NS}
Mg	0.539 ^{NS}	0.669 ^{NS}	0.922**	0.925**	0.780*	0.285 ^{NS}	0.583 ^{NS}	0.778*	0.499 ^{NS}	0.678*
S	0.609 ^{NS}	0.655 ^{NS}	0.927**	0.899**	0.842**	0.341 ^{NS}	0.621 ^{NS}	0.763*	0.540 ^{NS}	0.661 ^{NS}
Fe	0.605 ^{NS}	0.587 ^{NS}	0.935**	0.916**	0.709*	0.520 ^{NS}	0.689*	0.848**	0.592 ^{NS}	0.754*
Mn	0.777 ^{NS}	0.379 ^{NS}	0.916**	0.769*	0.705*	0.643 ^{NS}	0.725*	0.743*	0.713*	0.616 ^{NS}
Zn	0.700 ^{NS}	0.444 ^{NS}	0.887**	0.824**	0.696*	0.554 ^{NS}	0.647	0.729*	0.630 ^{NS}	0.706*
Cu	0.688 ^{NS}	0.533 ^{NS}	0.920**	0.871**	0.724*	0.605 ^{NS}	0.756*	0.845**	0.669 ^{NS}	0.734*
B	0.662 ^{NS}	0.717*	0.771*	0.822**	0.746*	0.891**	0.662 ^{NS}	0.717*	0.771*	0.822**

Av = Available ** = Significant at 1% level * = Significant at 5% level

The nutrient uptake by tomato for all nutrients was significantly and positively correlated with available Ca, Mg, S, Fe, Zn and B in the soil (Table 163).

The correlation matrix presented in Table 164 revealed that uptake of the most of the nutrients by amaranthus was significantly and positively correlated to the availability of Ca, Mg S, Zn and B in the soil.

4.6 SYSTEM PRODUCTIVITY

4.6.1 Tomato equivalent yield

The highest tomato equivalent yield of amaranthus (103.02 t ha^{-1}) was obtained from treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR) and T_5 (MC + STBR). The lowest value was recorded by absolute control.

Tomato equivalent yield of cropping system was highest for treatment T_7 (F-TOF + STBR) and it was statistically on par with treatment T_4 (VC + STBR).

4.6.2 Production efficiency

The highest production efficiency for the cropping sequence was obtained from the treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR) and T_5 (MC + STBR). Treatment T_7 and T_4 were statistically on par with each other.

4.6.3 Equivalent energy

The highest equivalent energy for the cropping sequence was obtained from the treatment T_7 followed by T_4 and T_6 (TOF + STBR). The lowest value was recorded by absolute control.

Table 165. System productivity of tomato - amaranthus cropping sequence

Treatments	System productivity			
	Tomato equivalent yield amaranthus (t ha^{-1})	Tomato equivalent yield of cropping system(t ha^{-1})	Production efficiency (kg ha^{-1} day^{-1})	Equivalent energy (MJ ha^{-1})
T_1-FYM + NPK $_{POP}$	62.38 ^{e}	134.96 ^{e}	374.89 ^{e}	83016 ^{g}
T_2 - FYM + STBR	65.30 ^{e}	140.57 ^{d}	390.47 ^{d}	86336 ^{f}
T_3- OC + STBR	90.30 ^{d}	167.48 ^{c}	465.22 ^{c}	97864 ^{e}
T_4- VC + STBR	99.54 ^{b}	184.93 ^{a}	513.69 ^{a}	108128 ^{b}
T_5- MC+ STBR	95.12 ^{c}	173.05 ^{b}	480.69 ^{b}	100392 ^{d}
T_6- TOF + STBR	87.14 ^{d}	169.69 ^{c}	471.36 ^{c}	100896 ^{c}
T_7- F-TOF + STBR	103.02 ^{a}	187.52 ^{a}	520.89 ^{a}	108808 ^{a}
T_8- F-TOF alone	31.26 ^{f}	72.00 ^{f}	200.00 ^{f}	45096 ^{h}
T_9-Absolute control	16.26 ^{g}	23.21 ^{g}	64.47 ^{g}	12064 ^{i}
SEm±	1.06	0.98	3.04	52.03
CD (0.05)	3.17	2.93	9.11	156.08

4.7 ECONOMICS OF CULTIVATION

In the first cropping sequence (Table 165) the highest B:C ratio (2.46) was obtained with treatment T_4 (VC + STBR) for tomato. But in the second cropping sequence the highest B:C ratio (2.73) was recorded by treatment T_7 (F-TOF+ STBR) followed by treatment T_4 (2.67). Similarly for amaranthus the highest B:C ratio for both the cropping sequences (Table 166) was recorded by the treatment T_7 (2.45 and 2.68, respectively) followed by treatment T_4 (2.44 and 2.58, respectively).

Table 166. Economics of tomato cultivation under tomato - amaranthus cropping sequence

Treatments	Economics of tomato cultivation					
	Cropping sequence 1			Cropping sequence 2		
	Gross income (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	B:C ratio	Gross income (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	B:C ratio
T_1- FYM+NPK $_{POP}$	618800	290000	2.13 ^{e}	612800	290000	2.11 ^{g}
T_2 - FYM + STBR	628800	290000	2.17 ^{de}	656600	290000	2.26 ^{e}
T_3- OC + STBR	688000	307162	2.24 ^{c}	715600	307162	2.33 ^{d}
T_4- VC + STBR	819400	332893	2.46 ^{a}	888400	332893	2.67 ^{b}
T_5- MC+ STBR	748000	337931	2.21^{cd}	810600	337931	2.40^{c}
T_6- TOF + STBR	771600	410811	1.88 ^{f}	879400	410811	2.14^{f}
T_7- F-TOF +STBR	790000	337143	2.34 ^{b}	920000	337143	2.73 ^{a}
T_8- F-TOF alone	326000	337143	0.97 ^{g}	488800	337143	1.45 ^{h}
T_9- Absolute control	51200	80000	0.64 ^{h}	43800	80000	0.55 ^{i}
SEm±	-	-	0.017	-	-	0.007
CD (0.05)	-	-	0.050	-	-	0.021

Table 167. Economics of amaranthus cultivation under tomato - amaranthus cropping sequence

Treatments	Economics of amaranthus cultivation					
	Cropping sequence 1			Cropping sequence 2		
	Gross income (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	B:C ratio	Gross income (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	B:C ratio
T_1- FYM + NPK $_{POP}$	580000	330000	1.76^{e}	667600	330000	2.02 ^{f}
T_2 - FYM + STBR	620000	330000	1.88^{d}	686000	330000	2.08 ^{e}
T_3- OC + STBR	860800	363952	2.37^{b}	881200	363952	2.42 ^{d}
T_4- VC + STBR	968400	396116	2.44^{a}	1022400	396116	2.58 ^{b}
T_5- MC+ STBR	896400	402414	2.23^{c}	1006000	402414	2.50 ^{c}
T_6- TOF + STBR	744000	493514	1.51^{f}	998800	493514	2.02 ^{f}
T_7- F-TOF + STBR	984800	401429	2.45^{a}	1075600	401429	2.68 ^{a}
T_8- F-TOF alone	307200	401429	0.77^{g}	318000	401429	0.79 ^{g}
T_9- Absolute control	57600	80000	0.64^{h}	48000	80000	0.53 ^{h}
SEm±	-	-	0.011	-	-	0.012
CD (0.05)	-	-	0.033	-	-	0.035

DISCUSSION

5. DISCUSSION

An investigation entitled "Effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics and crop productivity in Ultisols" was conducted to study the effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics, leaching loss and retention and their effect on crop productivity in tomato-amaranthus cropping sequence for two seasons. The results of the study are discussed in this chapter.

5.1 PRODUCTION AND CHARACTERIZATION OF ORGANIC FERTILIZER

Biodegradable wastes are widely used for the production of organic fertilizers so as to manage the waste in an ecofriendly manner and to ensure its recycling. The utilization of bio-waste as organic fertilizer is a solution for the proper disposal of biodegradable waste and brings economic benefits by enhancing soil productivity. At the same time, its improper handling results in environmental pollution and serious health issues (Sim and Wu, 2010). Several methods are employed for processing of biodegradable waste and the characteristics of organic fertilizers may vary depending on source of the waste material and the method of processing.

In this study, an evaluation on quality of thermochemical organic fertilizer was done by comparing its properties with that of other organic fertilizers viz., ordinary compost (OC), microbial compost (MC), vermicompost (VC) and FYM.

Thermochemical organic fertilizer possesses physical, chemical and biological properties in accordance with the standards of FCO (FAI, 2018) though it was produced by rapid thermochemical processing, imposing speedy decomposition of biowastes. It is odourless and dark brown in colour indicating the completion of decomposition and formation the stable humus compound (Table 7). In composting process different types of hetrotrophic microorganisms act on the substrate to produce a stable dark coloured, carbon rich compound called humus (Nada, 2015) and it takes at least 30- 45 days to complete the process. In the case of thermochemical organic fertilizer (TOF and F-TOF), a temperature of 100 ˚C and the chemical reagents added were able to decompose the organic constituents within short time. The chemical environment at a temperature regime of 100 ˚C was able to breakdown the complex long chain, cellulose constituents to short chains simple compounds.

The pH of TOF and F-TOF was slightly lower than that of other organic fertilizers (Table 8). The thermochemical process has been standardized to attain a pH around 7. The TOF had a pH of 6.76. F-TOF had comparatively a lower pH (6.62) and a higher EC than all other organic fertilizers and is due to fortification done at the time of production with mineral supplements that are acidic in nature. Similar results were reported by Sudharmaidevi *et al.* (2017) and Jacob (2018) that F-TOF recorded a lower pH and higher EC than FYM, aerobic compost, vermicompost and microbial compost even though the substrates used were same.

Total organic carbon is an important quality parameter of organic fertilizers. In accordance with FCO standards (FAI, 2018), the TOC content of organic fertilizers should be > 12 %. Among the organic fertilizers, TOF had the highest TOC (Fig. 3) followed by F-TOF. During thermochemical degradation, leaching and volatilization loss of organic carbon is comparatively less due their rapidness in production resulting in a higher TOC content for TOF and F-TOF. The addition of coir pith and charcoal during the production also enhance their TOC content. The slightly lower TOC for F-TOF compared to TOF is due the dilution effect resulted from fortification. Similarly, all the carbon fractions such as water soluble, labile and recalcitrant organic carbon were the highest with TOF followed by F-TOF, due to

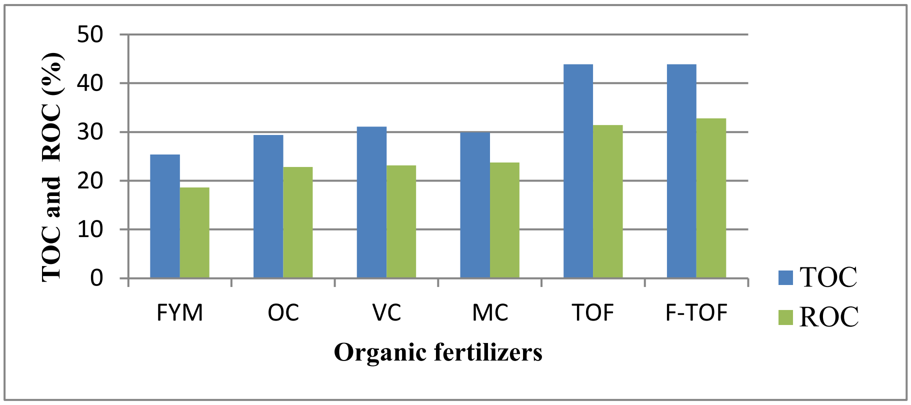

Fig. 3 Total and recalcitrant organic carbon in different organic fertilizers

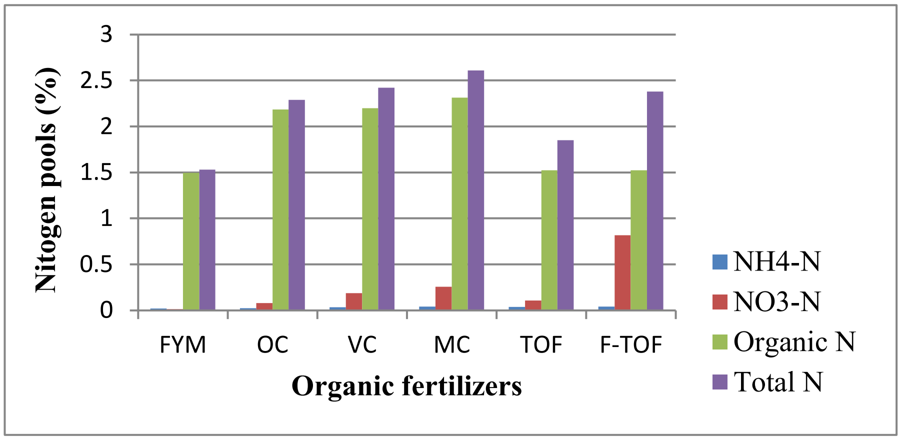

Fig. 4 Nitrogen pools in different organic fertilizers

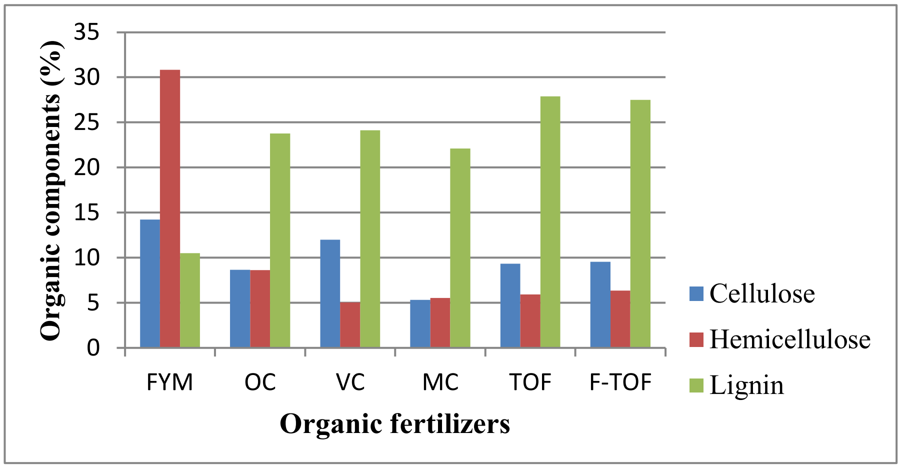

Fig. 5 Organic components in different organic fertilizers

their highest TOC content and thereby proportionate increase in the carbon fractions (Fig. 3 and Table 9). Water soluble and labile fractions are the carbon that is readily available for microorganisms to use. So, organic fertilizers with high WSOC and LC content have the potential to support soil flora and fauna.

The recalcitrant fractions which are resistant to microbial activity were also higher in TOF and F-TOF. Recalcitrance nature of thermochemical organic fertilizer was mainly due to their high lignin content (Table 11). Complexity in the chemical structure of lignin makes it resistant to microbial degradation (Ladisch *et al.,* 1983; Lynch, 1992). Recalcitrance nature indicates the stability of carbon compound and its ability to store carbon for longer time in soil. Mariaselvam *et al.* (2014) reported that the SOC pool of the soil can be maintained by addition of materials of recalcitrance nature. Thermochemical organic fertilizers (TOF and F-TOF) had a higher TOC content than other commonly used organic manures (Jacob, 2018; Ramesha, 2019) and it had maintained the SOC pools for longer duration (Jacob, 2018). During the decomposition process, degradation of hemicellulose, cellulose and lignin contributes to the production of stable humic material while simple carbohydrate molecules are mineralized into carbon dioxide (Lynch, 1992). The suitability of F-TOF as a substitute for organic manure in crop production was proved by Jayakrishna and Thampatti (2016) and Leno *et al.* (2016).

The other three organic fertilizers viz., OC, VC and MC had a comparable TOC as well as recalcitrant organic carbon fraction. FYM had the lowest recalcitrant organic carbon content and it indicates its lower soil residential potential and higher decomposition rate. Mariaselvam *et al.* (2014) reported that addition of materials of wide C:N ratio like straw along with cattle manure decreases its decomposition rate and maintains soil organic carbon pools and nutrient status of soil for a longer period.

Total N content in the organic fertilizer is an important parameter as it determines the mineralization and immobilization of nutrients when they are added to the soil. Thermochemical organic fertilizers had lower total N and organic N content compared to OC, VC and MC (Fig. 4), while total N and other fractions were highest with MC. The microbial decomposition might have facilitated better conservation of N through their body synthesis, since a large number of microbes are involved in it including nitrogen fixers. Apart from fixing atmospheric N, they immobilize nitrogen and decrease volatilization loss. Similar results were reported by Manna *et al.* (1997) and Kavitha and Subramanian (2007) where nitrogen content in the compost increased due to the addition of microbial inoculants.

C:N ratio of organic fertilizer determines its mineralization rate when added to the soil. As per the prescribed FCO guidelines of FAI (2018), the C:N ratio of organic fertilizer should be less than 20 to avoid the initial immobilization of nutrients. The higher organic carbon content and lower nitrogen content has resulted in a C:N ratio >20 for TOF while fortification reduced it to a value less than 20 in the case of F-TOF. But, the C:N ratios of MC and VC were lower than that of F-TOF due to their higher N content. The lower C:N ratio indicates faster mineralization and release of nutrients from these organic fertilizers.

For TOF and F-TOF, major part of organic fraction was lignin followed by cellulose (Fig. 5). This provides high recalcitrance nature to thermochemical organic fertilizers. For FYM the dominating fraction is hemicellulose and the lignin fraction is the lowest. This imparts a faster decomposition and less residential potential for FYM. Eiland *et al.* (2001) reported that hemicellulose was easily utilized by microorganisms and degrade faster than cellulose and lignin. Other organic fertilizers VC, MC and OC had comparable lignin content (Table 11) which contributes to soil residence potential which was intermediate between FYM and thermo chemical organic fertilizers. It is the chemical composition that determines the stability and recalcitrance nature of the compost. The compost rich in lignin is highly stable and resists fast degradation and contributes organic carbon of recalcitrant nature to the soil (Baddi *et al.,* 2004).

In the case of nutrient composition, F-TOF had the highest K, Ca, Mg, Zn and B contents definitely due to fortification with those nutrients at the time of its production. The higher P content with VC is attributed to the nutrient metabolism in earthworm gut (Shak *et al*., 2014). The organic fertilizers OC, VC, MC and TOF had almost a comparable nutrient content. However the slight difference occurred was due to the difference in the method of production and in the supplements used. This is in conformity with the findings of Jacob (2018) and Ramesha (2019).

In the case of biological properties, the microbial count as well as dehydrogenase activity was the lowest with thermo chemical organic fertilizers. It was because of mode of treatment of bio-waste where microorganisms were not involved. The thermal and chemical treatment kills the inherent microbial load with the substrates and whichever microbes present in the final product were developed during its processing under exposed condition. The highest microbial load and dehydrogenase activity was recorded by microbial compost (MC), of course due to the intense microbial activity during its formation. Adegunloye *et al.* (2007) also opined the same.

Thermochemical degradation of bio-waste is an innovative technology for the rapid production of organic fertilizers. The quality of the thermochemical organic fertilizers was on par with the conventional and non-conventional organic fertilizers commonly used for crop production. Two important indices to estimate the quality of organic fertilizers are fertilizing index and clean index (Saha *et al*., 2010).

Fertilizing index indicates the fertilizing potential of organic fertilizers and it is usually > 4 for organic fertilizers. The organic fertilizers OC, VC and MC had the highest fertilizing index of 4.8 and lowest for TOF (Fig. 6). F-TOF had a fertilizing index of 4.6 definitely due to the presence of more nutrients compared to TOF.

Clean Index (CI) is a measure of heavy metal contamination in the organic fertilizers. By maintaining a higher clean index for organic fertilizers, the entry of heavy metals into sensitive environment such as agricultural land and water bodies are restricted (Mandal *et al.,* 2014). Among the organic fertilizers, TOF had the highest clean index followed by F-TOF indicating lesser heavy metal contamination on soil application compared to FYM, OC, VC and MC. Leno *et al.* (2021) also reported similar results.

Thus, the quality of thermochemical organic fertilizers is quite comparable to other organic fertilizers, where F-TOF is superior in certain aspects like TOC, clean index and K, Ca, Mg, Zn and B contents.

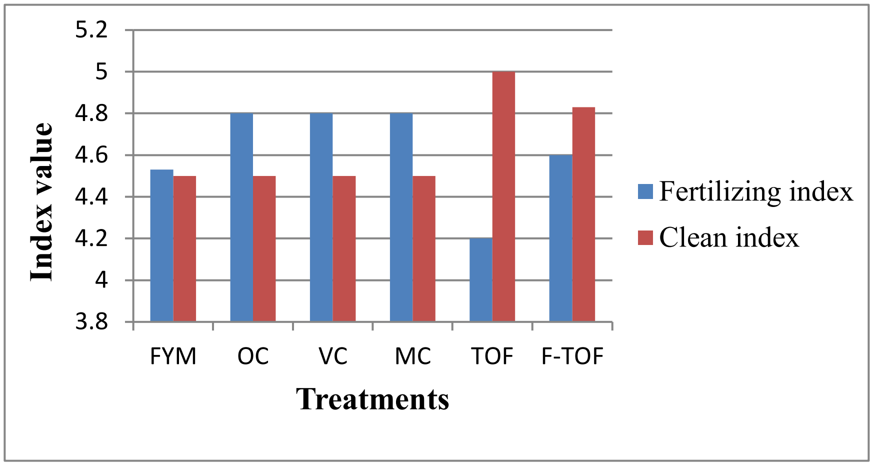

Fig. 6 Fertilizing index and clean index of different organic fertilizers

5.2 LEACHING STUDY WITH SOIL COLUMNS

Organic fertilizers applied to the soil release nutrients slowly. The nutrients left unutilized by the crop plants and microorganisms are subjected to leaching loss. The nutrients released in water soluble form as well as that held loosely are removed from the soil through leaching if not taken up by the plants. Annually a large quantity of nutrients is lost from agricultural lands through runoff and leaching. The soil column experiment carried out during 2017-18 revealed the retention and leaching pattern of nutrients from organic manure amended soil giving an indication on the extent of loss and retention of nutrients. The extent of retention and leaching loss of nutrients from thermochemical organic fertilizers are discussed here in comparison with other organic fertilizers.

5.2.1 Leaching loss of nutrients from organic fertilizers amended soil columns

The leachates collected from all the treatments were acidic in nature and F-TOF treated soil maintained the highest pH throughout the incubation period (Fig. 7). This is due to presence of more soluble salts of alkaline nature in the leachate (Fig. 12). Treatments receiving organic fertilizers maintained a higher pH compared to control due to better release of basic cations from the organic fertilizers while the control treatment might have a dominance of acidic cations and anions in the leachate.

All the treatments receiving organic fertilizers showed a declining trend for pH up to 8 W followed by an increase towards 12 W and again declining up to 24 W. The increase in the pH was due to mineralization and release of basic cations (Brar *et al.,* 2015) and decrease was due to the release of acidic cations and organic acids produced during the decomposition of organic manures (Wakene *et al.*, 2005).

EC indicates the amount of nutrient ions present in the leachate. For all the treatments, EC was highest at 1 W and decreased afterwards, except for a slight rise at 12 W (Fig. 8). In the first week, the highest EC was for F-TOF followed by VC, indicating their higher mineralization rate. After 12 W the EC was more or less steady which indicates that most of the leachable nutrients were removed by that time. An increase in soil EC with the application of organic fertilizers was reported by Rahman *et al*. (2013) and Jacob (2018)

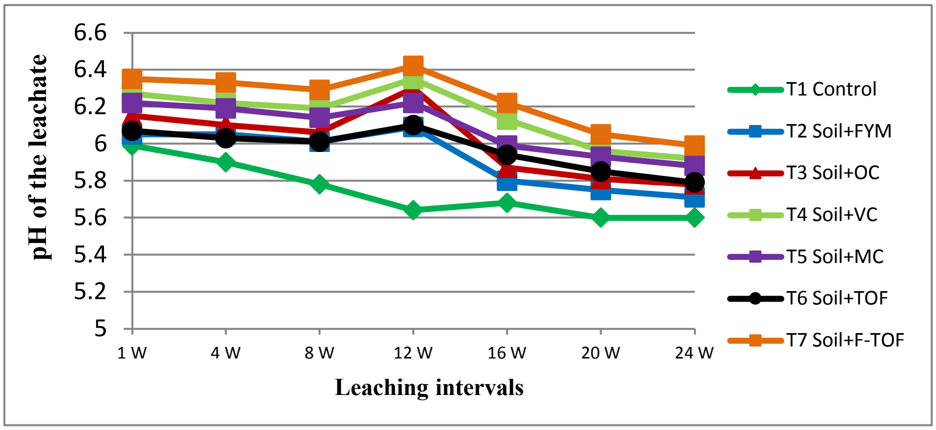

Fig.7 pH of the leachate at different period of leaching

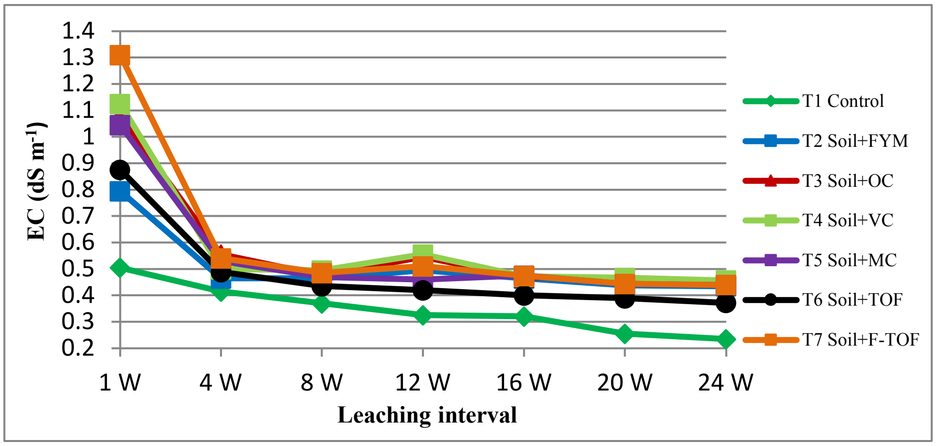

Fig. 8 EC of the leachate at different period of leaching

The presence of dissolved organic carbon in the leachate indicates the mineralization and release of nutrients from the organic fertilizers by the activity of microorganisms. During this process simple organic molecules soluble in water were produced and that were leached along with the water. Cumulative leaching loss of dissolved organic carbon (Fig. 9) from the soil column amended with organic fertilizers were in the order VC > OC > TOF > F-TOF > TOF> FYM. Perusal of the data on DOC content of leachate (Fig. 10) revealed that nearly 35-50 % of total DOC loss had occurred with the first leaching itself with the highest percentage loss from FYM (50.83 % of the total loss) followed by OC (47.05 % of the total loss) and VC (46.9% of the total loss). Afterwards there was a drastic decline in the DOC content in the leachate at each sampling interval (Fig. 10) indicating the stabilization of organic carbon in the soil. Similar results were reported by Zhao *et al.* (2008), where 45-50 % of dissolved organic carbon was extracted during beginning of soil incubation and declined later due to the depletion in labile carbon. At the second leaching (4 W), comparatively higher DOC content in the leachate from TOF and F-TOF (Fig. 10) was due to the release of immobilized organic carbon from microbial biomass. Burford and Bremner (1975) reported that microbial activity aggravate in the presence of water soluble carbon which increase the C-mineralization rate and cause more production of water soluble organic carbon. Thus the high WSOC content in the thermochemical organic fertilizer had promoted microbial activity and caused production of more WSOC at 4 W.

The percentage loss of organic carbon with respect to the total organic carbon content of fertilizers was in the order FYM > OC > VC > TOF= F-TOF > MC. With respect to TOC content of the organic fertilizer, the lowest percentage loss of organic carbon was with MC. It indicates the stability of organic carbon content in the microbial compost. Microorganisms belonging to genera *Bacillus* and *Pseudomonas* are found to be efficient in decomposing and stabilizing the organic waste (Pant *et al.*, 2012). Zhang *et al.* (2013) reported an increase in dissolved organic carbon in the soil

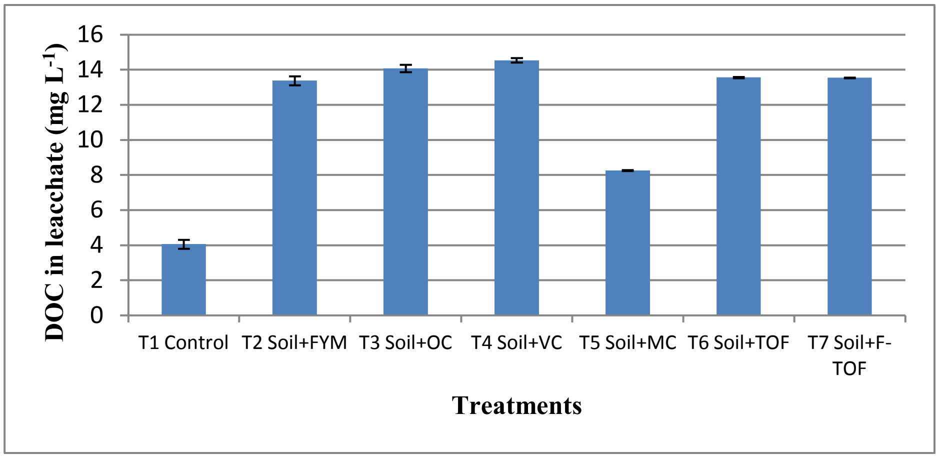

Fig. 9 Cumulative loss of DOC through the leachate during the period of incubation

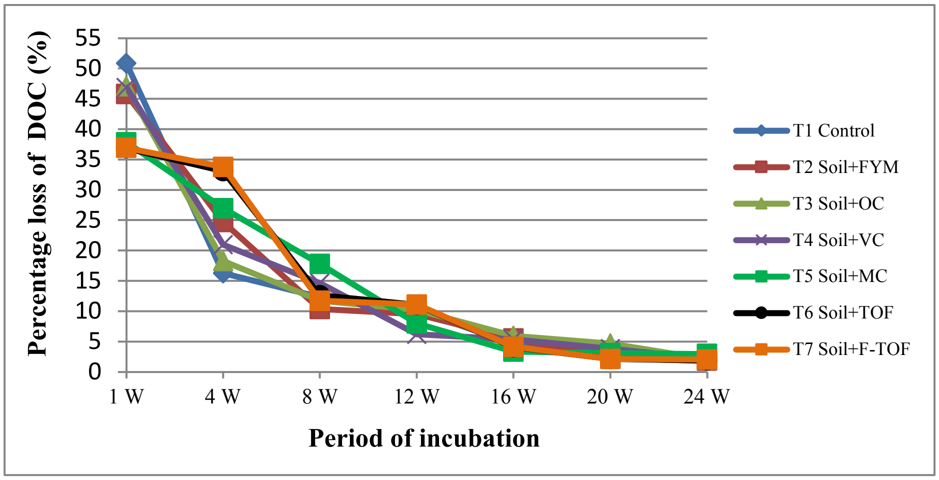

Fig. 10 Percentage loss of DOC through leachate during the period of incubation

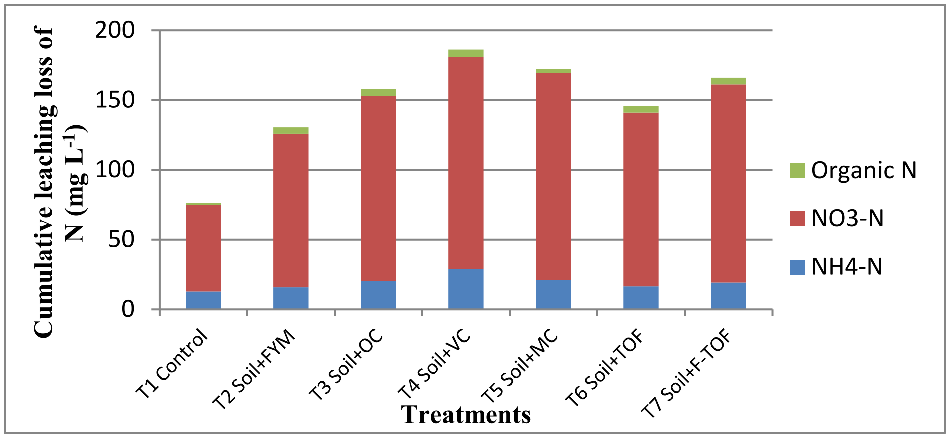

Fig. 11 Cumulative leaching loss of nitrogen from organic fertilizer amended soil during the period of incubation

with the addition of organic manure and quantified loss to be 0.47 % of the TOC of the soil.

The mineralization of organic fertilizers released N in different forms and they were leached from soil columns by the leaching water. The highest cumulative loss of total N was from vermicompost amended soil followed by microbial compost (Fig.11). It was mainly due to their higher N content. Based on the nitrogen concentration and the quantity of organic fertilizers added, the total amount nitrogen added to the soil column through organic fertilizers were 765 mg by FYM, 1145 mg OC, 1210 mg by VC, 1305 mg by MC, 825 mg by TOF and 1190 mg by F-TOF. The cumulative loss of total N (Fig. 11) from the treatments was in the order VC > MC > F-TOF > OC > TOF > FYM > Control. The cumulative loss of total N from F-TOF was comparable to VC and MC due their higher total N content. The peak loss of total N from FYM was at 16 W, while that from VC and MC at 12 W and OC and TOF at 20 W and declined afterwards. F-TOF had peak leaching loss of N at 8 W and 20 W and declined after 20 W (Table 51).

When the cumulative loss of total N is expressed as the percentage of total quantity of N added, it followed a slightly different order compared to that explained above. The percentage loss (Fig. 16) followed the order of VC >TOF > F-TOF > MC > FYM > OC with a percentage loss of 36.22, 33.71, 30.11, 29.34, 28.46 and 28.45 respectively. The leaching done at the first week after the incubation caused the highest percentage of total N loss from all the treatments.

Similar to the total N, the cumulative leaching losses of NH_4-N and NO_3-N were also highest from VC amended soil followed by MC, due their higher total N content (Fig. 11). Cumulative loss of NO_3-N and NH_4-N from organic fertilizer was in the same order VC > MC> F-TOF > OC > TOF> FYM as that of total N. The peak loss of NO_3-N from FYM was at 16 W and that of VC and MC at 12 W and OC, TOF and

F-TOF was at 20 W. Afterwards the NO_3-N content in the leachate declined (Table 49). Even though MC had higher nitrogen content than VC, the higher microbial activity in MC might have immobilized more N, thus reducing the leaching loss. Lim *et al.* (2010) reported total N concentration in organic fertilizer as a major factor affecting N leaching from different soils amended with organic fertilizers.

Application of cattle and pig slurry to the sandy soil caused very high leaching loss of N, while FYM caused comparatively less N loss due to its lower proportion of available N (Beckwith *et al.,* 1998).

At the first week of leaching, NO_3-N loss was highest from F-TOF due to the higher content of NO_3-N. For NH_4-N, leaching loss during the last two weeks was constant, irrespective of treatments indicates that the NH_4-N in the leachates was solely contributed by soil and contribution from organic fertilizer was already removed by the leaching water. It indicates the completion of nitrification process and conversion of all available NH_4-N form to nitrate form. Also there was chance of fixation of NH_4^+ ion in the soil due the presence of kaolinite clay content in the soil.

Organic N content in the leachate was comparatively very low (Fig. 11). It might be due to its hydrophobic nature and deposition in lower layers during the downward movement along the soil column. The peak loss of organic N from all the treatments was at first leaching and declined after each leaching (Table 20). There was no significant difference in the cumulative loss of organic N content of leachate from different organic fertilizer amended soil column except for MC. In MC added soil, organic N loss was comparatively least due to its conversion to microbial biomass or immobilization. Murphy *et al.* (2000) quantified the amount of total N in the drainage water collected at 150 cm depth from agricultural land as total N content of 21.03 mg l^{-1}, of which 20.40 mg l^{-1} was NO_3-N, 0.08 mg l^{-1} was NH_4-N and 0.55 mg l^{-1} was organic N and the ratio of dissolved organic carbon to organic nitrogen in the leachate found to be 3.1. Water soluble organic N is always in equilibrium with organic N adsorbed on clay colloids, and the pH of the extractant, as well as its ionic strength, composition and concentration in the solution (Haynes, 2005). As organic N form partially composed of easily decomposable form which contribute for the mineralizable N and thus have a significant effect on the size of the inorganic soil N pools such as NH_4^+ and NO_3^- (Mengel *et al*., 1999).

Organic fertilizers are balanced fertilizers as it contains all the nutrients required for the crop plants. Also the nutrient release from the organic fertilizers is slow and maintains an optimum proportion among different nutrients. It is the mineralization rate and water soluble nature of the mineralized nutrients that affect the quantity of nutrients leached from the soil. Composting of organic residue stabilizes the nutrients and causes their slow release and thus reduces the leaching losses (Adeli *et al.,* 2017).

The cumulative leaching loss of P was highest from F-TOF due to its high P content (Table 22). The leachates collected from 8 W onwards were free of phosphorus. It was due to the fixation of mineralized phosphorous in the soil and also due to anion adsorption by the site contributed by the kaolinitic clay present in the red soil. Only a very small amount of P removed from the soil through leaching and remaining was retained in soil at different depths. The cumulative loss of P from the treatments was in the order F-TOF > OC >MC >VC >FYM > TOF > Control. The loss when expressed in relation to quantity of P applied the percentage of P loss (Fig. 13) was in the order F-TOF > OC < FYM < MC < TOF < VC.

K was leached out continuously throughout the study period with peak release from FYM, OC, VC and TOF at 12 W and MC and F-TOF at 16 W (Table 23) indicating a better retention time for MC and F-TOF. From control treatment, there was a cumulative loss of 987.19 mg of K since the soil was high in available K. Among the organic fertilizers amended treatments the highest cumulative loss of K

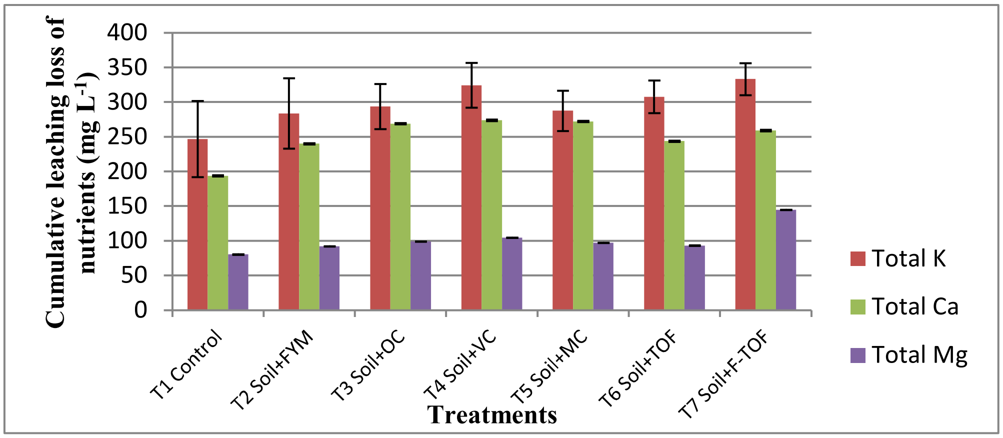

Fig.12 Cumulative leaching loss of K, Ca and Mg from organic fertilizer amended soil during the period of incubation

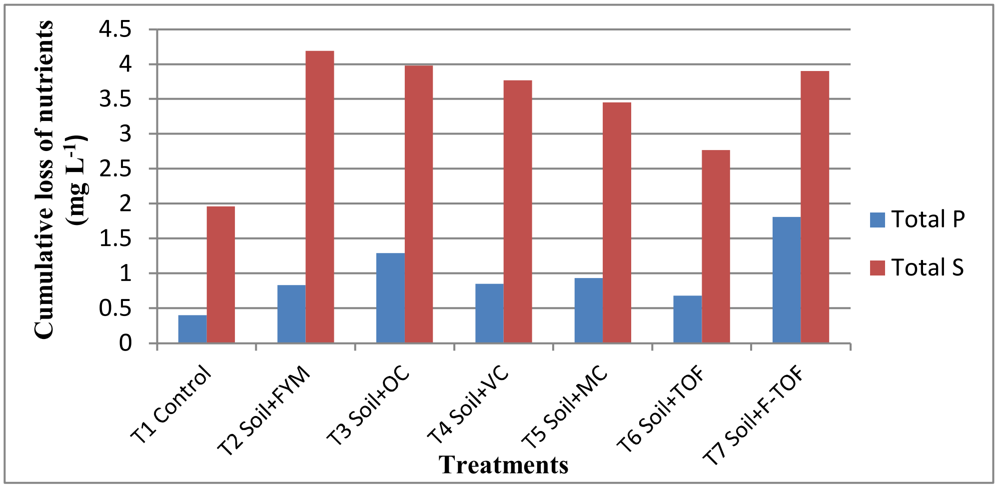

Fig. 13 Cumulative leaching loss of P and S from organic fertilizer amended soil during the period of incubation

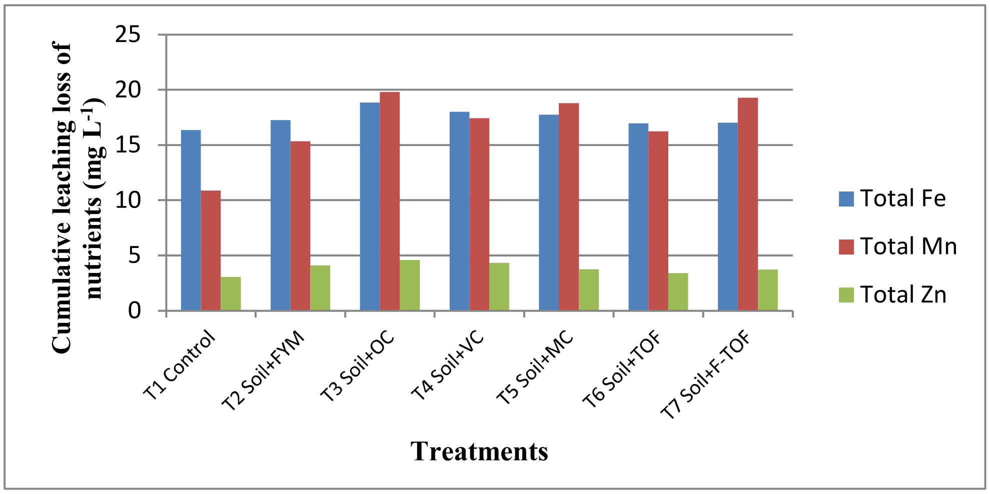

Fig. 14 Cumulative leaching loss of Fe, Mn and Zn from organic fertilizer amended soil during the period of incubation

was with F-TOF and VC (Fig. 45). It was mainly due to their higher K content. The lowest cumulative loss was from FYM due to its lower K content. The percentage of loss of applied K (Fig. 49) from the organic fertilizers were in the order FYM $_{(31.48\ \%)}$ > VC $_{(29.84\ \%)}$ > F-TOF $_{(27.05\ \%)}$ > TOF $_{(25.14\ \%)}$ > OC $_{(20.22\ \%)}$ > MC $_{(18.12\ \%)}$.

Similarly for Ca, the highest cumulative leaching loss was from VC (Fig. 12) and Mg was from F-TOF. It was due to their higher Ca and Mg contents and higher mineralization. The peak loss of Ca from all the treatments was at 8 W except for MC which had at 12 W and declined thereafter (Table 54). The percentage of applied Ca loss from the organic fertilizers (Fig. 16) were MC $_{(78.50\ \%)}$ > FYM $_{(77.32\ \%)}$ > OC $_{(75.31\ \%)}$ > VC $_{(66.85\ \%)}$ > TOF $_{(55.66\ \%)}$ > F-TOF $_{(46.70\ \%)}$. The peak loss of Mg from organic fertilizers amended soil column was at 12 W and declined afterwards. The percentage loss of applied Mg loss from organic fertilizers (Fig. 16) was in the order; VC $_{(67.64\ \%)}$ < F-TOF $_{(67.34\ \%)}$ < MC $_{(58.24\ \%)}$ < OC $_{(57.32\ \%)}$ < FYM $_{(50.85\ \%)}$ < TOF $_{(48.91\ \%)}$.

The highest cumulative loss of sulphur was highest from FYM followed by OC and VC due to their high sulphur content (Fig. 13). The leaching loss of S gradually increased after each leaching and reached its peak loss at 16 W and declined later (Table 56). It might have taken 16 weeks for the mineralization of organic S and afterwards the cycle might have reversed. The percentage loss of applied S from the organic fertilizers (Fig. 16) was in the order F-TOF $_{(36.56\ \%)}$ > VC $_{(31.28\ \%)}$ > OC $_{(30.04\ \%)}$ >MC ($_{29.38\ \%)}$ > FYM $_{(24.81\ \%)}$ >TOF $_{(10.48\ \%)}$.

The cumulative loss of Fe was highest from OC followed by VC and MC (Fig. 14). The percentage of loss of Fe from organic fertilizers (Fig. 18) was in the order OC $_{(0.60\ \%)}$ > VC $_{(0.42\ \%)}$ > MC $_{(0.38\ \%)}$ > TOF $_{(0.37\ \%)}$ > F-TOF $_{(0.28\ \%)}$ > FYM $_{(0.19\ \%)}$. Leaching loss of Fe was very less. It was mainly due to immobility of chelate- Fe complex formed in the soil. Similar results regarding the immobility of chelates of micronutrient were reported by Fageria *et al.* (2011). For other micronutrients such as Mn, Zn and Cu, downward mobility was restricted might be due to complex

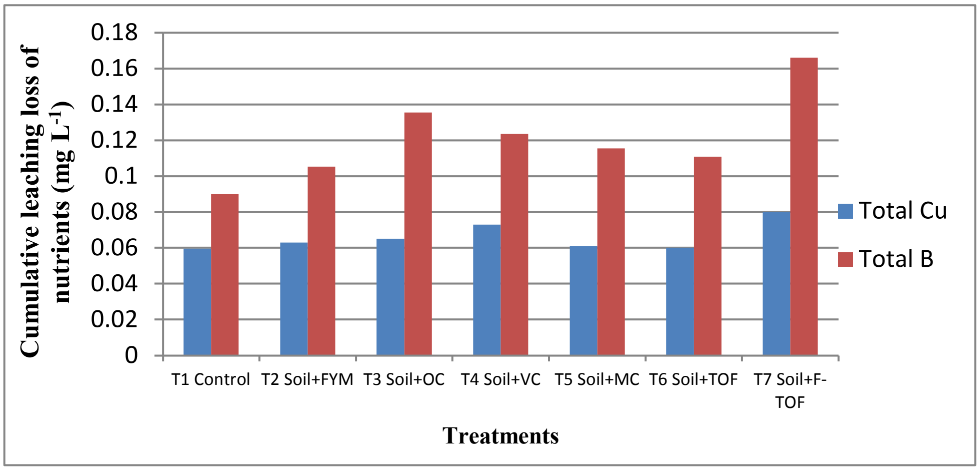

Fig. 15 Cumulative leaching loss of Cu and B from organic fertilizer amended soil during the period of incubation

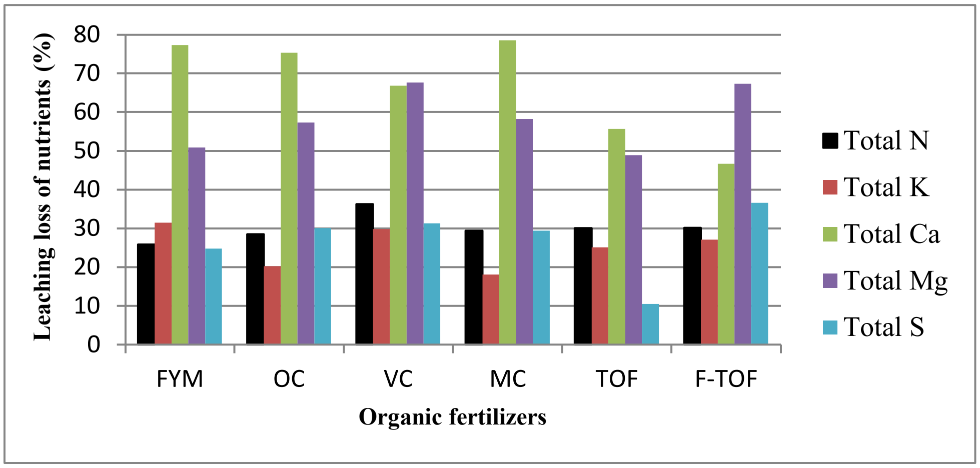

Fig.16 Percentage loss of N, K, Ca, Mg and S from organic fertilizer amended soil through leachate

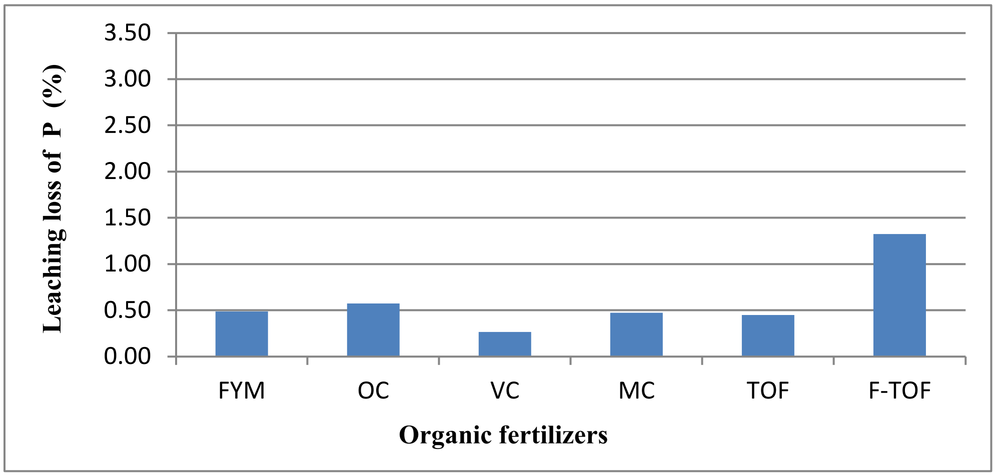

Fig.17 Percentage loss of P from organic fertilizer amended soil through leachate

formation with the organic molecules. For Mn the highest cumulative loss was from VC followed by OC and FYM (Fig. 14). The percentage of loss of Mn from organic fertilizer (Fig. 19) was in the order F-TOF (25.88 %) >VC (20.88 %) >OC (19.23 %) > FYM (17.10 %) >TOF (16.44 %) >MC (14.11 %).

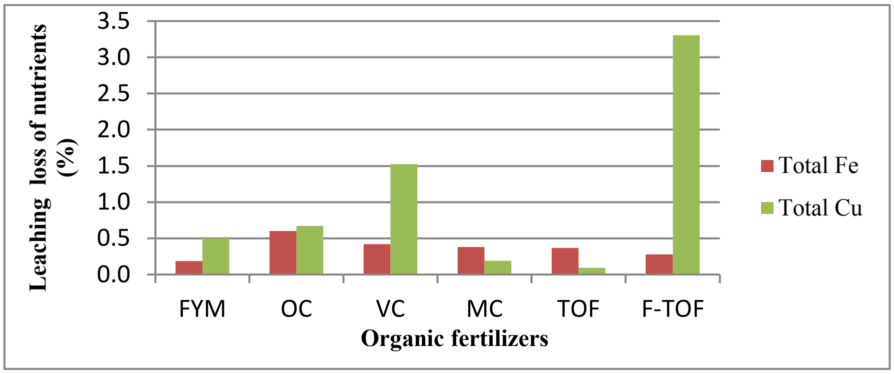

Fig.18 Percentage loss of Fe and Cu from organic fertilizer amended soil through leachate

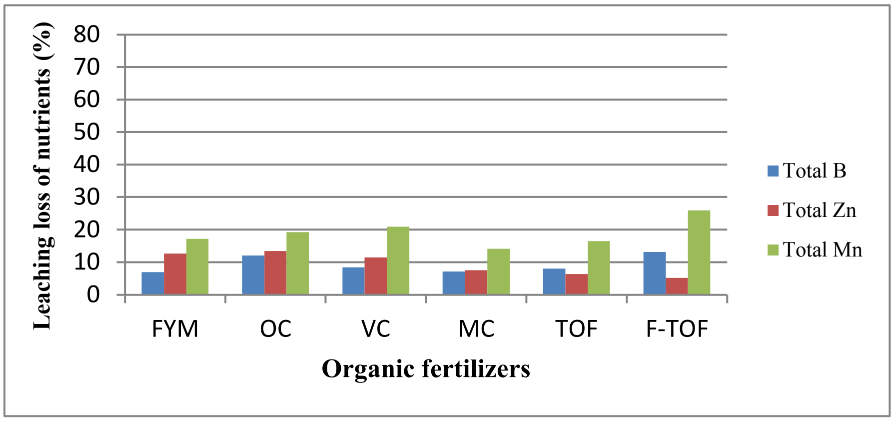

Fig.19 Percentage loss of Mn, Zn and B from organic fertilizer amended soil through leachate

The cumulative loss of Zn from the treatments were in the order OC > VC > FYM > MC > F-TOF > TOF > Control (Fig. 14). For the micronutrients Fe, Mn and Zn, had their peak leaching loss at first week itself and which declined after wards. The acidic pH of the soil had maintained the micronutrients in soluble form, which might have promoted their speedy removal. For Zn, the percentage of loss from the organic fertilizer (Fig. 19) was in the order OC $_{(13.38\%)}$ > FYM $_{(12.62\ \%)}$ >VC $_{(11.47\ \%)}$ >MC $_{(7.49\ \%)}$ > TOF $_{(6.32\ \%)}$ > F-TOF $_{(5.12\ \%)}$.

Similarly cumulative loss of Cu (Fig. 15) from treatments were in the order F-TOF > VC > OC > FYM > MC > TOF > Control. For Cu, all the treatments had their peak leaching loss at first week itself. Even though VC and MC amended soil had a second peak leaching loss at 20 W and 16 W, respectively. The loss for Cu when expressed as percentage of applied Cu, the organic fertilizers (Fig. 51) followed the order of F-TOF $_{(3.31\ \%)}$ > VC $_{(1.53\ \%)}$>OC $_{(0.67\ \%)}$> FYM $_{(0.50\ \%)}$>MC $_{(0.19\ \%)}$> TOF $_{(0.09\ \%)}$.

The B content in the leachate decreased after each leaching. The highest loss was at the first week and decreased gradually (Table 31). The highest cumulative loss was from F-TOF (Fig. 15) and it was due its high B content and water soluble nature of borax which it contained. The cumulative loss of the B from the treatments (Fig. 15) was in the order F-TOF > OC > VC > MC > TOF > FYM >Control. The loss expressed as the percentage of applied quantity, it followed the order of (Fig. 52) F-TOF $_{(13.10\ \%)}$ > OC $_{(11.97\ \%)}$ > VC $_{(8.38\ \%)}$ > TOF $_{(7.98\ \%)}$ >MC $_{(7.08\ \%)}$ > FYM $_{(6.93\ \%)}$. The percentage loss of the nutrients from the organic fertilizer indicates the amount of nutrient mineralized and their potential mobility in the soil column (Lim *et al*., 2010 and Kim *et al*, 2011).

The cumulative leaching loss of N, Ca and Mn was highest from VC, while that of P, K, Mg, Cu and B were highest from F-TOF. The loss of S was highest from FYM and that of Fe and Zn from OC. The cumulative loss is not in proportion with their nutrient content. It was mainly due to the difference in the retention capacity of different organic fertilizers. The leaching loss P, K, Mg, Cu and B from F-TOF was 1.09, 27.06, 46.70, 3.31 and 13.10 % of its total nutrient content, respectively and the remaining portion was retained in the soil at different depths.

Considering the leaching loss of nutrients from F-TOF, the loss of P was very small compared to K, Mg, Cu and B. It was mainly because of the very low mobility of P and insoluble nature P source used for fortification. These two had reduced the P loss to minimum. The high K content F-TOF was mainly due to the use of KOH as a reagent during the production of the organic fertilizer. The high K content coupled with its high mobility resulted in its loss to an extent of 27 % of the total K content from F-TOF (Fig. 16). In the case of Mg, nearly half of Mg added for fortification is being lost and it is mainly due to water soluble nature of Mg source added during the fortification. Hence, an alternate source for Mg or use of some binding agents can be looked into to reduce its losses. In the case of copper, the leaching loss was 3.3 % and for B, it was 13.1 %. The presence of crop may change the pattern of nutrient loss, especially for elements with high mobility. The balanced nutrient content of the organic fertilizers promotes microbial activity and release of nutrients making it available to plants. In the absence of plants these are subjected to other types of losses and this might have favoured the leaching loss of nutrients. The leaching loss of nutrients from the organic fertilizers amended soil indicates the potential availability of nutrients due to the mineralization of organic fertilizers (Lim *et al*., 2010). This suggests the time of application of organic fertilizers needs a revisit for crops.

5.2.2 Retention and availability of nutrients in organic fertilizer amended soil columns after leaching for 24 weeks

Nutrient retention in soil columns amended with different organic fertilizers after leaching for a period of 24 weeks is presented in Fig. 53 to 80. The nutrient retention ability of thermochemical organic fertilizers, both F-TOF and TOF is discussed here in comparison with other organic fertilizers.

F-TOF amended soil maintained a higher pH after leaching compared to other organic fertilizers, mainly because of the retention of elements of alkaline nature in higher concentration (Table 32**)**. The decrease in pH due to leaching was lowest for TOF and highest for F-TOF. Treatments receiving MC, VC and F-TOF maintained a pH just above 6.0 in surface soil after leaching, though most of the organic fertilizers used were having a pH greater than 7.0 Organic fertilizers treated soils at different depths showed a higher pH compared to control treatment (Fig. 20), which is the influence of basic cations released from organic fertilizers. The nutrients have been released from the organic fertilizers during mineralization and their movement and deposition in the lower layers contributed to the higher values. There was an increase in the pH of the soil by the continuous addition of organic fertilizers (Laurent *et al.*, 2019) and improved the buffering capacity of the soil against acidification (Vasak *et al.,* 2015).

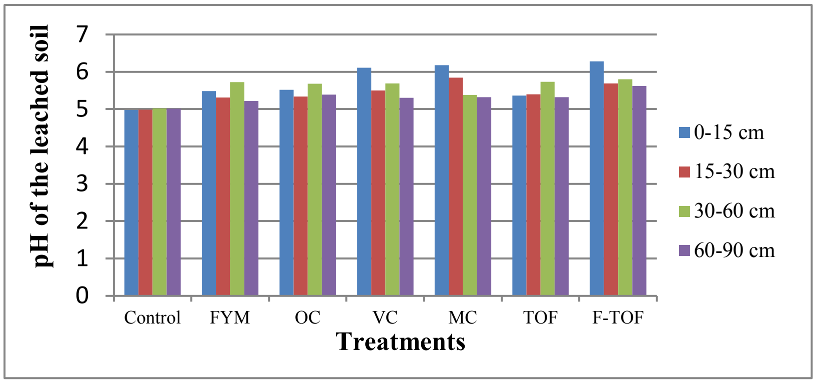

Fig. 20 pH of leached soil at four different depths

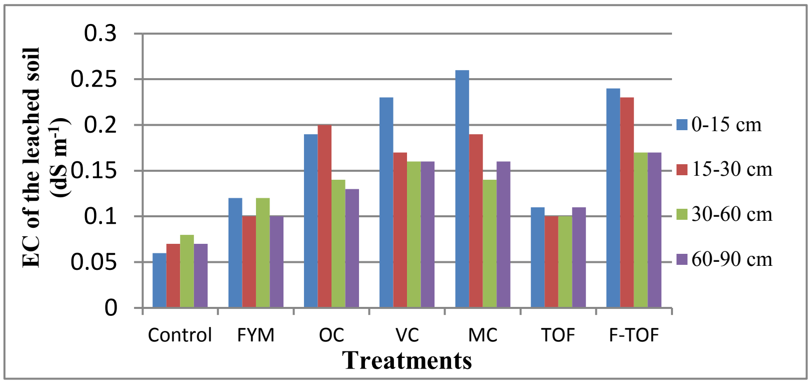

Fig. 21 EC of leached soil at four different depths

In the leached soil MC and F-TOF had showed higher EC in the surface layer, indicating better nutrient retention (Fig. 21). Organic fertilizers increased the retention of nutrients in the soil mainly by increasing the CEC of the soil (Czarnecki and During, 2015). In the lower layers, F-TOF maintained the highest EC. Increase in the EC at the lowers layers indicates the mobilization and deposition of mineralized nutrients from the surface layer. Similar results regarding the mobilization of mineralized nutrients from organic fertilizers during leaching where reported by Lim *et al.* (2010) and Kim *et al.* (2011)

5.2.2.1 Retention and downward movement of carbon

Organic fertilizers are the main carbon source in the agricultural lands. Addition of organic fertilizers to the surface layer of soil column (0-15 cm) has increased TOC content of the soil (Table 34) and the increase ranged from 54.9 percent for FYM to 95.6 % for thermo chemical organic fertilizers (TOF and F-TOF) before leaching. The increase in the TOC content of surface layer with the addition of OC, VC and MC was 54.9, 62.8, 67.3 and 63.7 %, respectively. The increase in TOC of red soil by the addition of organic fertilizers was reported by Zhang *et al.* (2013) and Wang *et al.* (2019).

After the leaching, TOC in the surface layer of control treatment decreased by 15.04 % and sub-surface layer by 13.27 % (Fig. 22). The TOC content of organic fertilizer amended soils was not affected much by leaching as the leaching loss of organic carbon was very low compared to the TOC content of the organic fertilizers. However, the TOC content in the surface layer decreased than the initial (0 D) value due to leaching. After leaching the In the leached soil, the percentage increase in the TOC of surface layer was decreased from 54.9 % to 32.74 % for FYM and decreased from 95.6 % to 81.41 % for F-TOF amended soil. This has further confirmed the better ability of F-TOF for retention of carbon in soil (Fig. 22).

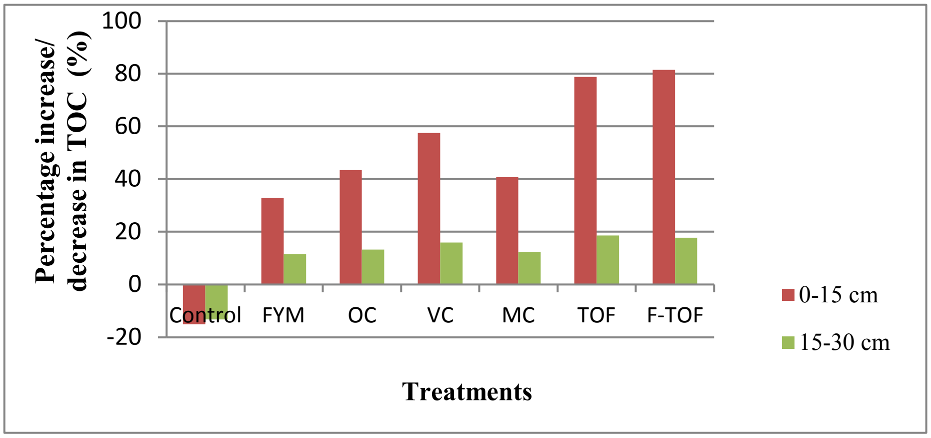

Fig. 22 Percentage increase/ decrease in the TOC content of leached soil at 0-15 and 15-30 cm depth

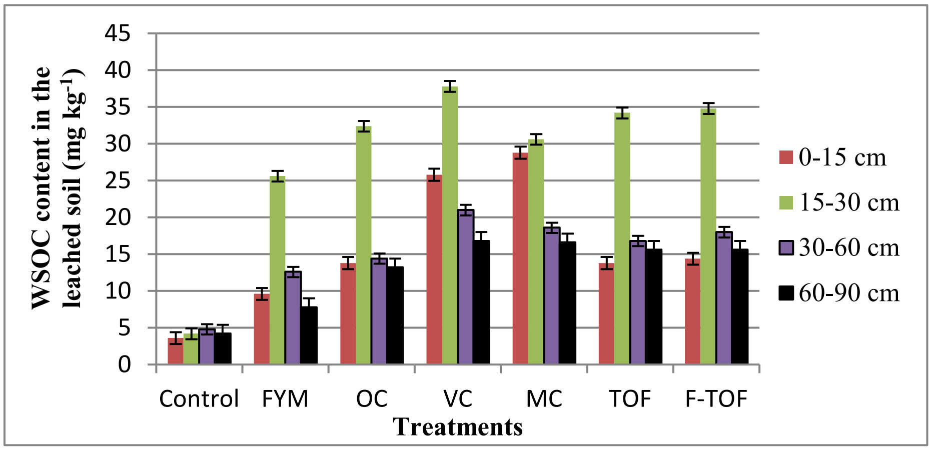

Fig. 23 WSOC in the leached soil at four different depths

There was an increase in the TOC content of the subsurface layer (15-30 cm) due the downward movement of organic carbon from the surface layer. Thus the TOC of the sub-surface layer increased by 11.5 %, 13.3 %, 15.9 %, 12.4 %, 18.6 % and 17.7 % respectively for FYM, OC, VC, MC, TOF and F-TOF (Fig. 55) after the leaching. In lower layers beyond 30 cm, there was no significant increase in the TOC of the soil with leaching. It shows that restricted mobility and accumulation of organic matter within 30 cm of depth from the surface soil. Similar results regarding the leaching loss of DOC from agricultural land amended with organic fertilizers were reported by Hussain *et al.* (2020).

Various pools of carbon, *i.e.,* WSOC, labile carbon, MBC and ROC in the leached soil were influenced by the addition of organic fertilizers and leaching. Thermochemical organic fertilizers maintained higher WSOC in surface layer and leaching had made a noticeable decrease by the end of 24 W (Fig. 23). After leaching, the WSOC content in sub-surface layer (15-30 cm) of all treatments except control, was higher than the initial value due to the downward movement of the WSOC. MC maintained highest WSOC in the surface layer (0-15 cm) indicating the potential for further mineralization. While for all the lower layers (15-90 cm), VC showed highest WSOC content, which reflects better mineralization and downward movement of WSOC. The WSOC released during the decomposition of organic fertilizers had restricted mobility in loamy soil (Kaschi *et al.,* 2002). Thus the major share of accumulation was within 30 cm, even though there was deposition beyond 30 cm depth.

In surface (0-15 cm) and sub-surface layer (15-30 cm), the highest value for labile carbon (Fig. 24) and MBC (Fig. 25) was maintained by F-TOF and TOF. It was mainly due their higher TOC content and the proportionate contribution to labile and MBC pool. The downward movement might have been restricted under the influence of TOF due to better retention. In the lower depth of 30-90 cm, VC and MC have maintained a higher value for labile carbon and MBC, respectively. It was due to the downward movement and deposition of organic carbon from surface layer to the lower layers. There exists a positive correlation between the SOC content of the soil and its labile fractions and also between the labile fractions (Souza *et al.,* 2016). The labile fractions of soil organic matter include micro-organisms, plant and soil fauna residues at different levels of decay and the products of their decomposition, easily decomposable non-humic organic substances such as carbohydrates, polysaccharides,

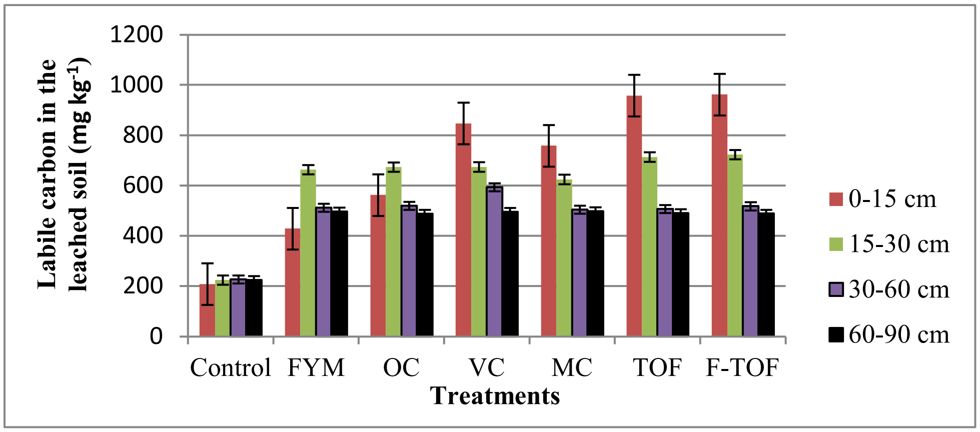

Fig. 24 Labile carbon in the leached soil at four different depths

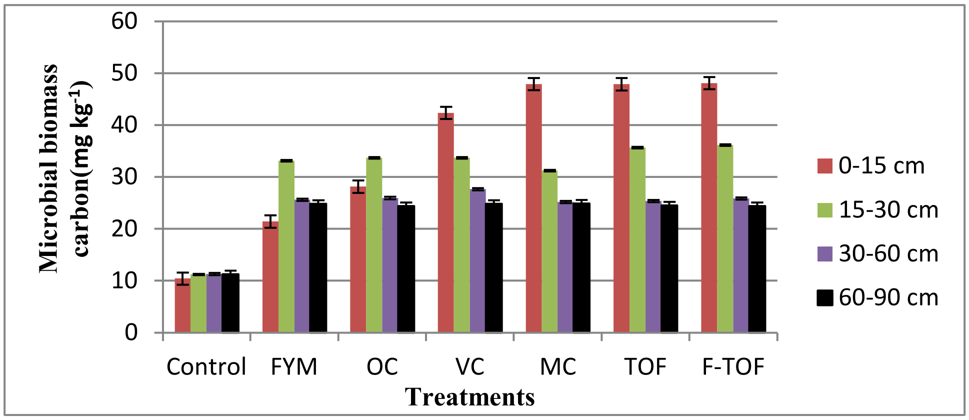

Fig. 25 MBC in the leached soil at four different depths

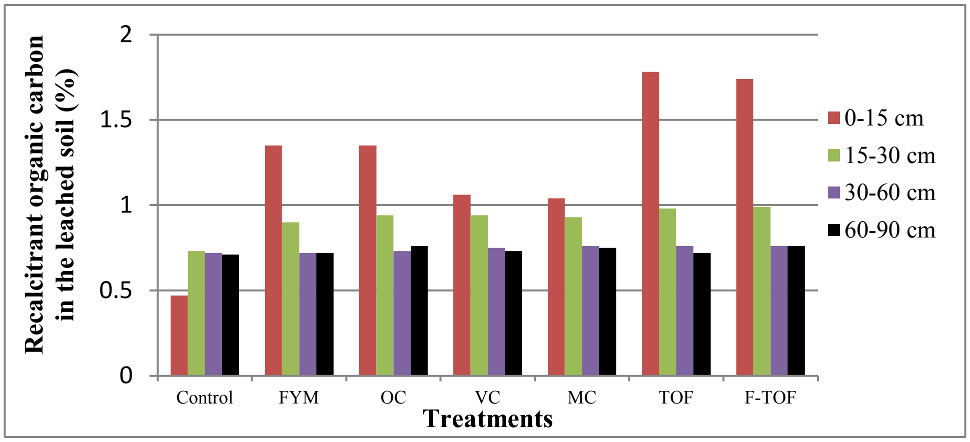

Fig. 26 ROC in the leached soil at four different depths

proteins, organic acids, amino acids, waxes, fatty acids, and other non-specific compounds (Poirier *et al.,* 2005). Among the labile fractions, the lowest contribution was from MBC and it is only 2 % of the SOC. But, it is considered as extremely sensitive and active fraction of SOM (Costa *et al.,* 2013).

The thermochemical organic fertilizers maintained higher amount of recalcitrant organic carbon in the surface and sub-surface layers of leached soil (Fig. 26) due to their high lignin content that contributes to recalcitrance nature. The complexity in the lignin structure and longer duration for its microbial degradation was reported by Ladisch *et al.,* 1983 and Lynch, 1992). Also the amount of recalcitrant organic carbon in the sub-surface layer (15-30 cm) increased than its initial value due to its downward movement along with leaching water. The amount of ROC in the surface layer of VC and MC amended soil decreased after leaching due to the downward movement of organic carbon. The ROC content decreased with depth and the highest value was at surface layer. The results were in conformity with the finding of Sahoo *et al.* (2019) were there recalcitrant organic carbon in the various land use system decreased with depth.

5.2.2.2 Retention and downward movement of nitrogen

Organic fertilizers added to the surface layer (0-15 cm) have enhanced the total N content of the layer, based on its total N content. Thus MC had the highest total N content followed by VC and F-TOF. The nitrogen added through the organic fertilizer was retained in the soil in different forms such as NH_4-N, NO_3-N and organic N. In the surface layer of leached soil, VC had retained the highest NH_4-N content. While MC had retained the highest NO_3-N, organic N and total N. MC had the highest N content among the organic fertilizers used. In the surface layer, MC had retained (Fig. 27) 36.34 % of its total N followed by OC (34.63 %) and FYM (33.43 %). In the lower layers, F-TOF had the highest total N and organic N contents mainly due to the downward movement of N from the surface layer. F-TOF has retained 26.99 %, 23.34 %, 11.04 % and 8.82 % of its total N, respectively at four different depths 0-15, 15-30, 30-60 and 60-90 cm. However, on the basis of total N content of the organic fertilizers the highest percentage retention in the overall depths (Fig. 27) was with FYM $_{(71.57\ \%)}$ and OC $_{(71.42\ \%)}$ and lowest for VC.

On evaluating the overall performance of organic fertilizers on percentage of nitrogen retention over control, MC showed the highest retention closely followed by OC (Fig. 27). Percentage increase in the total N content at four different depths over the control was highest for MC followed by OC and F-TOF (Fig 28)

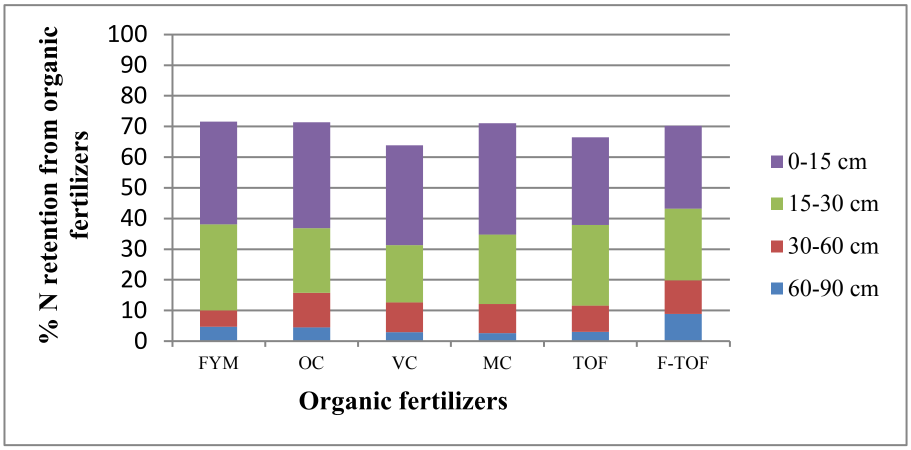

Fig. 27 Percentage of N from organic fertilizers retained at four different depths

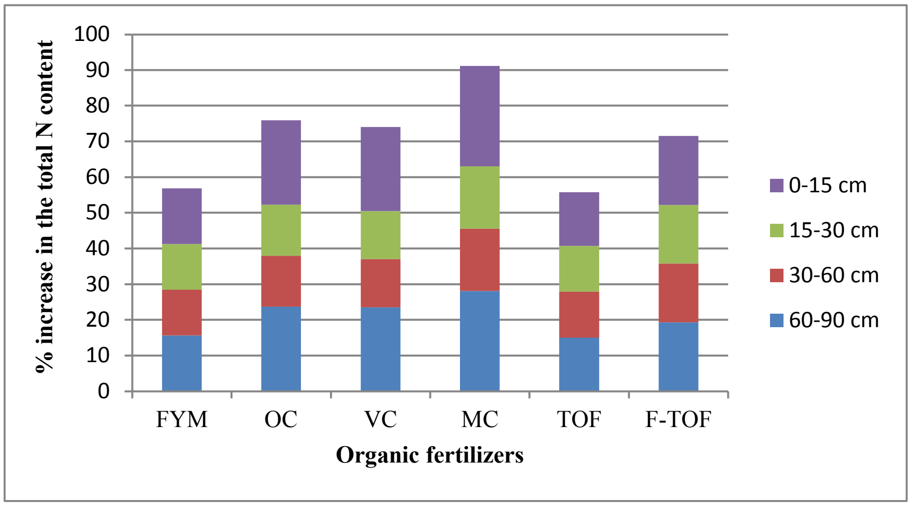

Fig. 28 Percentage increase in the total N content at four different depths over the control at 24th week

5.2.2.3 Retention of other nutrients

The nutrient retention potential of organic fertilizers is the ability to retain the maximum share of its nutrients in the soil. The humic substances added to the soil from the organic fertilizers enhance the CEC of the soil and thereby improves its nutrient retention capacity (Preusch *et al.,* 2002). The nutrients mineralized beyond the retention potential move downwards along the leachates and retained at different soil depths. From the total nutrients added to soil by the organic fertilizers, how much is retained after leaching for 24 weeks and the variation in the availability of nutrients is discussed below.

With the application of organic fertilizers, the highest total P content in the surface layer was with VC followed by OC and MC (Table 43). At the end of leaching, P retention in the soil (from top to 60 cm depth) was highest for VC followed by OC and MC. It was mainly due to their higher P content and the retention of mineralized P at different depth during its downward movement. But the rate of retention on the basis of P content of the organic fertilizers were 35.66 %, 34.89 % and 36.66 % respectively for VC, OC and MC in the surface layer. In the sub-surface layer they retained nearly 32-33 % of its total P (Fig. 29)

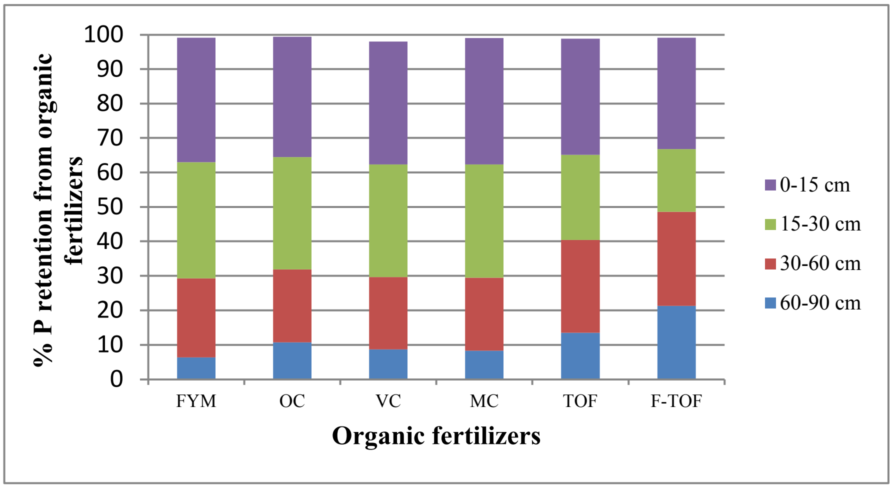

Fig. 29 Percentage of total P from organic fertilizers retained at different depths after leaching

Mineralization of organic fertilizers releases organic acid and it retains the mineralized phosphate anions in the soil solution (Guppy *et al.* 2005) and move downward along the leachate. During the downward movement, P gets fixed in the lower layers by the sesquioxide and kaolinite clay mineral present in the different layers. The potential of kaolinite clay and other clays minerals for the fixation of phosphate anion was reported by Chatterjee and Datta (1951). For all the organic fertilizers, more than 98 % of their total P (Fig. 29) was retained within 60 cm depth indicating its availability to a depth of 60 cm in red soils.

Considering the availability of P, it was highest from VC followed OC. The highest availability of P (Fig. 30) was from VC followed by OC and FYM. It was due to the higher P content in the organic fertilizers. Griffin *et al.* (2003) reported that the application of organic manures had increased the crop recovery of soil phosphorus and retained soil P in labile form which becomes available to crop in the course of time. Organic amendments increase the P availability in the acidic soil mainly by increasing the soil pH and thus by mineralizing the inherent soil P (Opala *et al.,* 2012). It was reported the vermicompost had a recovery of 42 per cent in contributing to P availability (Moghimi *et al.,* 2018). The availability of P from leached soil amended with F-TOF and TOF was comparatively less due to their lower P content and higher loss during leaching. However in the surface layer all the organic fertilizers maintained an available P content higher than that of organic fertilizer addition. But, in the sub soil this was not the case. At the lower depths also, availability of P decreased than their initial values, irrespective of the increase in the total P content. It indicates conversion of added P into the P- reserve of the soil. From the overall depths, the highest availability of P was from VC followed OC and FYM (Fig. 30)

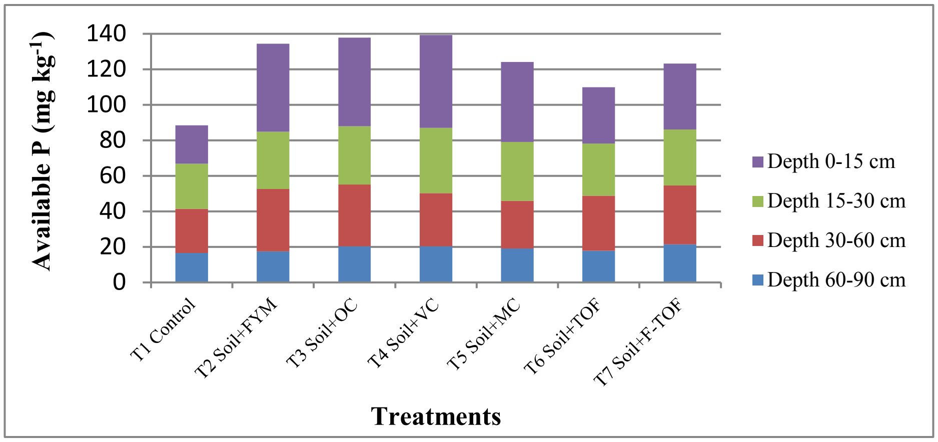

Fig. 30 Available P in the leached soil at different depths at 24th week

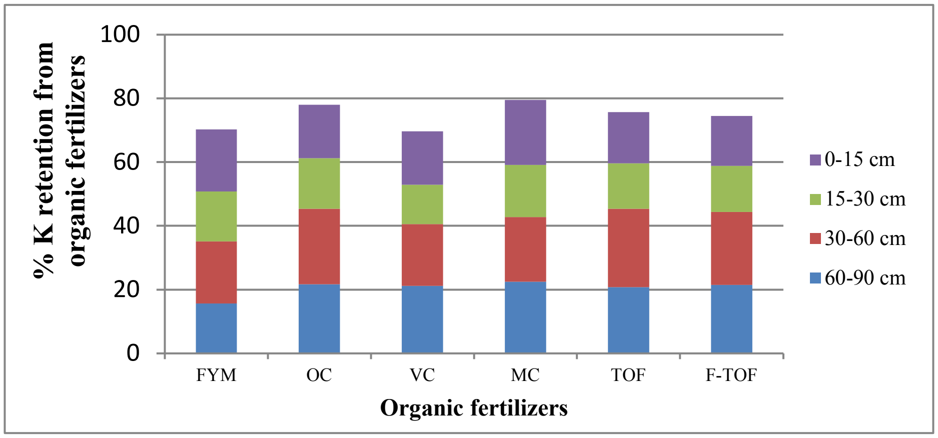

Fig. 31 Percentage of total K from organic fertilizers retained at different depths after leaching

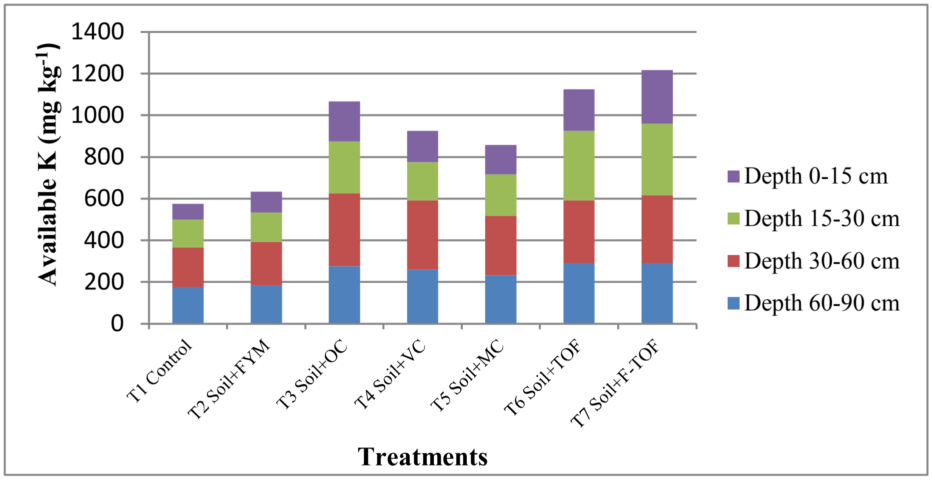

Fig. 32 Available K in the leached soil at different depths at 24th week

With the application of organic fertilizers, the highest K content in the surface layer was with F-TOF followed by VC and TOF and it was in proportionate with the K content of the organic fertilizers (Table 44). After leaching, the highest K content was retained with F-TOF at all the four depths. It indicates the mobility of mineralized K from the F-TOF at the surface layer and its retention at different depths. It was followed by MC and VC which has retained a higher K content at surface and sub-surface layer.

On the basis of the total K content of the organic fertilizers, MC had retained highest K content in the surface where 20.37 % of its total K content and in the sub-surface layer (15-30 cm) 16.36 % of its total K content was retained (Fig 31). VC has retained 16.74 % and 12.38 % of its total K in surface and sub-surface layer, respectively. F-TOF retained more K in lower layers *i.e.,* 23 % and 21 % in 30-60 and 60-90 cm vs. 16 % and 14.38 % in surface layers. It indicates that higher quantity of mineralized K from F-TOF has moved downwards and deposited at lower depths.

Considering the availability of K, in the surface and sub-surface layer, the highest availability of K (Fig. 32) was from F-TOF due their higher K content. It was followed by TOF and OC. The availability of K from overall depths was highest for F-TOF followed by TOF and OC (Fig. 32)

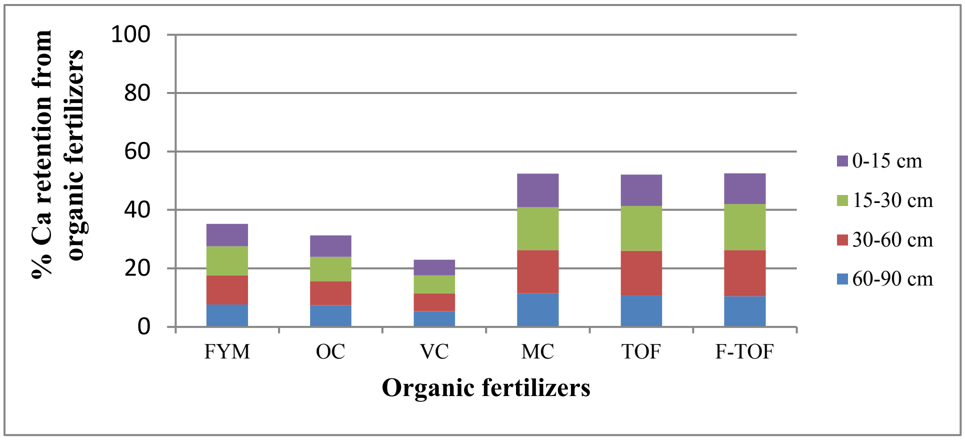

Fig. 33 Percentage of total Ca from organic fertilizers retained at different depths after leaching

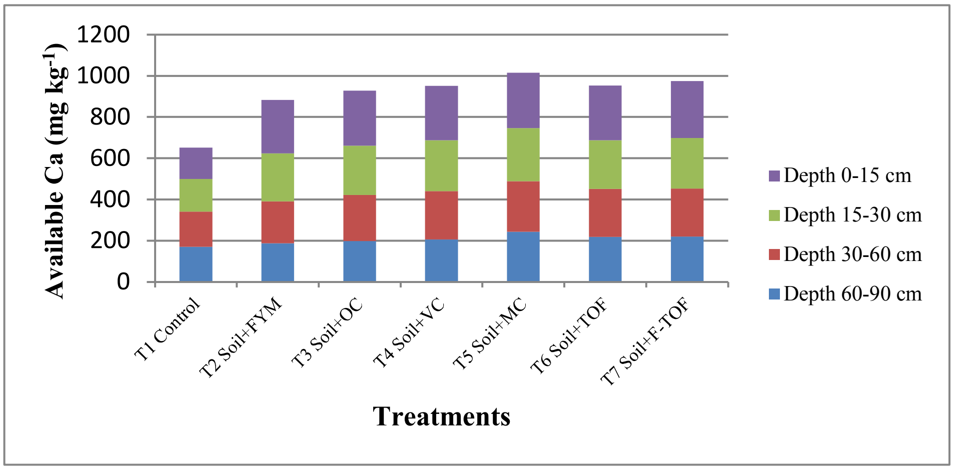

Fig. 34 Available Ca in the leached soil at different depths at 24th week

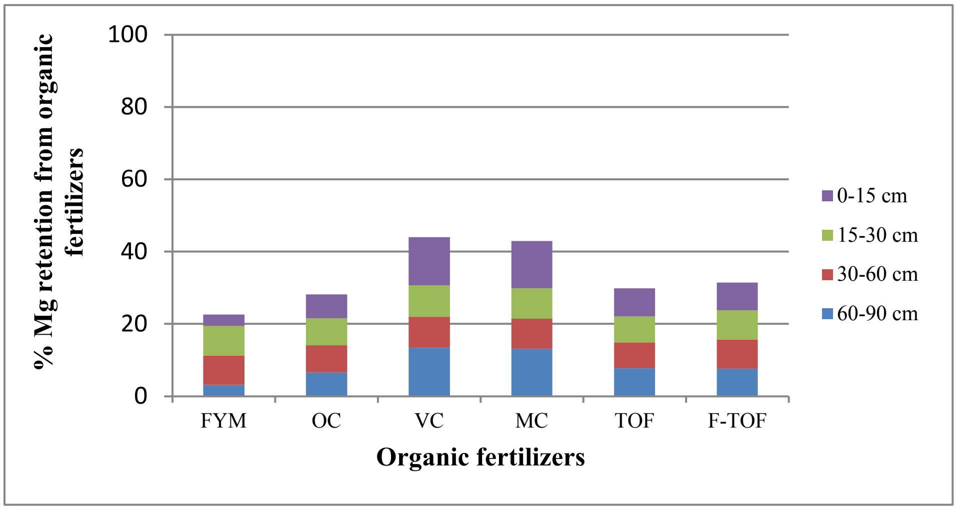

Fig. 35 Percentage of total Mg from organic fertilizers retained at different depths after leaching

With the application of organic fertilizers, the highest Ca content in the surface layer was with F-TOF followed by MC, VC and OC due their high Ca content (Table 75). After leaching, the highest Ca content in all the four depths was maintained by F-TOF followed by MC and TOF. On the basis of the total Ca content of the organic fertilizers, MC retained 11.5 % of its total Ca in the surface layer, while TOF and F-TOF retained nearly 10.5 % of its total Ca (Fig. 33). Considering all the depths, F-TOF retained 51% of its total Ca in soil, while TOF and MC retained 40 % and 30 % respectively. The availability of Ca in surface layer was highest for F-TOF followed by OC (Fig. 34). In the overall depth the highest availability of Ca was from MC followed F-TOF.

With the application of organic fertilizers, the highest Mg content in the surface layer was with F-TOF followed by VC and OC due their high Mg content (Table 46). After leaching, the highest Mg content in the surface layer was maintained by F-TOF (94.2 mg kg^{-1}) followed by VC and MC. F-TOF maintained a higher Mg contents at lower depths also. It indicates the mobility and deposition of Mg mineralized from the F-TOF. At the end of the leaching, F-TOF has retained 38 % of its total Mg within the four depths while VC and MC has retained 41 % and 40 % of its total Mg content, respectively. The highest availability of Mg in the surface layer (Fig. 35) was from F-TOF followed by VC and MC. The highest availability of Mg from overall depths was from F-TOF followed by VC. Application of organic amendments increases the nutrient availability by improving soil physical, chemical

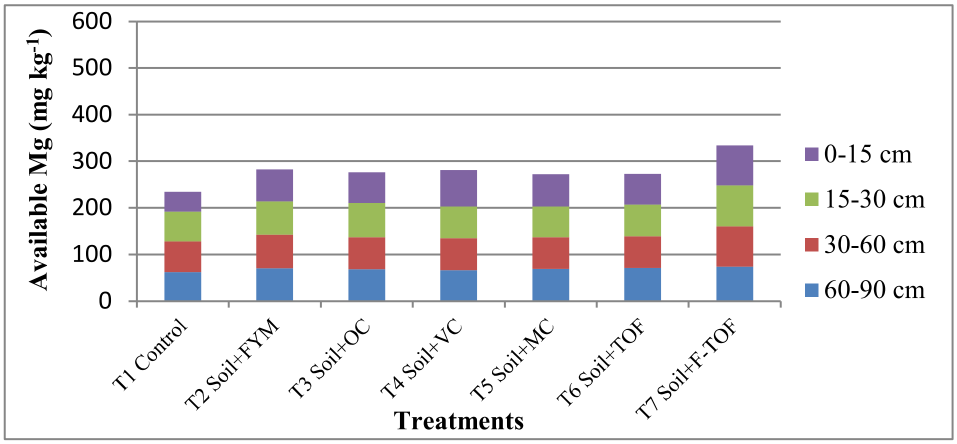

Fig. 36 Available Mg in the leached soil at different depths at 24th week

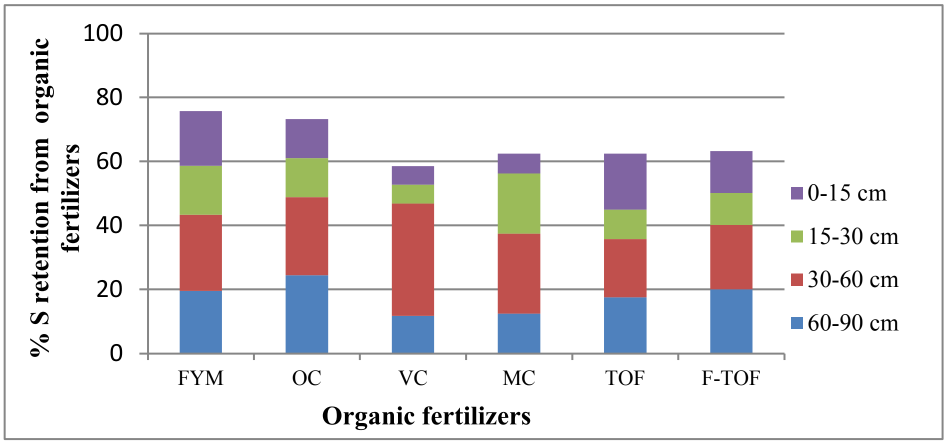

Fig. 37 Percentage of total S from organic fertilizers retained at different depths after leaching

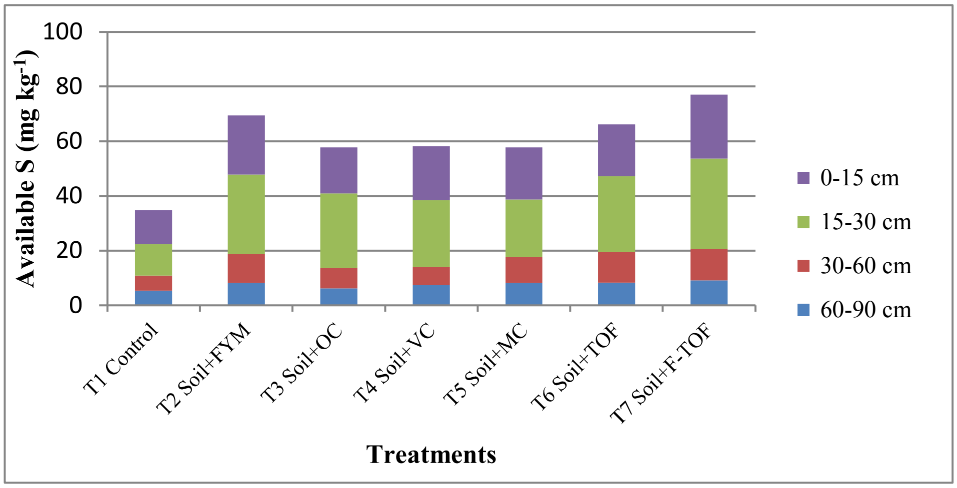

Fig. 38 Available S in the leached soil at different depths at 24th week

and biological properties of soil (Han *et al.,* 2016). Since water soluble source of Mg was used for fortifying the F-TOF, Mg^{2+} ions have moved downwards due its high mobility and thus the cumulative loss of Mg was highest from F-TOF (Fig. 36). Even though F-TOF retained a higher total Mg content and availability in the surface layer due the highest Mg content in the F-TOF.

After the application of organic fertilizers, the highest S content in the surface layer was with FYM (507.5 mg kg^{-1}) followed by OC and VC. After leaching there was a decrease in the content of S, but the same trend was followed. At 24 W, FYM has retained 17.16 % of its total S, while OC retained 12.20 % and VC retained 5.86 % of its total S (Fig. 37). Due to the higher mobility of SO_4^{2-} anion, the highest retention of S was at 30-60 cm depth when entire soil column was taken into account, FYM had the highest retention of S followed by OC. Considering the availability of S in the surface layer as well as in the overall depths, it was highest from F-TOF followed by FYM (Fig. 38).

With the application of organic fertilizers, the highest Fe content in the surface layer was with FYM followed by OC and VC due their high Fe content. After leaching at 24 W, the retention was highest for FYM followed by OC and MC. More than 98 % of total Fe was retained within the soil and about 40 % was locked in surface layer itself (Fig. 39).

In the overall depths, the availability of Fe availability was highest from F-TOF followed by VC (Fig. 40).

Before and after leaching, the highest Mn content in the surface layer was with VC followed by OC and MC due to their high Mn content. On the basis of the Mn content of the organic fertilizers, VC has retained 79 % of its total Mn content in the surface layer while, OC and MC has retained 82 % and 86 %, respectively of its total Mn content in the surface layer (Fig. 41).

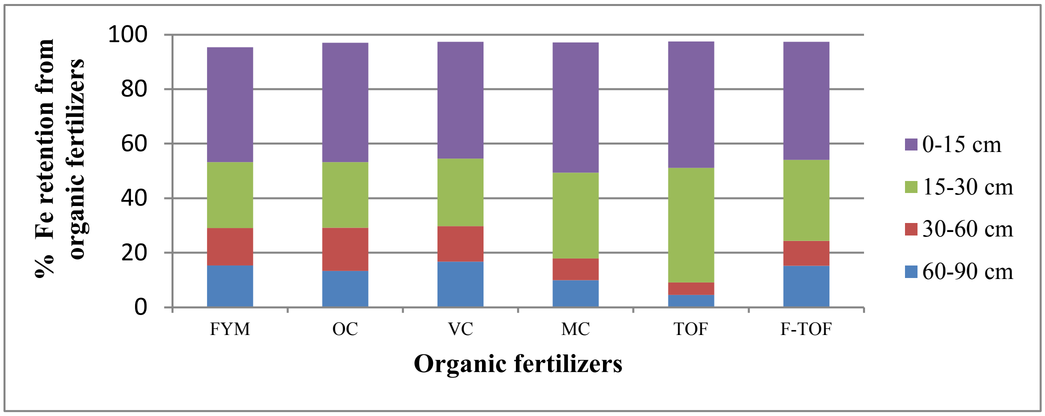

Fig. 39 Percentage of total Fe from organic fertilizers retained at different depths after leaching

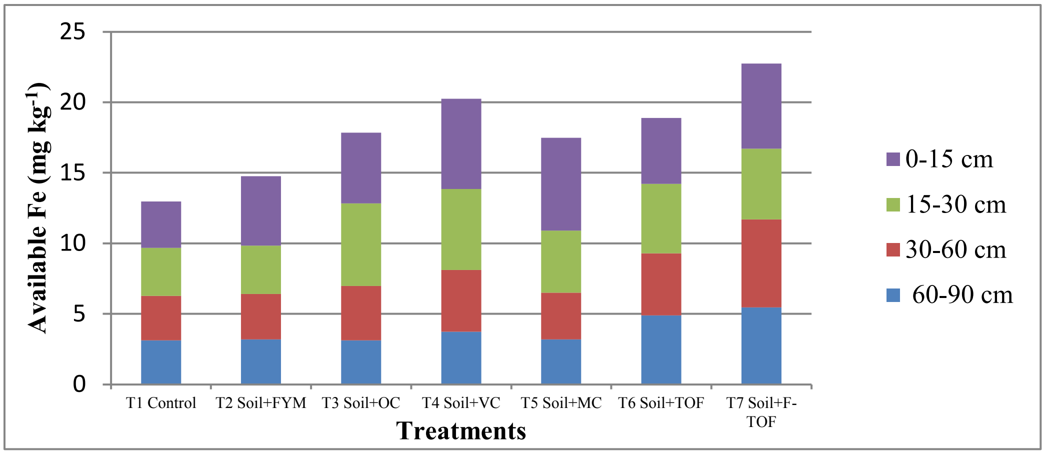

Fig. 40 Available Fe in the leached soil at different depths at 24th week

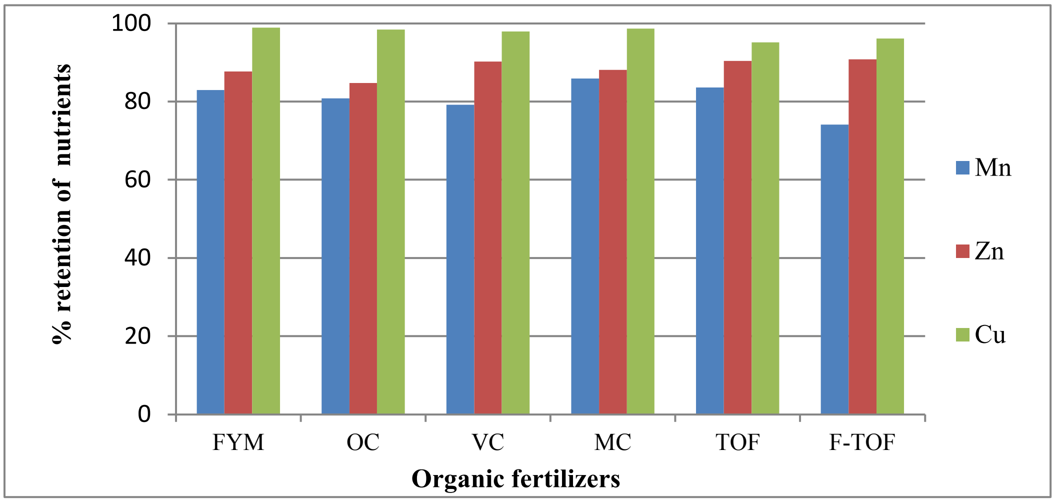

Fig. 41 Percentage of total Mn, Zn and Cu retained in the surface layer from organic fertilizers after leaching

The highest Zn content in the surface layer before and after leaching was with F-TOF followed by VC and OC due their high Zn content. After leaching F-TOF has retained 91 % of its total Zn in surface layer, while VC retained 90 % and OC retained 85 % of its total Zn in the surface layer (Fig. 41). Similarly for Cu also, the highest content in the surface layer before and after leaching was with VC followed by OC and MC. After leaching, VC has retained 3.54 % of its total Cu content in the surface layer, while OC and MC have retained 3.28 % and 3.16 % of their total Cu content (Fig. 41). For Fe, Mn and Zn, only a small portion was lost through leaching and remaining portion from the organic fertilizers was retained in the surface layer (0-15 cm) itself (Fig.41). Thus the content of these nutrients in the lower depths (15-90 cm) did not vary significantly among the treatments. The leaching loss and the downward mobility of micronutrients was comparatively less as these nutrients forms their chelated complex with the organic molecules. High amount of SOM in soils catalyze a series of reactions resulting in formation of more stable complexes of micronutrients (Dhaliwal *et al.,* 2019). The presence of functional groups like carboxylic acids and phenolics, are responsible for the complex formation and it determines the retention and mobility of the metal ions in soil (Sparks, 2003; Kleber *et al.,* 2010).

The availability of Mn (Fig. 42) was highest from VC followed by F-TOF .The availability of Zn (Fig. 43) was highest from F-TOF followed by VC. Similarly, for Cu the highest availability was from F-TOF followed by VC (Fig.44).

The total B content in the surface layer before leaching was highest with F-TOF followed by VC and OC in proportion to their B content. After leaching, the highest B content was with F-TOF followed by VC and MC. F-TOF has retained 54 % of its total B in the surface layer while VC retained 52 % and MC retained 56 % of its total B. In the overall depths F-TOF has retained 86 % of its total B, while VC and MC retained 91 % and 93 % of its total B content, respectively (Fig. 45). The high water soluble nature B source used for fortification is responsible for reducing the B

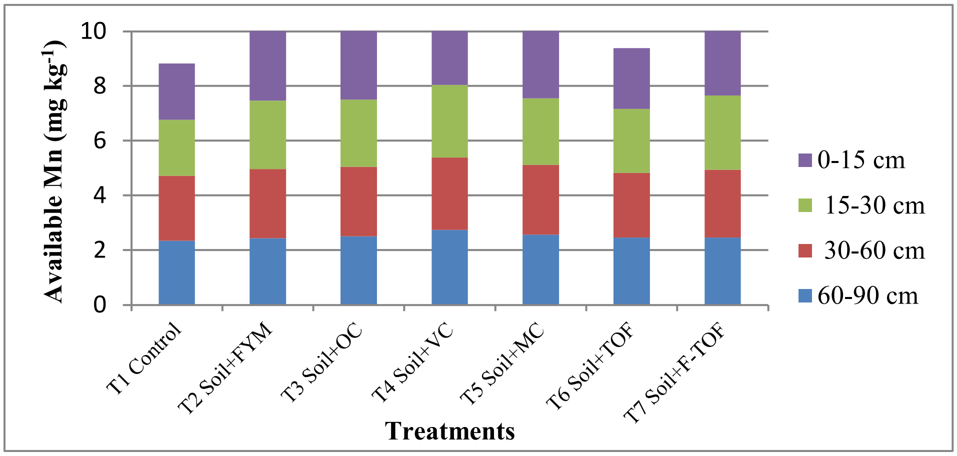

Fig. 42 Available Mn in the leached soil at different depths at 24th week

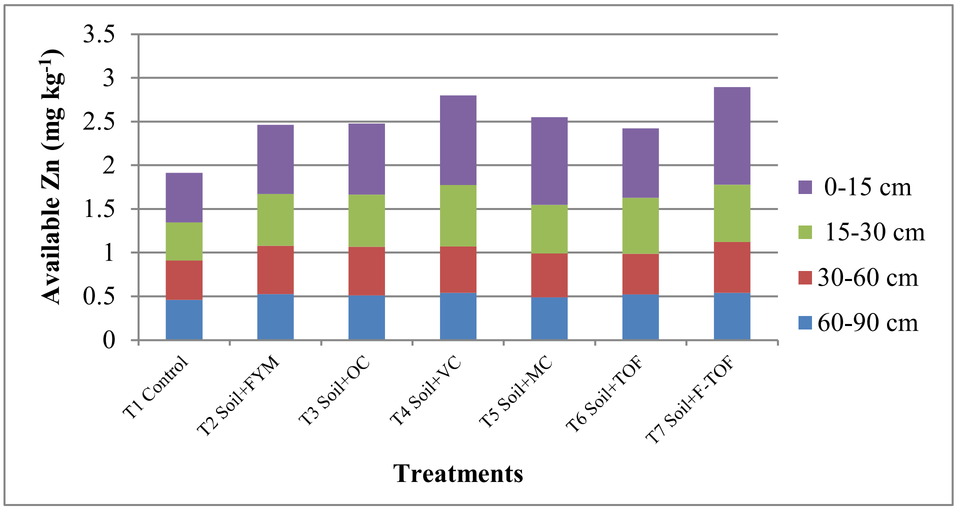

Fig. 43 Available Zn in the leached soil at different depths at 24th week

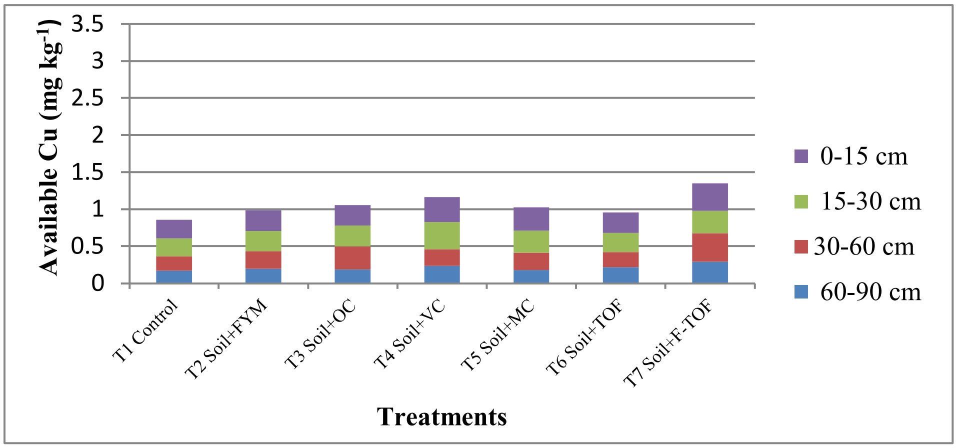

Fig. 44 Available Cu in the leached soil at different depths at 24th week

retention by F-TOF to 86 %. While in VC and MC, might have B in a organically complexed form to enhance the retention.

In the leached soil, all the fractions of B in the surfaces layer were highest in F-TOF amended soil, definitely due to its higher content. The availability of B in the soil is determined by two fractions of B such as readily available B (Ra-B) and specifically adsorbed B (Spa-B). In the leached soil, the highest value for these two fractions was maintained by F-TOF followed by VC and MC. Thus the availability of B is highest from F-TOF followed VC and MC (Fig. 46).

The percentage contribution of Ra-B to total B for F-TOF, VC and MC were 1.16 %, 1.69 % and 1.74 %, respectively and to Spa-B was 1.59 %, 2.25 % and 2.29 % respectively (Fig. 47) for Spa-B.

The leaching loss of nutrients was highest with F-TOF (Table 16). Even though, the application of F-TOF retained a higher level of nutrients in the surface layer due their higher nutrient content. The soil column amended with F-TOF retained higher concentration of K, Ca, Mg, Zn and B in the leached soil compared to other organic fertilizers. It was mainly due to the higher content of these nutrients in F-TOF. Among the organic amendments FYM found to be the best option for retaining S and Fe in the soil and VC for retaining P and micronutrients, such as Mn, and Cu.

In the case of availability of nutrients in the leached soil, F-TOF has maintained the highest availability of K, Mg, S, Fe, Zn, Cu and B. The availability of P and Mn was highest from VC and that of Ca from MC. The availability of the nutrients from the soil depend on different factors such as soil pH, nutrient content in the soil, their chemical form, nature and amount of clay minerals, organic matter content in the soil, soil process like immobilization and fixation etc.

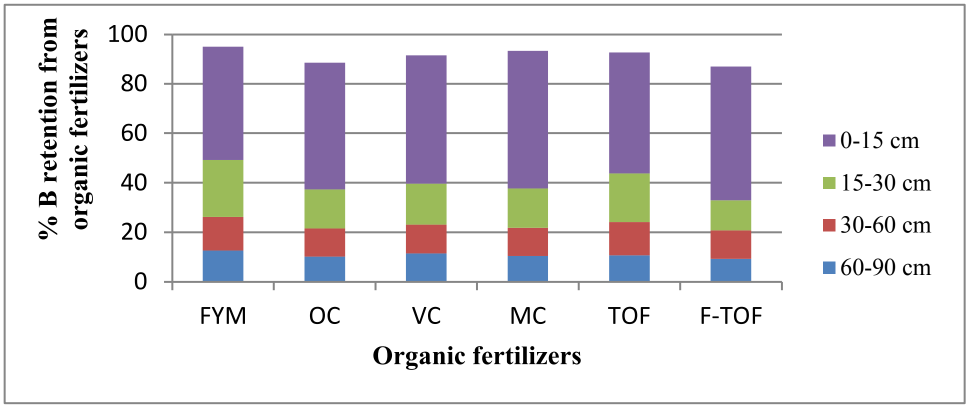

Fig. 45 Percentage of B from organic fertilizers retained at four different depths

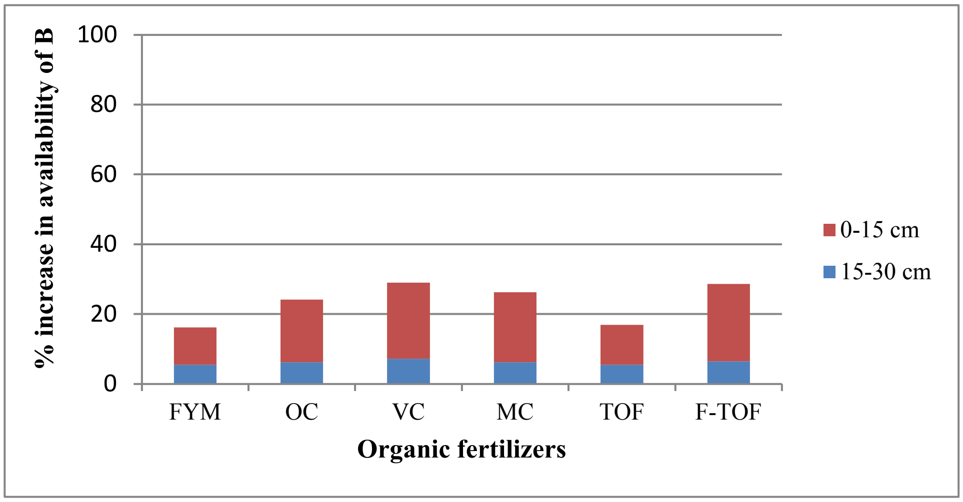

Fig. 46 Percentage increase in the B availability at surface and subsurface layer over the control at 24th week

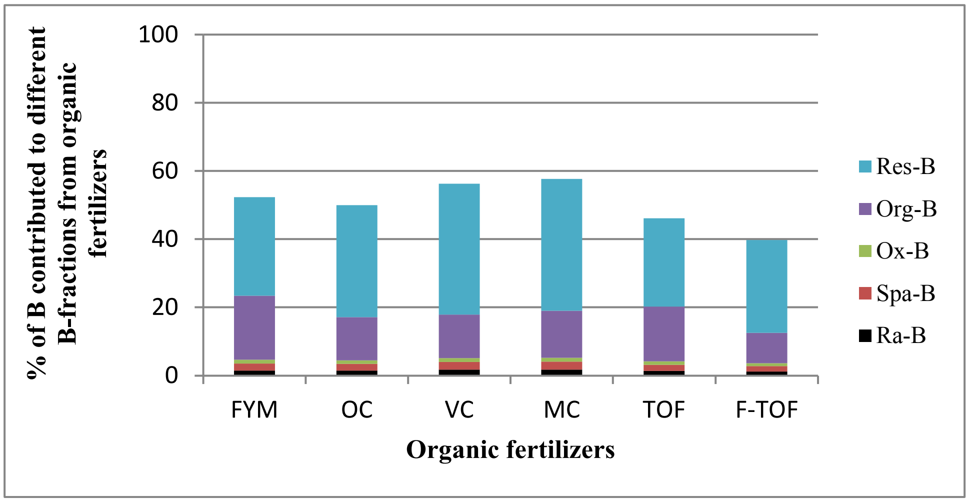

Fig. 47 Percentage contribution of organic fertilizers to different fractions of B

Addition of organic fertilizers had definitely increased the nutrient content of the soil. Even after leaching for 24 weeks, the nutrient content of organic fertilizer amended soil were higher than that before the addition of organic fertilizers for most of the nutrients. This has indicated the ability of organic fertilizers to improve soil nutrient status in tropical soils which receives very high precipitation. The organic fertilizers tested vary in their capacity for nutrient retention. F-TOF was able to retain the highest quantity of K, Mg, S, Fe, Cu and B in the soil compared that of pre-organic fertilizer addition. But the leaching loss of P, K, Mg, Cu and B was also highest from F-TOF. Thus evaluating the performance of thermochemical organic fertilizers, especially F-TOF, further research is needed for selecting the most suitable fortifying agent for P, Mg Cu and B. In the case of K, since it is needed for decomposing organic matter as the reagent KOH, an alternative reagent may also be explored to reduce its leaching loss.

5.3 INCUBATION STUDY

Organic fertilizers are good source of nutrients though their contents are far below that of chemical fertilizers. But their slow decomposition ensures slow and continuous availability of nutrients for longer periods. Organic fertilizers applied to the soil for improving the soil physical properties enhances the nutrient availability and maintains the soil health for sustainable crop production.

Organic fertilizers include different types of composts; FYM, green manures, bio-fertilizers etc. and they differ from each other in the nutrient contents and release pattern based on their physicochemical characteristics. However, it is crucial to study the nutrient release pattern of the organic fertilizers so as to understand the stages of peak nutrient release and net mineralization. Thus, we can adjust the time of application in such a way that stages of nutrient requirement of the crop plants coincide with peak nutrient availability from the organic fertilizers. Otherwise the mineralized nutrients remain unutilized and lost from the soil polluting the ecosystem.

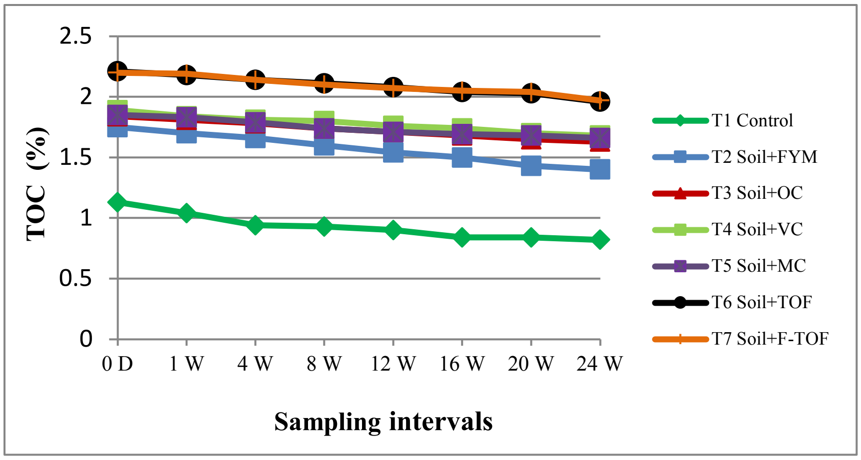

Fig. 48 TOC content of soil at different periods of incubation

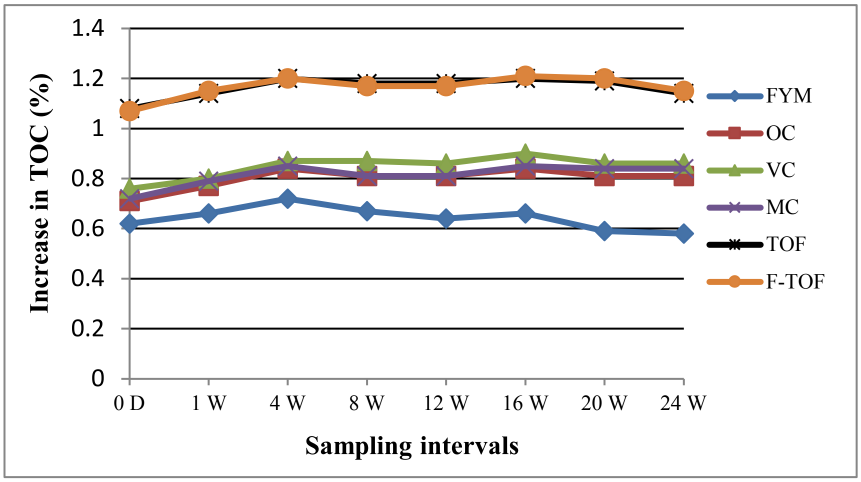

Fig. 49 Percentage increase in TOC on addition of organic fertilizers

5.3.1 Decomposition of organic fertilizers and contribution to soil carbon pools

The decomposition and rate of mineralization of organic fertilizers were mainly controlled by their C:N ratio. Hence they differ in their decomposition pattern and release of organic constituents. All the organic fertilizers tested had a C:N ratio less 25 and thus the mineralization process was not hindered. Paul and Clark (1989) reported that net N mineralization occurs when C:N ratio of organic residues is less than 25. Similar results were also reported by Trinsoutrot *et al.* (2000).

Organic fertilizers are added to the soil to enhance the soil organic carbon pools apart from the nutrient supply. The different carbon pools in the soil are total organic carbon, labile carbon, water soluble organic carbon, microbial biomass carbon and recalcitrant organic carbon. Mineralization of organic fertilizers is mediated by microorganisms. They consume labile portion of organic carbon and mineralize the nutrients in the organic fertilizers. During the process a portion of organic carbon was lost as CO_2. Remaining portion is conserved in different carbon pools. Based on the nature of the organic substrate their contribution to different pools is varied.

Due to the uniqueness in the method of production, thermochemical organic fertilizers (F-TOF and TOF) are characterized with a high TOC content and thus they maintained a higher TOC in the soil throughout the incubation (Fig. 48). The organic fertilizers OC, VC and MC also contributed similarly to the TOC content of the soil (Fig. 49) as the TOC content of these organic fertilizers were also high (Table 50). As incubation proceeded, the TOC of the soil amended with organic fertilizers decreased gradually, indicating the narrowing of C:N ratio and C mineralization. The water soluble organic carbon (WSOC) was the highest at 0 D (Fig. 50) which declined up to 4 W due to the utilization by microbes. An increasing trend was shown towards 8 W followed by a decrease from 12 W onwards, indicating the decrease in mineralization and stabilization of organic carbon in the soil. Similar results were reported by

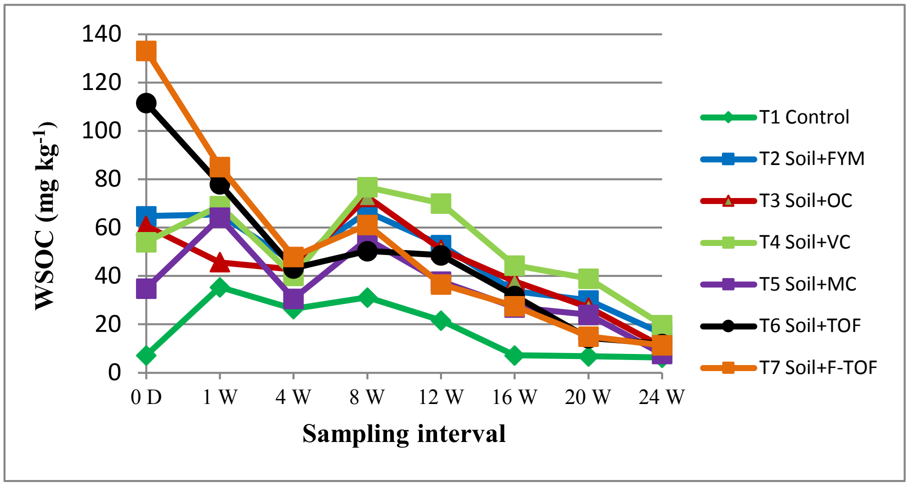

Fig. 50 WSOC content of soil at different periods of incubation

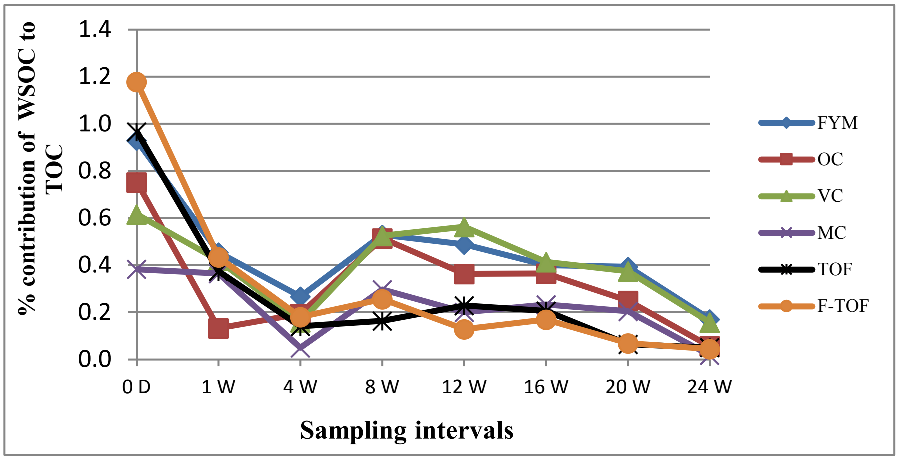

Fig. 51 Percentage of WSOC contributed to TOC

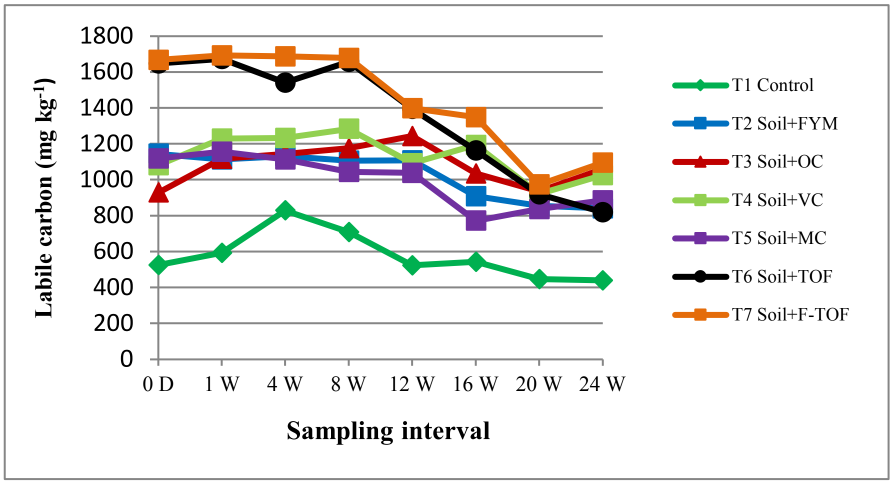

Fig. 52 Labile carbon content of soil at different periods of incubation

Trinsoutrot *et al.* (2000) where WSOC increased with decomposition of organic matter and decreased later with stabilization of the organic carbon. Stabilization of soil organic carbon occurs by the adsorption of organic carbon onto clay minerals and iron or aluminium hydrous-oxides (Saidy *et al*., 2012). On 0 D, thermochemical organic fertilizers contributed higher percentage of WSOC to TOC (Fig. 51), due to peculiarities in the method of production which conserve the labile portion of organic carbon. Later it declined due to the conversion to microbial biomass carbon. From 8 W onwards, the organic fertilizers such as FYM, OC and VC contributed a higher percentage of WSOC to TOC (Fig. 51). WSOC is the most mobile and reactive C fraction (Marschner and Kalbitz, 2003) and is involved in several processes that occur in the soil (Chantigny, 2003). Thus it enhances the microbial mediated mineralization activities in the soil. This fraction consists of the intermediate products of organic residue degradation, such as proteins, carbohydrates, hydrocarbons, and their derivatives as well as of fractions of low-molecular-weight humic substances and numerous other simpler organic compounds (Gonet and Debska, 2006) and increase in WSOC is an indication of mineralization and release of nutrients from organic substrate.

The labile carbon is considered as an indicator of soil health as this C-fraction is readily available for microorganisms as an energy source. The F-TOF and TOF have maintained a higher level of labile carbon throughout the incubation period (Fig. 52) and it was mainly due to their high TOC content and a proportionate contribution to the labile carbon pool of the soil. The positive correlation between the TOC content of the soil and its labile carbon fractions was reported by Souza *et al.* (2016). However the contribution to labile pools by TOF and F-TOF declined with time. In all the organic fertilizer added treatments, there was an increase in the amount of labile carbon up to 12 W (Fig. 52) and declined afterwards indicating the stabilization of organic carbon mineralization. The organic fertilizers OC and VC exhibited similar trend and maintained a higher labile carbon pool after F-TOF and TOF. Up to 8 W,

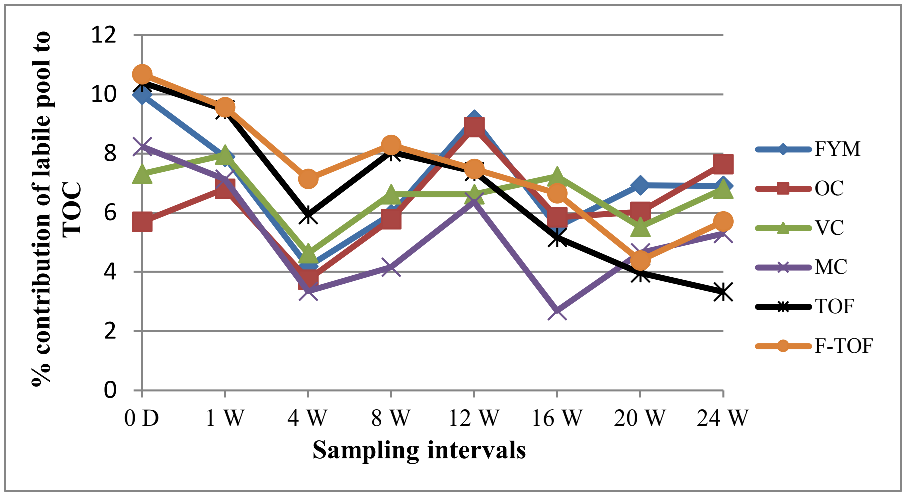

Fig.53 Percentage of labile carbon contributed to TOC

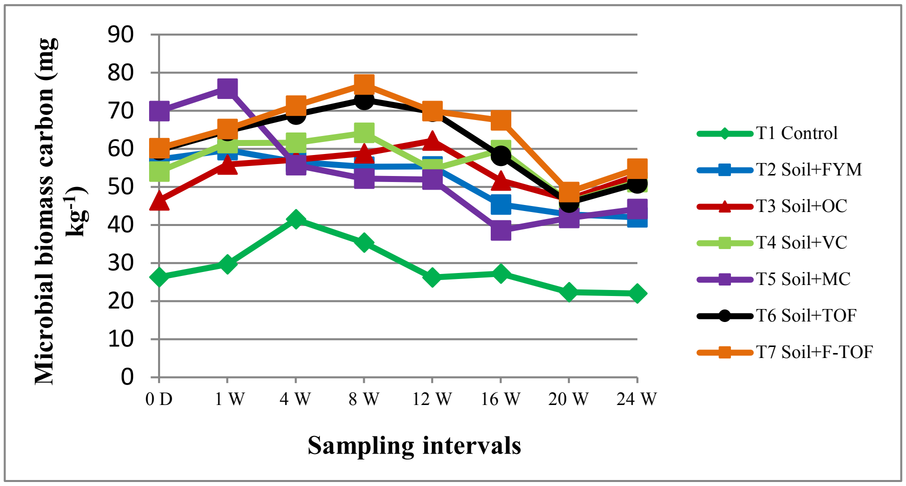

Fig. 54 MBC in the soil at different periods of incubation

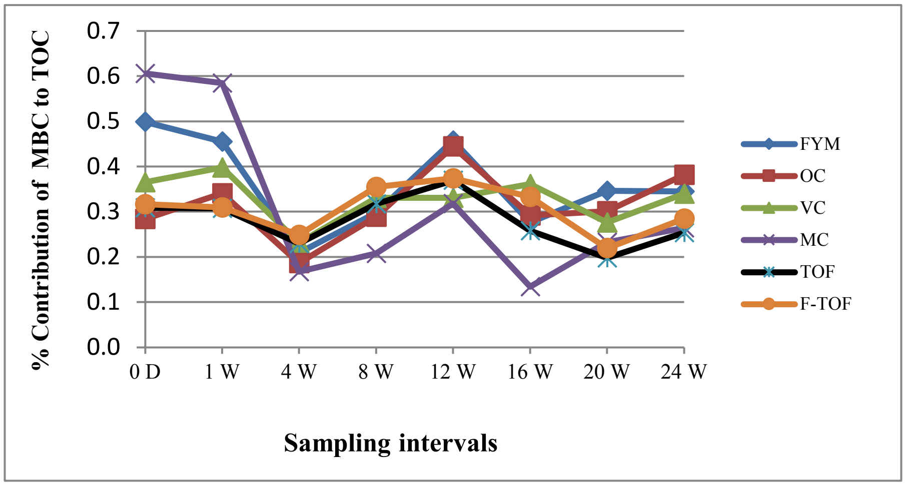

Fig. 55 Percentage of MBC contributed to TOC

thermochemical organic fertilizers contributed higher percentage of their labile carbon to TOC (Fig. 53) and later declined indicating that the peak decomposition is over by 8 W. From 12 W onwards other organic fertilizers have contributed comparatively higher percentage of labile carbon to TOC and indicate the process of mineralization and production of simpler carbon compounds from complex structures.

Microbial biomass carbon (MBC) is another indicator of soil health. Application of organic amendment increases the microbial population and thereby increases MBC in the soil. From 4 W onwards, the MBC was the highest with F-TOF amended soil (Fig. 54) and it was mainly due to the increased microbial load in the soil. The high amount of water soluble organic carbon content in the F-TOF amended soil (up to 4 W) promoted the growth of microbes and it has reflected as MBC. In all the organic fertilizer added treatments, the MBC increased up to 8 W and later declined due to decrease in the amount of labile carbon and stabilization of organic carbon (Table 73). All the organic fertilizers had their peak percentage contribution to MBC at 12 W, except VC where it had at 16 W (Fig. 55). Initially (up to 1 W), MC had the highest percentage contribution of MBC to TOC. There exists a positive correlation between the various labile fractions, as well as between these fractions and the total organic carbon in the soil (Souza *et al.,* 2016). Thus a decrease in the amount of labile carbon was reflected in the MBC content in the soil.

Recalcitrant organic carbon is the C-fraction that is highly resistant for decomposition. The TOF and F-TOF amended soil has maintained a higher level of ROC content in the soil (Fig. 56) throughout the incubation period and it was mainly due to their higher TOC and ROC contents in the thermochemical organic fertilizers (Table 9 and Fig. 3). The recalcitrance nature of TOF and F-TOF was mainly due their higher lignin content (Table 11). Lignin fraction is highly resistant to microbial degradation. The recalcitrant organic carbon usually refers to the component of SOM that is resistant to microbial decomposition or protected by mineral soil particles

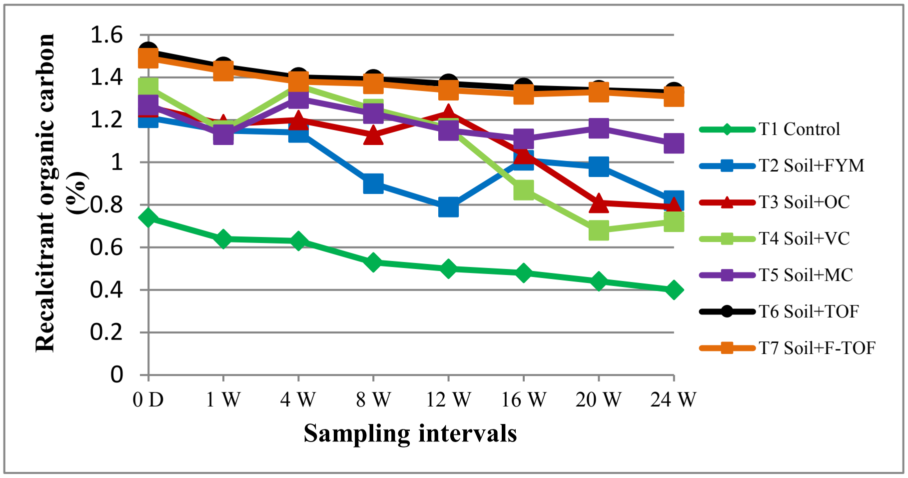

Fig. 56 ROC in the soil at different periods of incubation

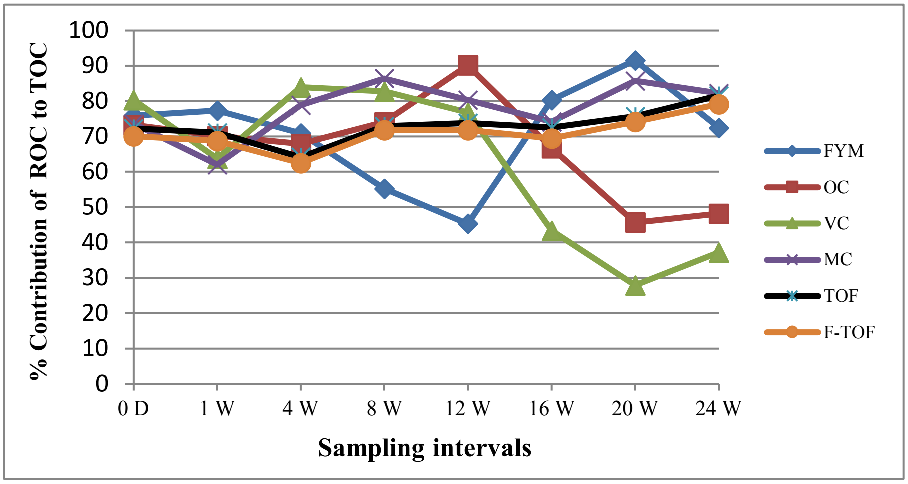

Fig. 57 Percentage of ROC contributed to TOC

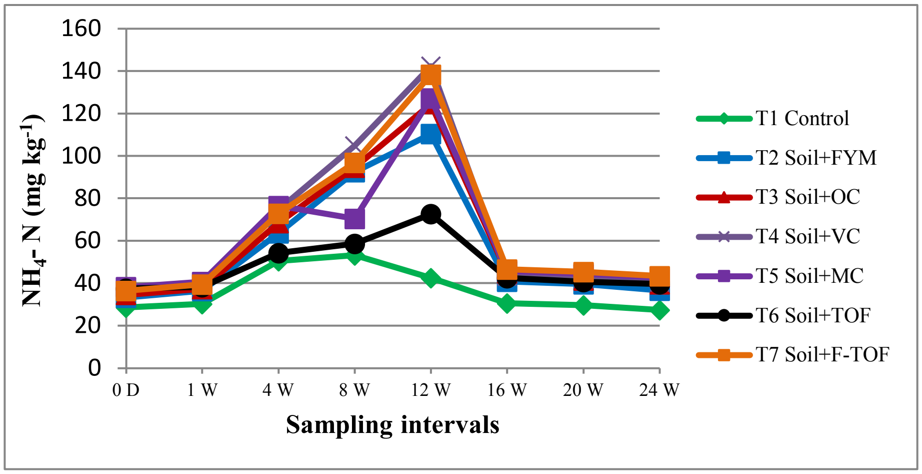

Fig. 58 NH_4-N content in the soil at different periods of incubation

(Fang *et al.* 2005; von Lützow *et al.,* 2007). The lignin content in the organic fertilizers such as OC, VC and MC were almost same. Thus a similar pattern in the ROC content maintained in the soil amended with these organic fertilizers. Also the higher C:N ratio of TOF and F-TOF checks the mineralization rate and evolution loss of C as CO_2. The higher content of ROC in the soil indicates longer residential potential of organic carbon and conservation of soil carbon pools. The percentage contribution of organic fertilizers to the ROC pool gradually increased with time. At the end of the incubation (24 W) MC, TOF and F-TOF has contributed 82.14, 81.58 and 79.13 % of their ROC to TOC pool respectively (Fig. 57).

5.3.2 Nutrient dynamics under application of thermochemical organic fertilizer

Nutrient dynamics is broadly defined as the way nutrients are taken up, retained, transferred, and cycled over time and distance, in an ecosystem (Hauer and Lamberti, 2006; Allan and Castillo, 2007). The nutrients present in the soil are in a dynamic state where they transform in to different forms. Organic fertilizers when added to the soil decompose to release nutrients and these nutrients are retained and transformed to their different forms in the soil.

5.3.2.1 N-mineralization and contribution to soil nitrogen pools

Organic amendments added to the soil mineralize slowly and enhance the soil nitrogen pools. The nitrogen mineralized from the organic fertilizers exists in their different forms and they are interchangeable. The nutrient dynamics in the organic fertilizer amended soil is highly versatile as these transformation processes are mainly mediated by microorganisms. The dynamics of mineral N mainly depend on organic N content and C:N ratio of the organic matter (Trinsoutrot *et al.,* 2000).

The thermochemical organic fertilizers both TOF and F-TOF added to the soil mineralized slowly contributing to the different pools of nitrogen. All the organic

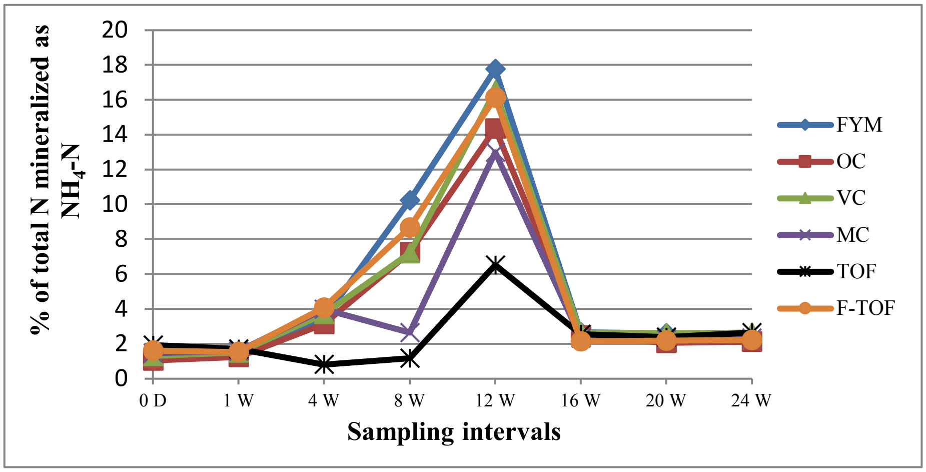

Fig. 59 Percentage of total N mineralized as NH_4-N

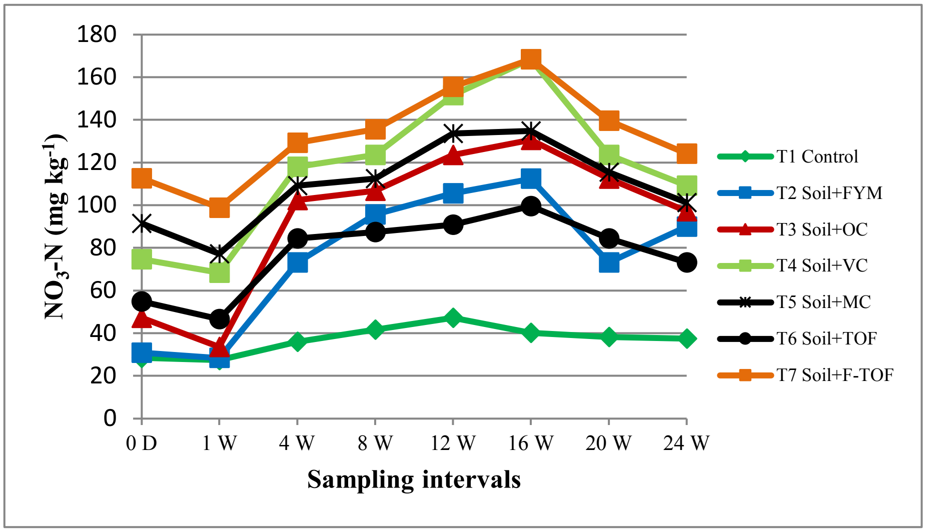

Fig. 60 NO_3-N content in the soil at different periods of incubation

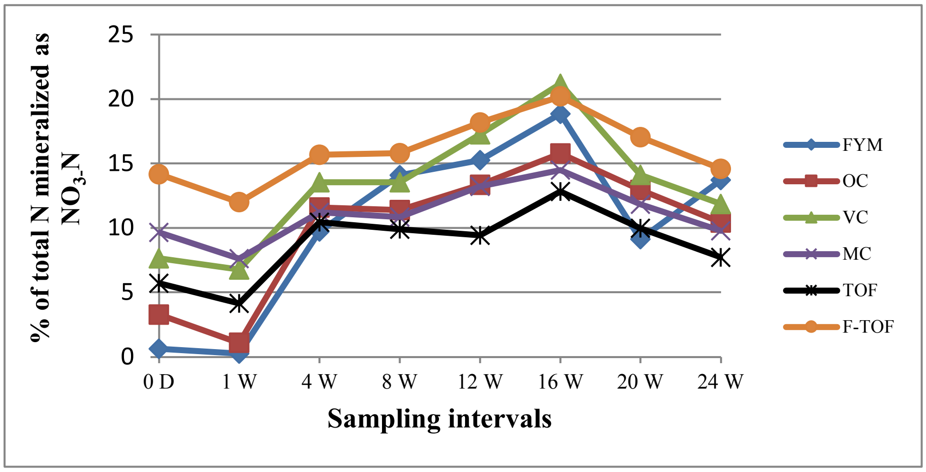

Fig. 61 Percentage of N mineralized as NO_3-N

fertilizers had similar pattern for ammonification where the highest NH_4-N content in the soil (Fig. 58) as well as highest percentage contribution as NH_4-N to total N was at 12 W of incubation (Fig. 59). At 12 W, NH_4-N contributed 17.75 % of total N from FYM followed by other organic fertilizers VC, F-TOF, OC and MC contributing 16.53, 16.13, 14.35 and 12.99 % respectively as NH_4-N to total N. The TOF contributed only 6.52 % as NH_4-N to the total N pool and was the lowest.

During the incubation all the organic fertilizers had the highest NO_3-N content at 16 W indicating the time for the completion of one cycle of N mineralization is about 16 weeks (Fig. 60) and nitrification is at its peak during 12 W to 16 W. The percentage contribution of NO_3-N to total N such as VC, F-TOF, FYM, OC, MC and TOF were 21.19, 20.20, 18.85, 15.78, 14.49 and 12.83 %, respectively (Fig. 61).

However, taking in to account, the total N mineralized from different organic fertilizers, all had their peak N value at 12 W (Table 75 and 76). It was mainly due to the peak drop in the NH_4- N content from 12 W to 16 W, while increase in the NO_3-N content for the period was gradual. Hence the peak period of ammonification coincided with that of total N mineralized. When the percentage mineralization from each organic fertilizer is considered it is slightly different from the pattern discussed above. The total N mineralization from different organic fertilizers, all the fertilizers except FYM had their peak N-mineralization at 12 W (Fig. 62) with the highest N mineralization from F-TOF (34.32 % of total N) followed by VC (33.79 % of total N) and FYM (33 % of total N). FYM had highest peak at 8 W. Results were in conformity with findings of Hartz *et al.* (2000).

The contribution of organic fertilizers to organic form N was the highest during 0 D and 1 W (Fig. 63). Later it decreased as mineralization proceeds. The depletion in the organic N content was noticeable from 8 W to 12 W. However, mineralization decreased and immobilization had replenished the organic N pool in the soil towards the end of incubation. At the end of the incubation, the highest percentage of organic N to total N (Fig. 63) was contributed by organic fertilizers TOF (89.64 %), MC (87.91%) and OC (87.44 %).

During the incubation, an abrupt and intense peak in NO_3-N mineralization was observed with VC at 16 W (Fig. 61). On the other hand, a constant, sustained and more or less uniform progressive rate of NO_3-N mineralization, reaching the highest at 16 W. Similar finding regarding N mineralization was reported by Calderón *et al.,* 2004.

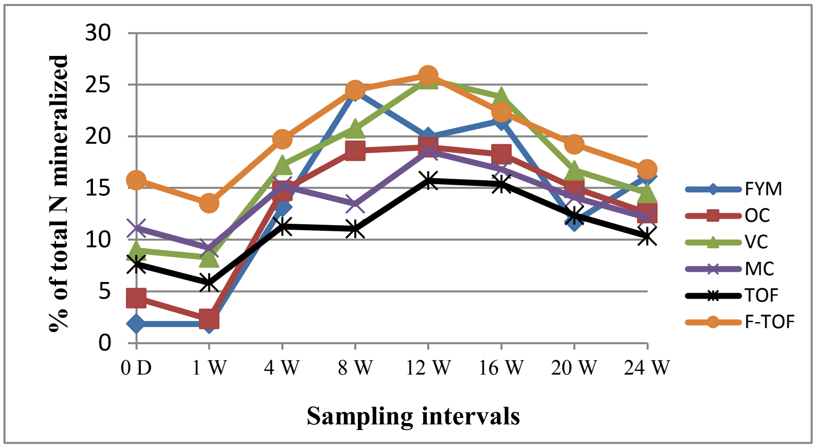

Fig. 62 Percentage of total N mineralized

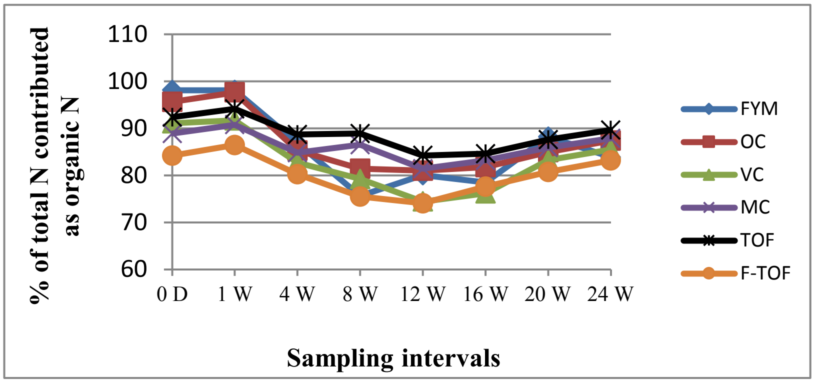

Fig. 63 Percentage contribution of organic N to total N

It was mainly due their higher N content and lower C:N ratio of VC which enhanced the N availability in the soil. However the highest percentage of total N was mineralized from F-TOF (Fig. 62). F-TOF also showed an intense peak on 16 W, but with slightly lower slope since it had a better NO_3-N on 12 W and 20 W. Both VC and F-TOF had shown almost similar performance during that period. Even though MC had a higher N content and lower C:N ratio than VC, the higher microbial load in MC had immobilized a part of N and decreased the amount of N mineralized. MC underwent short cycles of mineralization and immobilization in a repetitive manner, with the magnitude of mineralization being constantly lower throughout the period of incubation. Thus a higher organic N fraction was maintained by MC throughout the incubation and it was the nitrogen component that has immobilized in the microbial biomass. Similar result was reported by Jensen (1994) where organic residue with low C:N ratio had immobilized mineral N and a threshold value did not precisely monitor the changes that occur to mineral N with time. Similar results regarding the N-mineralization were reported by Hadas and Portnoy (1994) and Lazicki *et al.* (2020). The superior beneficial effect of F-TOF in contributing to the mineralization of N is more pronounced in the Fig. 62, where the steady progressive mineralization is represented by a smooth curve, gradual increment in total mineralization in a sustained manner.

5.3.2.2 Nutrients release from organic fertilizers and their dynamics in soil

The total nutrient content in the organic fertilizer amended soil increased in proportion to the nutrient content present in the organic fertilizers (Table 25 and 26). The highest total K, Ca, Mg, Zn and B contents in F-TOF amended soil was due to the higher concentration of these nutrients in F-TOF. Similarly total P, Mn and Cu contents in the soil was highest with VC, total N with MC and total S and Fe with FYM amended treatments.

The availability of nutrients in the soil amended with different organic fertilizers varied depending on the nature and nutrient content of organic fertilizers. Organic fertilizers contribute nutrients as well as help to mineralize the inherent nutrients in the soil. The total nutrient content in the soil had a direct influence on the availability of nutrients in the soil. Thus the availability of K, Ca, Mg, Zn and B was the highest in F-TOF amended soil. Similarly, the availability of P, Mn and Cu was highest with VC amended soil and that of S with FYM and F-TOF amended soil. But Fe was an exception. Even though Fe content was the highest in FYM, the availability during incubation was the highest from F-TOF. Fe availability might have been influenced by other factors like pH. FYM had a pH greater than 7 and this might have reduced the Fe availability.

The mineralization pattern of each organic fertilizer differs from the other as it was affected by the characteristics such as pH, carbon and nitrogen content, C:N ratio, nutrient content and composition etc. The highest availability of P from F-TOF amended soil on 0 D was due to presence of fertilizer P which was added to it at the time of production. In the later stages of incubation, the highest P availability was from VC amended soil, due to its higher P content. It is the C:P ratio of the organic substrate that determines the net P-mineralization from the soil. Higher P content reduces C:P ratio (< 200) and result in net mineralization of P from organic fertilizers. All the organic fertilizers had their peak P mineralization at 12 W, where 61.04, 38.19, 35.07, 52.20, 67.84 and 53.96 % of P was mineralized from FYM, OC, VC, MC, TOF and F-TOF, respectively (Fig. 64). After 12 W, available P decreased in the soil due to immobilization and fixation.

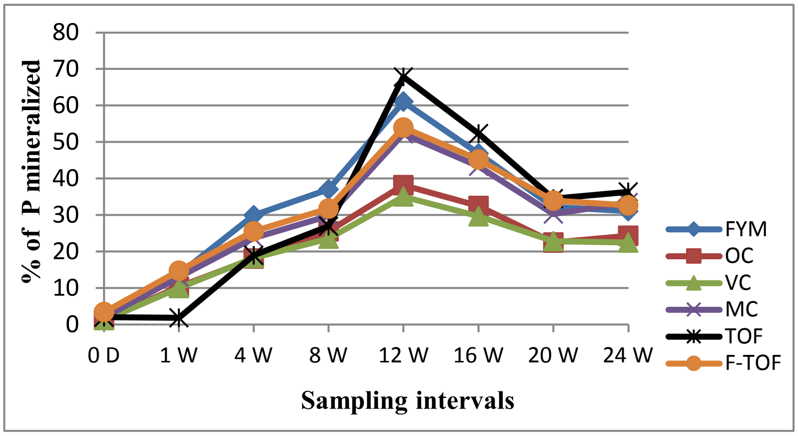

Fig. 64 Percentage of P mineralized from different organic fertilizers

Mineralization of P was mainly mediated by the extracellular phosphates enzymes released by the microorganism (McGill and Cole, 1981). A portion of mineralized P was immobilized in to microbial biomass (Wu *et al.,* 2007). The fixation of P as Fe-P and Al-P is a very common phenomenon in Kerala soil, thereby reducing the P availability in the soil (Dinesh *et al*., 2014).

The K availability was always highest for F-TOF amended soil mainly due its higher K content. The peak mineralization of K from FYM, OC, VC and MC was at 12 W and that of TOF at 20 W and F-TOF at 16 W. The percentage of K mineralized from FYM, OC, VC, MC, TOF and F-TOF were 73.62, 68.82, 66.92, 50.28, 41.75 and 59.38 %, respectively (Fig. 65). After 12 W, K availability slightly declined in the soil due to immobilization. Unlike other organic fertilizers studied, percentage mineralization of K from F-TOF yielded a smooth curve which registered a constant gradual increment up to 16 W and there after declined smoothly. Eghball *et al.* (2003) have reported that the organic manures mineralize 100% of K as similar to the inorganic fertilizers. Also the application of organic fertilizers reduces the fixation of K in the soil by masking the charges (Ahmad *et al.,* 2016)

Throughout the incubation, F-TOF maintained the highest Ca availability. The F-TOF had mineralized 48.57 % of its total Ca at 8 W itself and then the mineralization rate decreased (Fig. 66). The Ca release from F-TOF was consistently in a sustained manner represented by a flattened curve and that too maintaining the available Ca content in the soil at levels higher than deficient status, maintaining sufficiency. Though the percentage mineralization from OC, FYM and VC surpassed F-TOF after 8 W of incubation, available Ca in soil from these sources remained deficient throughout. The comparatively early release and availability was mainly due the presence of lime and other mineral nutrients it contained. But for TOF, Ca was released slowly and had its peak mineralization at 20 W where 46.11 % of its total Ca was mineralized. The availability of Ca in FYM, OC and F-TOF increased up to 12 W and declined while for VC, MC and TOF increased up to16 W, before the decline.

From 12 W onwards the Ca availability from VC amended soil was slightly higher than F-TOF and it indicates a higher mineralization from VC at later stages of incubation. The highest percentage contribution as available Ca from VC was at 16 W where 70 % of total Ca from VC was mineralized. Similar results were reported by Dey *et al.* (2019) where vermicompost had their peak mineralization after 120 days of

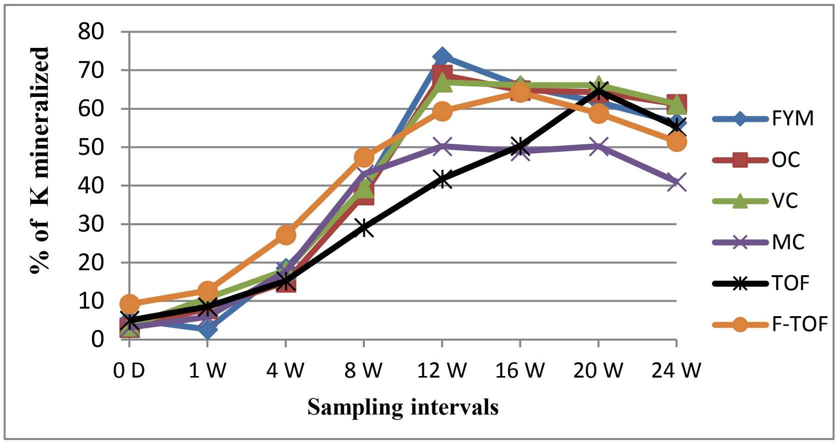

Fig. 65 Percentage of K mineralized from different organic fertilizers

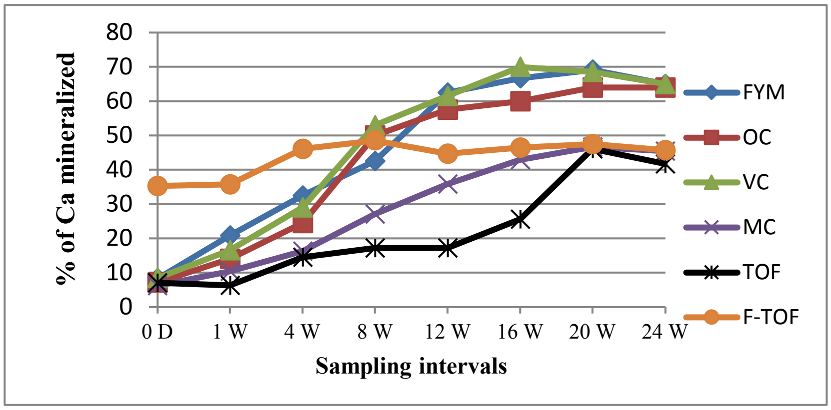

Fig. 66 Percentage of Ca mineralized from different organic fertilizers

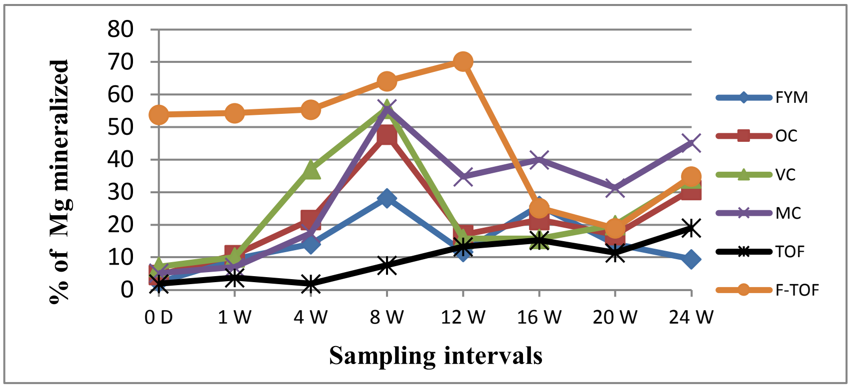

Fig. 67 Percentage of Mg mineralized from different organic fertilizers

incubation and mineralize 24.4 % of total Ca. For FYM, OC and MC, the highest contribution as available Ca was at 20 W, where 69.17, 64 and 68.50 % of total Ca was mineralized respectively from each organic fertilizer. Similar results were reported by Dey *et al.* (2019)

F-TOF was superior to all other organic fertilizers in supplying available Mg (Table 30) and it was mainly due to their higher Mg content. The availability Mg increased up to 8 W, in FYM, OC, VC, and MC and up to 12 W in TOF and F-TOF. The highest percentage contribution as available Mg from organic fertilizers were at 8 W, where 28.24, 47.69, 55.71, 55.65 and 64.10 % of the total Mg was mineralized from organic fertilizers FYM, OC, VC, MC, TOF and F-TOF, respectively. TOF had its peak mineralization at 16 W and only 15.24 % total Mg was mineralized (Fig. 67). Similar results were reported by Dey *et al.* (2019).

The availability of S from FYM and F-TOF increased up to 16 W, while that of other organic fertilizers up to 20 W. The availability of S was highest from F-TOF up to 4 W. But from 8 W onwards, the highest availability was from FYM followed by F-TOF. Similar results regarding the potential of FYM in supplying S was reported by Dey *et al.* (2019), where 26.3 % of total S mineralized and concluded as the best source of S in the soil. For S, the highest mineralization for FYM, TOF and F-TOF occurred at 16 W, where 12.53, 12.69 and 20.29 % of the total S was in available form. Similarly OC, VC and MC had contributed the highest percentage as available S at 20 W where 15.13, 17.42 and 18.87 % of S was mineralized (Fig. 68).

F-TOF and TOF have contributed to the highest Fe availability in the soil throughout the incubation and the highest value at 1W. Later declined and stabilized around constant value by 4 W which was comparable to the percentage contribution from the other organic fertilizers. The availability of Fe was highest from FYM, OC, TOF and F-TOF at 12 W and from VC and MC at 8 W.

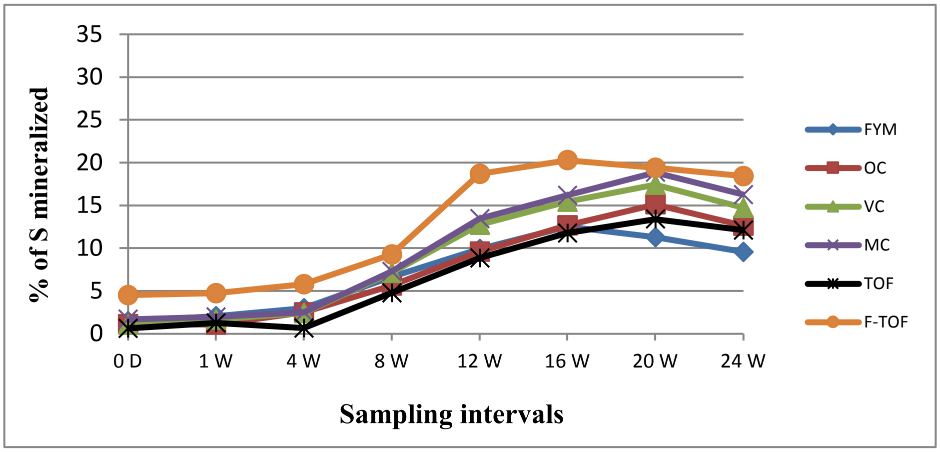

Fig. 68 Percentage of S mineralized from different organic fertilizers

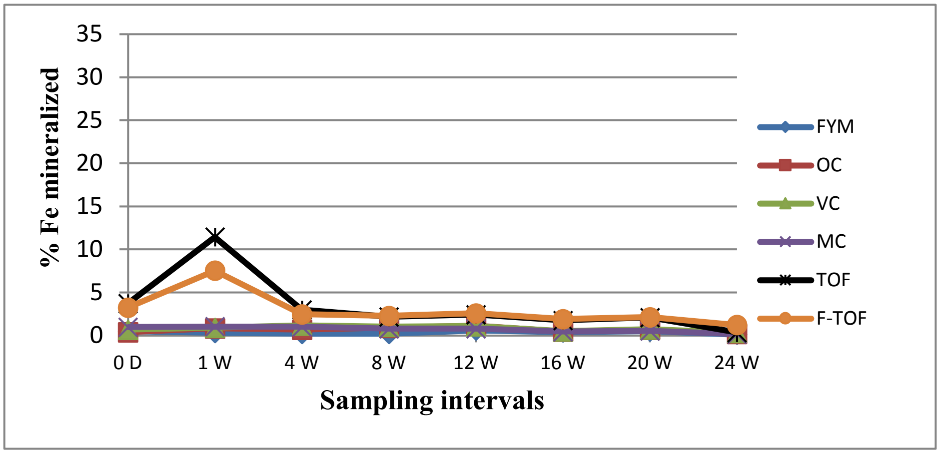

Fig. 69 Percentage of Fe mineralized from different organic fertilizers

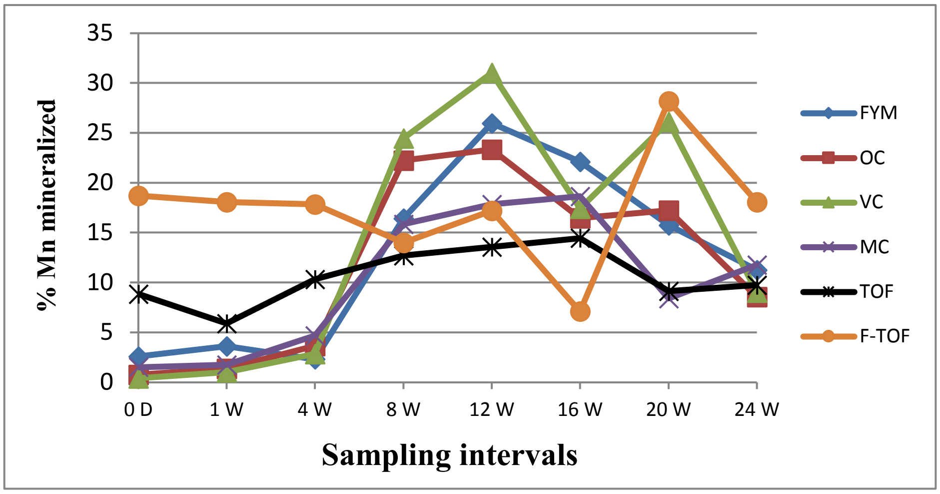

Fig.70 Percentage of Mn mineralized from different organic fertilizers

The percentage of Fe mineralized from VC and MC was the highest at 4 W and by FYM (0.61 %) and OC (1.16 %) was at 12 W (Fig. 69). Initially F-TOF and TOF had higher available Fe (4W). But that also declined with time (Table 85). The availability of Fe in the soil has decreased may be due to the formation of stable organic complexes of Fe (Barber, 2014).

The availability of Mn increased up to 12 W in FYM, OC, VC and F-TOF and up to 16 W in MC and TOF. The availability of Mn was highest with F-TOF up to 4 W and later VC had maintained the highest Mn availability. For available Mn (Fig. 70), the highest percentage contribution from FYM, OC, VC and F-TOF (17.20 %) was at 12 W and MC and TOF at 16 W. Results were in conformity with finding of Dey *et al.* (2019).

Throughout the incubation, the highest availability of Zn was from F-TOF mainly due to its higher Zn content. All organic fertilizers amended soil had their peak Zn availability at 12 W and declined thereafter. The highest percentage contribution to available Zn was from F-TOF (13.86 %) followed by FYM (11.52 %) and MC (10.79 %) at 12 W of incubation (Fig. 71). Similar results were reported by Dey *et al.* (2019).

All the treatments had their peak Cu availability at 12 W except TOF where it was at 16 W. Throughout the incubation, except 8 W, the highest availability of Cu was from F-TOF, but at 8 W the highest availability was from VC. All the organic fertilizers were almost similar in their Cu availability. In some stage Cu availability from different organic fertilizers were statically on par (Table 88). The highest percentage contribution to available Cu by F-TOF (9.84 %) was at 8 W and by TOF (2.24 %) and MC (5.95 %) at16 W, while FYM (8.50 %), OC (7.68 %), VC (7.46 %) was at 12 W (Fig. 72). The results obtained regarding the mineralization pattern of organic fertilizers were in conformity with findings of Eghball *et al.* (2003).

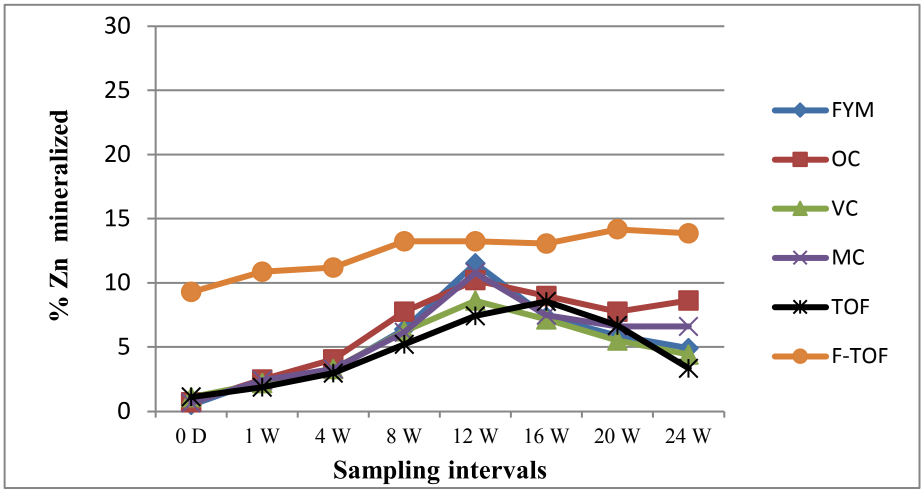

Fig. 71 Percentage of Zn mineralized from different organic fertilizers

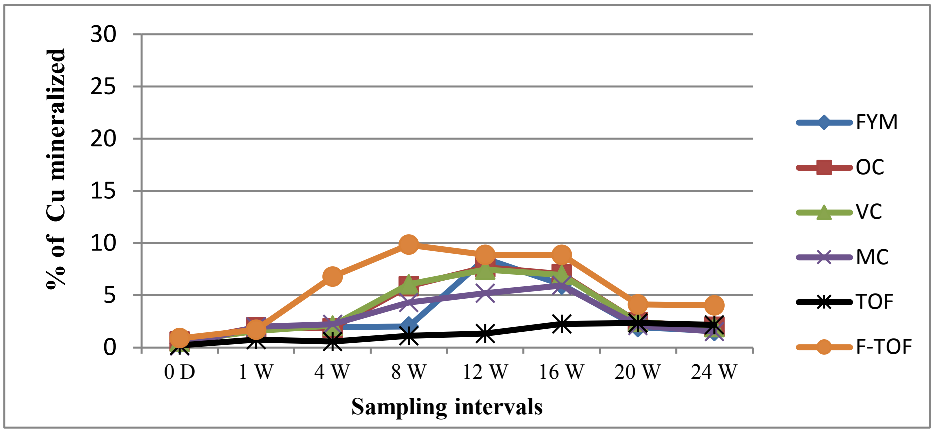

Fig.72 Percentage of Cu mineralized from different organic fertilizers

In all the organic fertilizer amended soils, the release of nutrients followed a pattern of increase towards a peak followed by a decline and the peak was at 12 W for most of the nutrients. It indicates the transformation and stabilization of nutrients in soil. The dynamic of nutrients in the soils is mainly influenced by the biological activity in the soil. The main biological properties studied in relation to nutrient dynamics are microbial count in the soil and dehydrogenase activity in the soil. The dynamics of different nutrients and the microbial activity in the soil are directly affected by the composition of different organic amendments added to the soil (Kwabiah *et al.,* 2003). However, throughout the incubation the highest microbial count as well as dehydrogenase activity was maintained by MC amended soil.

5.3.2.3 Dynamics of Boron under influence of organic fertilizers

The soil boron exists as different fractions. It includes readily available boron (Ra-B), specifically adsorbed B (Spa-B), oxide bound B (Ox-B), organically bound B (Org-B) and residual B (Res-B). The Ra-B is the fraction of B, weakly adsorbed on the soil particles, and is most readily available for plant uptake (Padbhushan and Kumar, 2017). The Spa-B is the fraction that are specifically adsorbed on to clay surfaces or associated with OM in soil (Jin *et al.,* 1987). The Ox-B fraction is associated with oxides and hydroxides of Fe and Al. The Org-B is the fraction of B associated with organic matter. Residual B is the fraction associated with primary and secondary minerals within the crystal structure and considered as the non-labile form of B (Shuman and Hargrove, 1985; Chao and Sanzolone 1989). So this fraction is totally unavailable for plant uptake. Residual B accounts for the major portion of total soil B and it is nearly about 87.4 - 99.7% of total B (Padbhushan and Kumar, 2017).

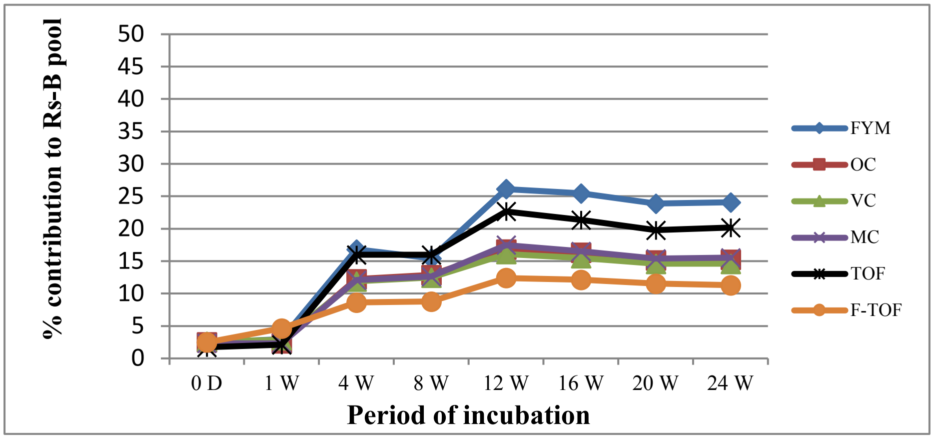

Fig. 73 Percentage contribution to readily available B from different organic fertilizers

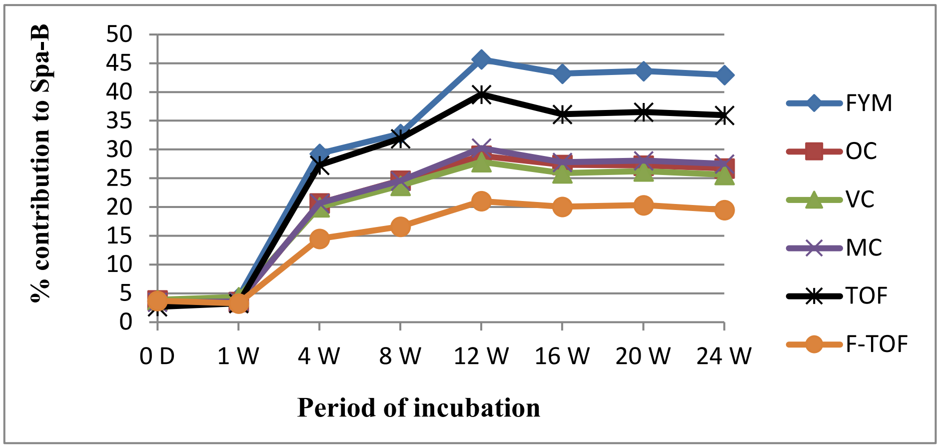

Fig. 74 Percentage contributions to specifically adsorbed B from different organic fertilizers

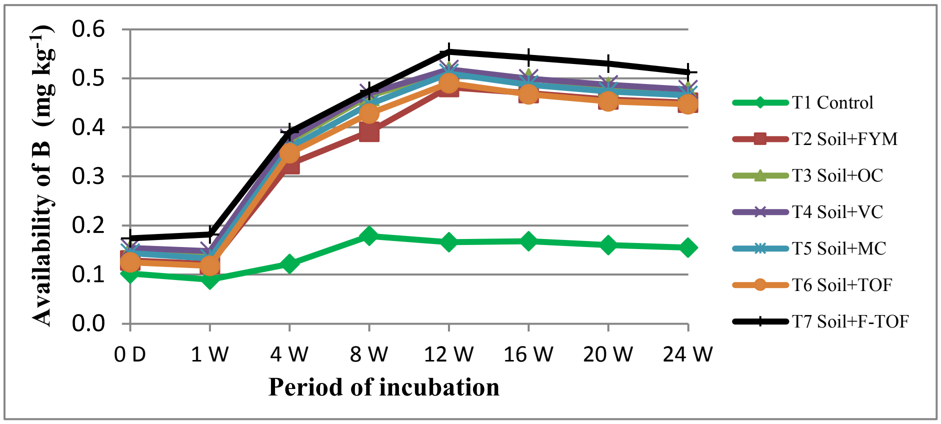

Fig. 75 Availability of B during the period of incubation

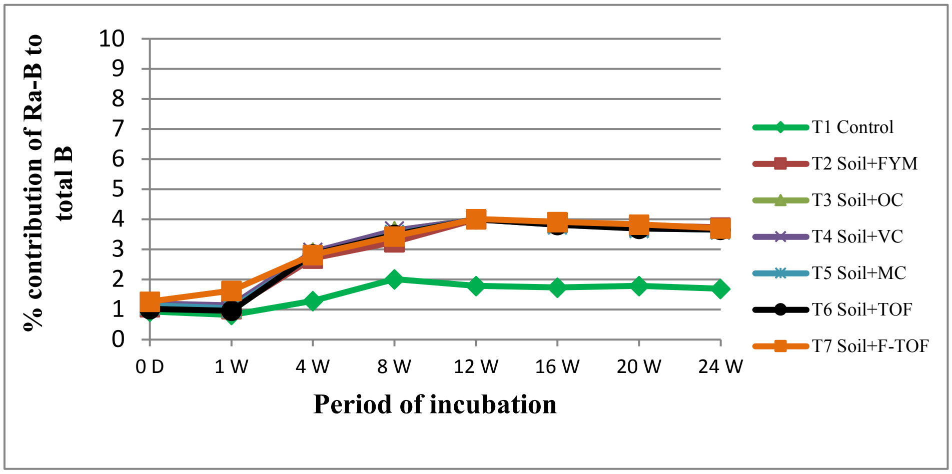

Fig. 76 Percentage contribution from Ra-B to total B

Application of organic fertilizers had a significant influence on different fractions of B and there by B availability. Throughout the incubation, B fractions were transforming among one another. All the organic fertilizers had their peak B mineralization at 12 W, where 26.14, 16.84, 16.13, 17.50, 22.69 and 12.41 % of total B was mineralized from FYM, OC, VC, MC, TOF and F-TOF, respectively (Fig. 73) and contributed to Ra-B. Similarly, 45.68, 28.95, 27.88, 30.28, 39.62 and 21.03 % total B was mineralized from FYM, OC, VC, MC, TOF and F-TOF, respectively and contributed to Spa-B (Fig. 74). It is the boron fractions such as Ra- B and Spa-B contribute towards the available of boron in soil (Padbhushan and Kumar, 2017). With the addition of FYM, OC, VC and F-TOF, the availability of boron gradually increased up to 12 W and for MC and TOF increased up to 20 W (Fig. 75). However, throughout the incubation higher availability of B was from F-TOF followed by VC and OC. It was mainly due to the higher B content in these organic fertilizers.

For control treatment, the percentage of Ra-B to total B in soil ranged from 0.82 to 2.01 %.With the application of organic fertilizers percentage of Ra-B to total B has increased up to 1.02 to 4.01 % of total B (Fig. 76). Similarly specifically adsorbed B increased from 1.23 -2.10 % to 1.45 - 6 % of total B (Fig. 77).

Oxide bound B is a less labile fraction of B, constitute less than 3 % of total B and is usually available for crop uptake (Jin *et al.,* 1987). With the application of organic fertilizers, oxide bound B increased from 0.32 to 0.64% to 0.49 - 2.59 % of the total B (Fig. 78). The red loam soil are with appreciable amount of oxides and hydroxides of Fe and Al and this also had favoured the increase in oxide bound B in the soil. The ox-B in increased up to 16 W in soil amended with FYM, OC, VC and F-TOF, while increased up to 20 W in MC and TOF.

In the entire organic fertilizer amended treatment organic bound B fraction increased up to 12 W and declined gradually with the stabilization of organic matter. Organically bound B in the soil increased from 1.53 to 1.71 % to 2.18 to 9.01% of the

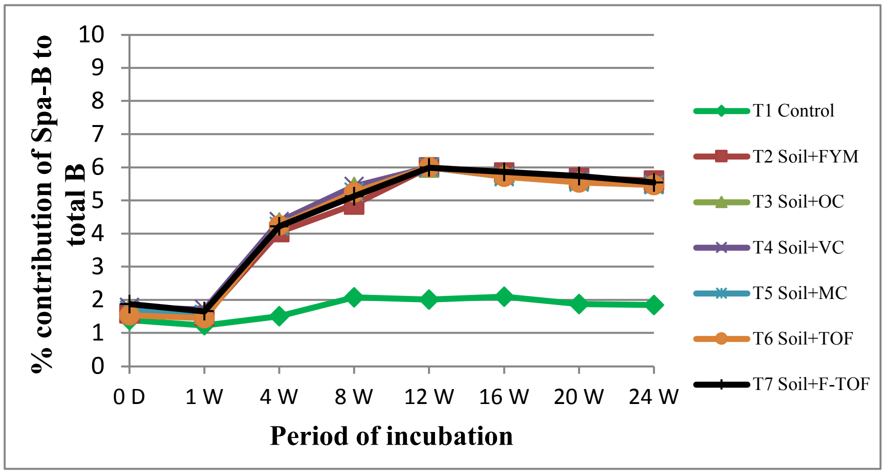

Fig. 77 Percentage contribution from Spa-B to total B

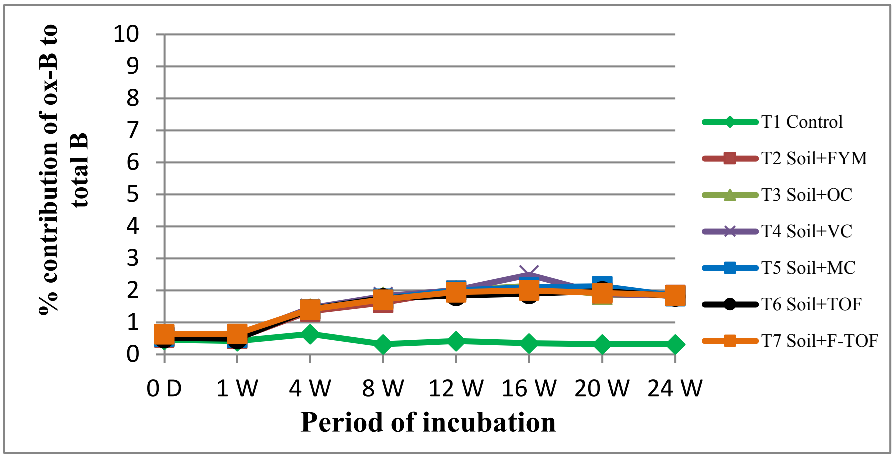

Fig. 78 Percentage contribution from Ox-B to total B

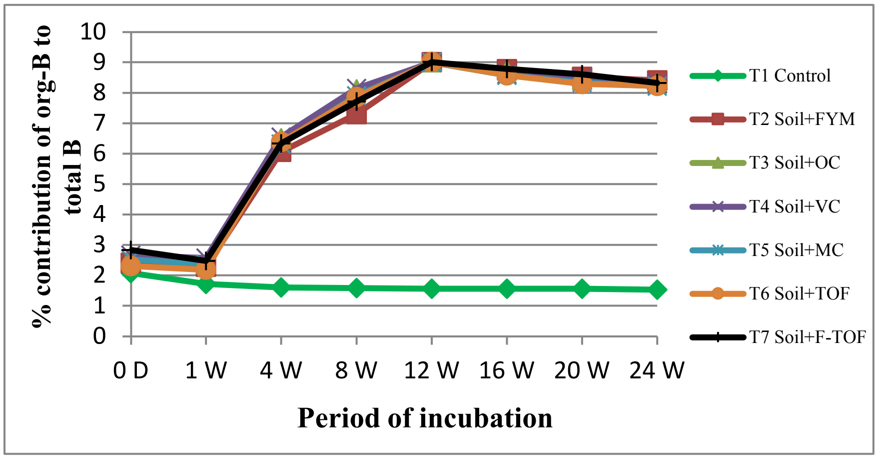

Fig. 79 Percentage contribution from Org-B to total B

total B with the addition of organic fertilizers (Fig. 79). The org-B increased up to 12 W and then declined.

With the addition of organic fertilizers, Res-B has decreased from 94.02-95.82 % to 79-94.67 % (Fig. 80) by the end of incubation. The decrease in the fraction was due to the transformations to other fractions of boron and indicates the mineralization of inherent B-reserve in the soil.

There exist a highly positive correlation between the residual bound B and oxide bound B in the soil (Barman *et al.,* 2017). When the equilibrium between the fractions gets disrupted, the system itself tries to re-establish it by various transformation reactions. In the end of the incubation, the highest residual B was recorded with F-TOF; it was due to the high boron content in the F-TOF which maintained a high B reserve after the establishment of equilibrium with the different fractions of B in the soil. At 24 W, the residual B fractions of treatments such as control, OC, VC and MC were statistically on par (Table 93). It was because in control, there was only a slight mineralization from B-reserve, while in organic fertilizers added treatments, there was a contribution of B from organic fertilizers. So even though the available B increased, the B-reserve in the organic fertilizers added soil was maintained almost same as that in control soil.

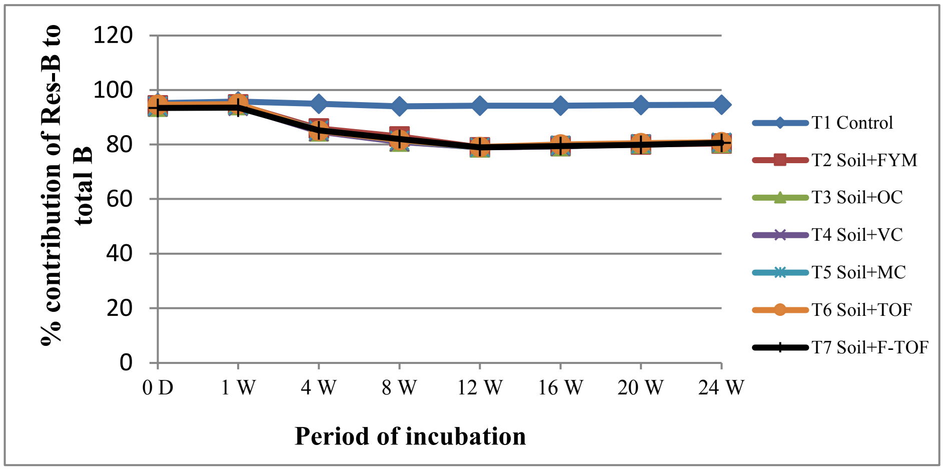

Fig. 80 Percentage contribution from Res-B to total B

5.4 FIELD EXPERIMENTS

5.4.1 Dry matter accumulation and yield by tomato and amaranthus

Thermochemical organic fertilizer proved to be a suitable alternate for organic manure in crop production (Jayakrishna and Thampatti, 2017; Leno *et al.,* 2016). Information on its effect on crop productivity under continuous application is lacking. Hence the same is evaluated in a tomato-amaranthus cropping sequence for two subsequent seasons.

Evaluating the performance of tomato, the dry matter production and fruit yield gave varied results for the first and second cropping sequences. In the first cropping sequence, the total dry matter production and fruit yield were highest for vermicompost T_4 (VC + STBR) followed by F-TOF which was statistically on par with each other (Fig. 81). But in the second cropping sequence it was just reverse with F-TOF being the highest closely followed vermicompost. The fruit yield for VC increased from 40.97 to 44.42 t ha^{-1} and 39.5 to 45 t ha^{-1} for F-TOF in the second cropping sequence. The percentage increase in yield was 13.9 for F-TOF while 8.42 for VC.

The better performance of vermicompost in the first cropping sequence was mainly due to better availability of nutrients (Table 80 to 88). In second cropping sequence F-TOF made more nutrients in available form and uptake of these nutrients resulted in high dry matter production and yield. It may be due to the comparatively higher C:N ratio of F-TOF that restricted the nutrient availability during the first crop of first cropping sequence but later nutrient availability increased as C:N ratio narrows. When the pooled means were compared VC showed a slightly higher statistically on par fruit yield of 42.69 t ha^{-1} versus 42.25 t ha^{-1} of F-TOF, revealing the comparability of F-TOF with other popular organic fertilizers.

F-TOF was found to perform better after each crop and its best was during the second cropping sequence showing highest values for growth parameters as well as yield and yield attributes. The continuous addition of F-TOF thus showed more beneficial effect on crop yield compared to other organic fertilizers (Fig. 76). In all the cases except absolute control an increase in dry matter production and fruit yield was noticed towards the second cropping sequence, revealing the benefit of continuous addition of organic fertilizers. It was mainly due to the better availability nutrients in the second cropping sequence that resulted in better growth, higher dry matter accumulation and yield. Addition of organic fertilizers enhances the nitrogen use efficiency, micro and macro nutrient recovery and help in P solubilization and its uptake by the plants and enhanced K availability that in turn resulted in better growth and yield of crop plant (Mahmood *et al.,* 2017).

In the case of amaranthus, F-TOF showed a remarkable performance during both the cropping sequences with highest shoot yield of 24.62 and 26.89 t ha^{-1}, respectively (Fig. 82). The higher quantities of WSOC, labile carbon and nitrate content of F-TOF (Table 140, 141 and 143) might have promoted the vegetative growth in the early stages itself in a better way. Apart from that amaranthus being the second crop in the sequence, slightly late nutrient availability from F-TOF have facilitated better growth (Table 145 to 150). The data on soil available nutrients at the harvest of first tomato (Table 145 to 150) confirmed the better nutrient availability in soil which is available to the next crop *i.e.,* amaranthus. The higher, constant and steady rate of mineralization of nutrients especially N, K, Ca and Mg from F-TOF after the first week to up to the 14 W of incubation have been synchronous with the active growth period of both tomato and amaranthus. Moreover the nutrient release pattern showed a high mineralization of secondary nutrients like S and micronutrients like Zn and B from the 16 W to 20 W of incubation. Hence it can be concluded that the F-TOF applied at the start of the tomato crop might have supplied these nutrients for the subsequent amaranthus crop as a residual effect. F-TOF can be considered as the best for continuous use since out of the four crops, it gave highest yield for three and its performance was found to improve after each crop. Thus F-TOF is very much suitable for its continuous use and its performance is comparable to other organic fertilizers. However, all the organic fertilizers showed an increase in crop yield due to continuous addition. Application of organic fertilizers enhances the organic matter content of the soil, thereby improve soil properties and result in better nutrient availability and higher crop yield (Li *et al.,* 2011).

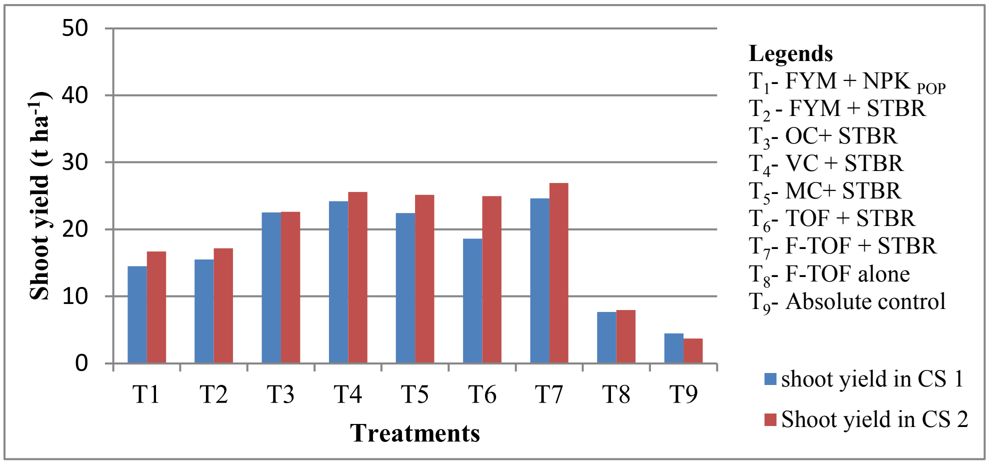

Fig. 81 Fruit yield of tomato during first and second cropping sequence

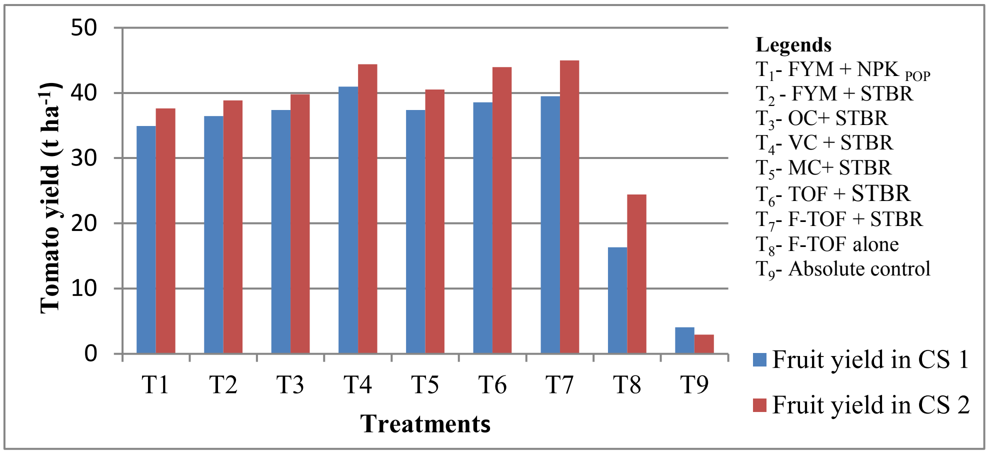

Fig. 82 Shoot yield of amaranthus during first and second cropping sequence

The continuous application of organic fertilizers has enhanced the soil carbon pools and total N content of the soil. Especially thermochemical organic fertilizers improved soil carbon pools much better than other organic fertilizers. The correlation analysis revealed that the yield as well as dry matter production of tomato and amaranthus in the second cropping sequence was significantly and highly correlated to soil carbon pools and total N content in the soil. The availability of Ca, Mg S, Zn and B showed a positive impact on the crop yield. The correlation data confirmed this as the correlation coefficient between yield of tomato with Ca, Mg, S, Zn and B were 0.964, 0.898, 0.899, 0.853 and 0.752, respectively. For amaranthus the same were 0.957, 0.805, 0.770, 0.805 and 0.724, respectively (Table 159 and 160).

5.4.2 Comparative assessment on quality of tomato and amaranthus

Application of organic fertilizers has enhanced the quality parameters of tomato and amaranthus compared to control. Similar result was reported by Chatterjee *et al.* (2013). It may be due to the effective and efficient utilization of the nutrient under the combined application of organic and inorganic fertilizers (Kumaran *et al.,* 1998; Abolusoro *et al.,* 2017). But there was no statistically significant difference among the treatments that has received different organic fertilizers. However, among the organic fertilizers, F-TOF was the best one since it recorded highest values for lycopene and ascorbic acid contents in tomato and carotene, ascorbic acid and crude fibre contents in amaranthus. The increased availability of macro- micro nutrients especially nitrogen and potassium, had enhanced the ascorbic acid content of tomato (Rajya *et al.*, 2015). At the same time anti nutritional factor oxalate in the amaranthus leaves was least for F-TOF application. Thus with regard to quality parameters, F-TOF showed better performance. The balanced availability of macro and micro nutrients from F-TOF might have positively influenced the quality parameters, though did not differed significantly from other organic fertilizers. The increase in the ascorbic acid content in tomato with the application of vermicompost was reported by Wang *et al.* (2017), while the TSS content was not influenced by the application of vermicompost (Azarmi *et al.,* 2008). The increase in the lycopene content of tomato with application of organic fertilizers was reported by Riahi and Hdider (2013). The quality parameters of amaranthus were improved by the combined application of organic and inorganic fertilizers (Ali *et al.,* 2009). Oxalates and nitrates present in the amaranthus are anti-nutritional factors as they have ill effects to human health (Ferrando, 1981).

For tomato and amaranthus, most of the quality parameters were found to increase towards the second cropping sequence. The antinutritional factor oxalate content of amaranthus leaves decreased, while nitrate content increased. The continuous availability of N from organic fertilizers had enhanced the N uptake and that has reflected on nitrate content of leaves. The nitrate accumulates in shoots when the rate of translocation from root to shoot is faster than the assimilation in the shoot (Mengel and Kirkby, 1980). However, Lidder and Webb (2013) have reported that the NO_3 content of amaranth can be ranged from 965 to 4259 mg kg^{-1}.

5.4.3 Uptake of macronutrients by tomato and amaranthus

Application of organic fertilizers had a remarkable effect on the nutrient concentration in plant parts and their uptake. The uptake of macronutrients by tomato and amaranthus were presented in Fig. 83 to 86

In tomato, during the first and second cropping sequences, the total N uptake and uptake of N in shoot and root were highest with treatment receiving F-TOF (T_7) but for fruit VC recorded the highest uptake. It was mainly because of higher fruit dry mater production by VC as well as higher N concentration in fruits in response to higher translocation to fruits. The total N uptake by the treatments receiving F-TOF and VC was statistically on par with each other, evidently due to higher N availability from these two (Table 75 and 76). The higher nutrient availability coupled with better crop removal resulted higher nutrient assimilation in plant parts. Singh and Varshney (2013) reported the increased NH_4- N and NO_3-N contents in soil due to the application of vermicompost had enhanced N uptake in tomato. Khan *et al*. (2017) reported that that application full dose of NPK along with compost @ 10 t ha^{-1} had resulted in the highest total N uptake (154.54 kg ha^{-1}) in tomato.

For amaranthus, during both the cropping sequences the N uptake was highest for F-TOF closely followed by VC and both were statistically on par with each other (Table 125). The dry matter production and N content in plant parts were higher for F-TOF, which yielded highest N uptake by that treatment. It showed the comparability between F-TOF and VC in performance. Oworu *et al.* (2010) reported the enhanced nutrient uptake in amaranthus under the application of organic fertilizers.

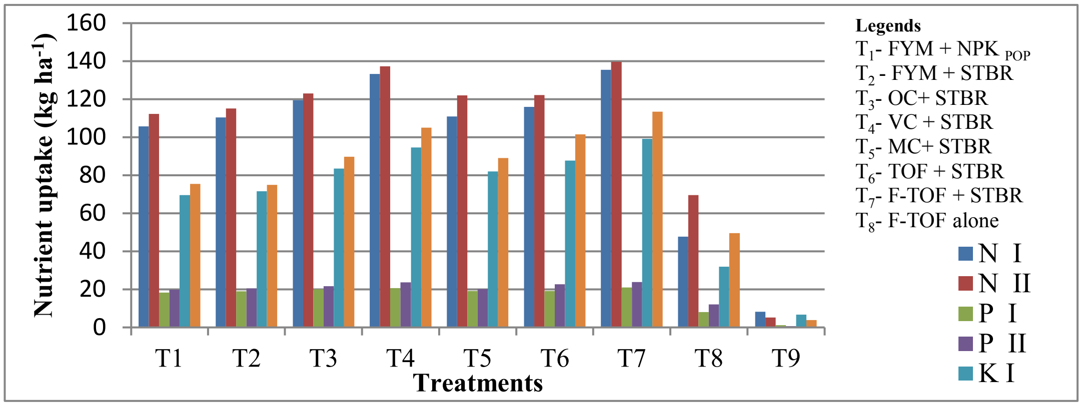

Fig. 83 Uptake of N, P and K by tomato I and II

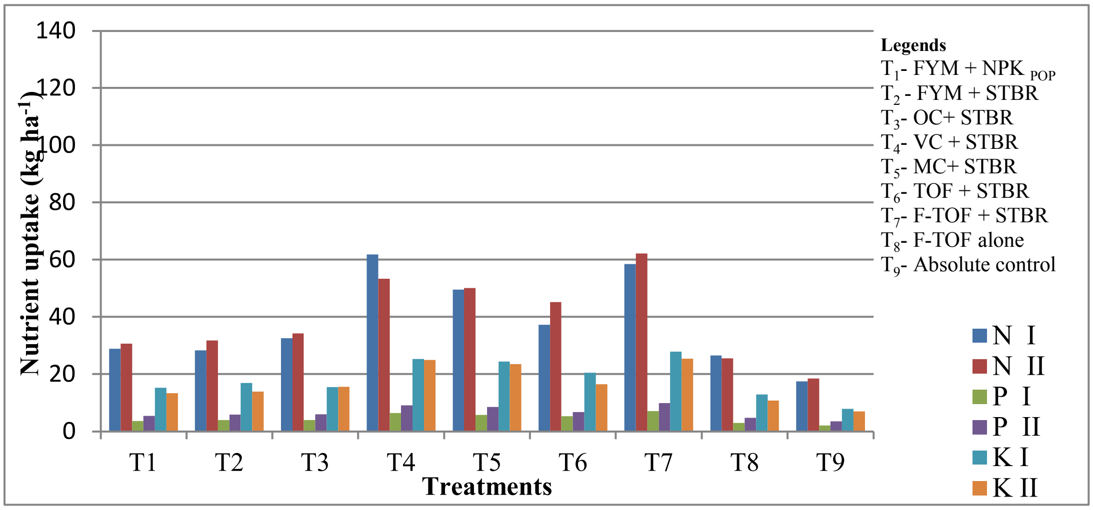

Fig. 84 Uptake of N, P and K by amaranthus I and II

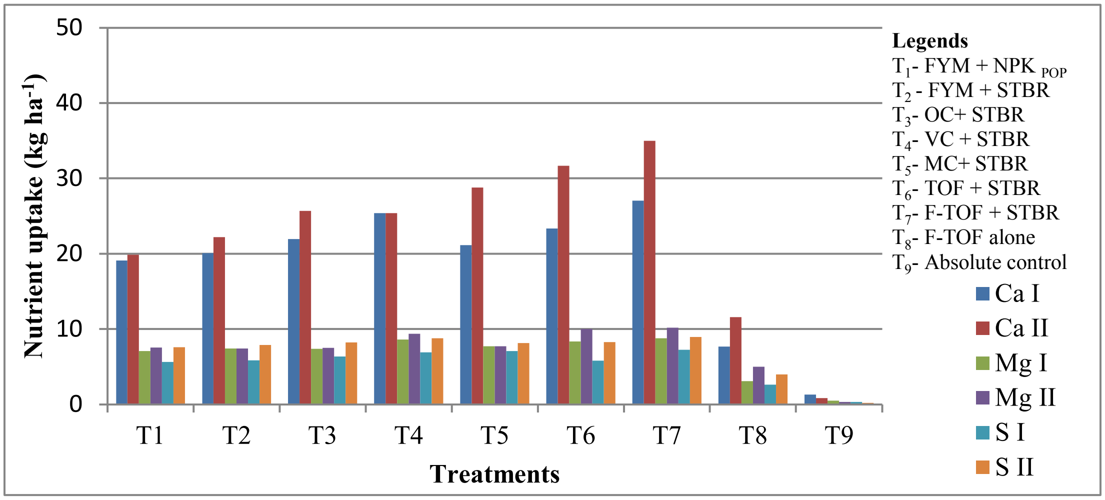

Fig. 85 Uptake of Ca, Mg and S by tomato I and II

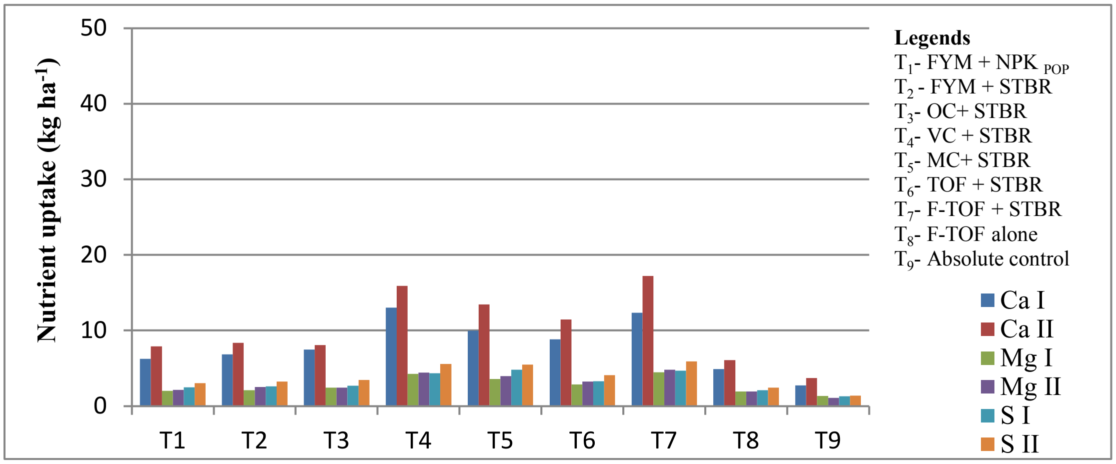

Fig. 86 Uptake of Ca, Mg and S by amaranthus I and II

P uptake by tomato also showed the same trend as that of N with total as well as the uptake by shoot and root were highest for F-TOF and for fruit with VC for the first cropping sequence. But in the second cropping sequence, the uptake of P in fruit as well as root was highest for VC. For both the cropping sequences, the total P uptake by VC and F-TOF were statistically on par. The results from soil incubation study support the higher availability of P from F-TOF and VC amended soils (Table 80). The P availability was highest for VC amended soil and it has constantly maintained that throughout the incubation. The availability of P in the post-harvest soil has also supplemented the P removal by these treatments (Table 145). The enhanced P uptake in tomato plant under the combined application of organic and inorganic fertilizers was reported by Khan *et al.* (2017). The increased uptake P might be due to the solubilization of insoluble phosphorous and reduced P adsorption and fixation in soil (Azam *et al.,* 2013).

For amaranthus, for both first and second cropping sequences P uptake was highest for F-TOF might be due to balanced availability of nutrients from the F-TOF amended soil. It is the residual effect of P carried over to the subsequent seasons resulted in higher P availability and uptake from F-TOF amended soil (Table 145).

For K also during both the cropping sequences, total as well as uptake in shoot and root were highest for F-TOF, (Table 109) but for fruit it was with VC. F-TOF was highest in K content and it always maintained higher available K in soil closely followed by VC throughout the incubation (Table 81). The higher K content in F-TOF promoted better K extraction from soil and its assimilation to plant parts. Abdel and Hossein (2001) reported the increased K uptake by sunflower may be due to the solubilization of soil inherent mineral source of K and improved soil exchangeable K under the application of organic fertilizers. Amaranthus also followed the same trend with highest total K uptake by F-TOF followed VC (Table 127).

For Ca, in the first cropping sequence, the highest total uptake as well as uptake in shoot, root and fruit were highest for F-TOF but in the second cropping sequence, root and fruit showed highest values for VC. The incubation study had revealed that the Ca availability up to 12 W was highest from F-TOF, while afterwards VC takes over the position. This might have resulted better Ca uptake by VC in succeeding crops. The same might have reflected on amranthus also, by VC showing highest uptake closely followed by F-TOF in the first cropping sequence. But the reverse has happened during the second cropping sequence. The further additions of organic fertilizers after each crop might have caused such small variations which were statistically on par with each other. Also the post-harvest availability of Ca was highest from F-TOF. The Mg uptake by both tomato and amaranthus was highest for F-TOF during both the cropping sequences, mainly due to the higher availability of Mg from it (Table 83). S also behave in the similar manner due to the higher availability of S from F-TOF amended soil (Table 84). The post-harvest availability of S was also highest for the same.

5.4.4 Uptake of micronutrients by tomato and amaranthus

For micronutrients such as Fe, Mn and Cu, the highest uptake in tomato for both the cropping sequences was observed for VC. It was mainly due to the higher content of these nutrients in VC as well as higher availability of these nutrients from VC amended soil (Table 85, 86 and 88). From the incubation study it was observed that the availability of these nutrients were highest from VC. So naturally it had favoured better uptake of these nutrients. Similar results were reported by Preetha *et al.* (2005).

For boron and zinc, the highest total uptake in tomato was associated with F-TOF. It was mainly due to the fortification of F-TOF with boron and zinc sources which enhanced the availability of these nutrients in F-TOF amended soil. Incubation study has already revealed the higher availability of Zn and B from F-TOF amended soil (Table 149 and 150).

The behaviour of amaranthus was inconformity with that of tomato except in the case of Fe. During both the cropping sequences, Fe uptake was highest for F-TOF (Table 132). The inherent richness in Fe content of red loam soil and the high phytoextraction ability of amaranthus for Fe might have resulted in the varied behaviour here. The phyoto-extraction ability of amaranthus for Fe was reported by Shankar *et al.* (2011). Meera (2017) reported the particular affinity of amaranthus for Fe. Hattab *et al.* (2019) also reported the ability of organic fertilizers for enhancing the micronutrient uptake by vegetables.

The continuous application of organic fertilizers during the first cropping sequences has enhanced the soil carbon pools and total N content of the soil. Also the nutrient built up in the soil during one season had enhanced the nutrient availability in the succeeding season. The enhanced nutrients uptake of tomato and amaranthus in the second cropping sequence compared to first was attributed to the positive impact of continuous application of organic fertilizers. The correlation analysis revealed the significant positive correlation between nutrient uptake of tomato and amaranthus with soil carbon pools and total N content. The correlation coefficients for uptake of N, P, K, Ca, Mg and S with TOC content for tomato were 0.737, 0.744, 0.791, 759, 0.807 and 0.691, respectively and that with total N were 0.966, 0.955, 0.976, 0.937, 0.962 and 0.945, respectively. For amaranthus the same were 0.694, 0.688, 0.697, 0.681, 0.683 and 0.671, respectively for TOC and 0.856, 0.857, 0.864, 0.855, 0.869 and 0.890, respectively for total N. Thus high TOC content of F-TOF had promoted the nutrient uptake by crop plants.

5.4.5 Nutrient absorption and translocation in tomato and amaranthus

In tomato, the total uptake of N, P, K, S and Zn for both the cropping sequences was highest with the treatment T_7 (F-TOF +STBR), but the uptake of these nutrients in tomato fruits was highest for treatment T_4 (VC +STBR). It indicates the better translocation of nutrients to economic part in soil amended with VC. But application of F-TOF was comparable with VC in the translocation of nutrients to economic part. For nutrients such as Ca, Mg and B, the total uptake as well as uptake in tomato fruits were highest for treatment T_7 and thus indicating the better translocation of the nutrients to the fruits. But for Fe, the highest uptake was with the treatment T_4 (VC + STBR), but higher nutrient translocation to fruit was with T_7 (F-TOF +STBR). For Mn and Cu, the higher uptake as well as better translocation to fruits was with VC amended soil (T_4). For all treatments uptake of nutrient was highest in fruits followed by shoot and fruit. Similar results regarding the enhanced nutrient uptake and better translocation of nutrients to the economic part under the combined application of organic and inorganic fertilizers was reported by Ilupeju *et al.* (2015)

Similarly for amaranthus, VC and F-TOF found to be the best in enhancing N and Ca uptake and translocation. For P, K Mg, B and Fe the highest uptake and translocation to shoot was found with F-TOF. MC and F-TOF found to be the best option for S uptake and it had higher translocation to shoot. For Mn, OC and VC found to enhance its uptake and translocation. For Zn, application of F-TOF enhanced the uptake as well as translocation to shoot. For Cu highest uptake was with T_7 (F-TOF +STBR), but the translocation was with T_4 (VC + STBR). For all treatments, the highest nutrient uptake was in amaranthus shoot compared to roots. Similar results of enhanced nutrient uptake in amaranthus shoot under the combined application organic and inorganic fertilizers were reported by Oworu *et al.* (2010) and Dlamni *et al.* (2020).

5.4.6 Heavy metal loading in crops

Among the heavy metals, only Pb was detected in plant parts and that too in roots only. As most of the plants do, further translocation of Pb to shoot or fruit was not observed. More deposition of heavy metals in plant roots compared to shoots has been already reported by Ogunkunle and Fatoba (2013). In tomato, Pb accumulation in root was observed only for FYM application and not for other organic fertilizers. Though all the organic fertilizers contained Pb, comparatively more quantity of FYM was added as it was applied on N equivalent basis. This might be the reason for presence of Pb in tomato roots that received FYM as organic fertilizer.

For amaranthus, presence of Pb was detected in the roots of all the treatments. The highest Pb concentration and uptake in roots was for FYM followed by VC. Though all the organic fertilizers contained Pb, the plants from all treatments showed the presence of Pb in amaranthus root. The higher quantity of organic fertilizers applied to amaranthus compared to tomato and the hyper accumulation potential of amaranthus might have favoured a better removal of Pb from soil. The hyper accumulation property of amaranthus enhanced the extraction of Pb from soil, but it retained within the root itself. As there was no accumulation of Pb in the amaranthus shoots, it is safe for consumption. Since amaranthus being a heavy metal accumulator (Khoramnejadian and Saeb, 2015) it had absorbed more Pb than tomato. The permissible limit of Pb in plant by WHO is 2 mg kg^{-1} (Nazir *et al.,* 2015) and the concentration of Pb in the amaranthus root was very low (< 0.16 mg kg^{-1}). Since the uptake of Pb was very low and there was no translocation to the shoots and the use of these organic fertilizers is within the purview of safe limits.

5.4.7 Agronomic use efficiencies of different organic fertilizers

Agronomic use efficiency is the quantity of yield increase over the unit kg of nutrients applied. Here the agronomic use efficiency was computed over the POP practice.

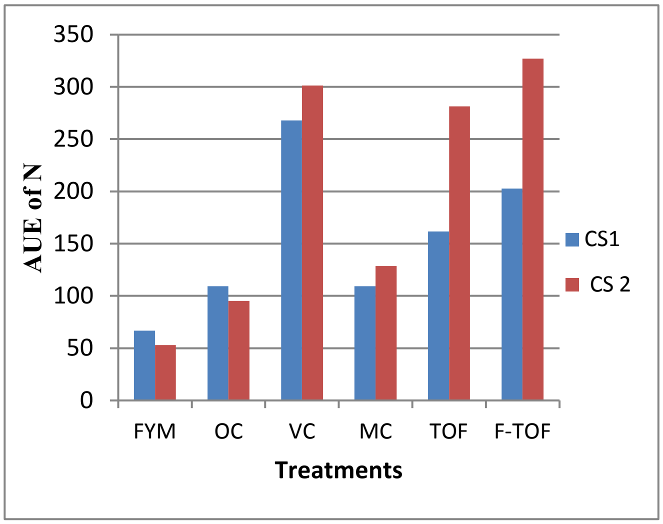

Fig. 87 AUE of N for different organic fertilizers under tomato crop in first and second cropping sequences

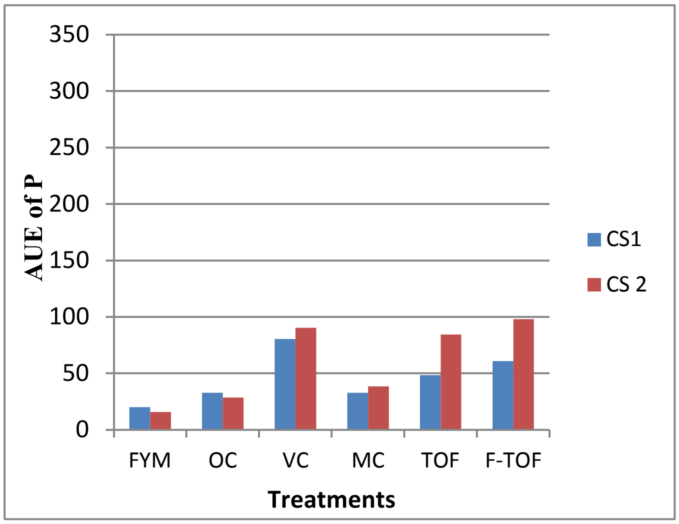

Fig. 88 AUE of P for different organic fertilizers under tomato crop in first and second cropping sequences

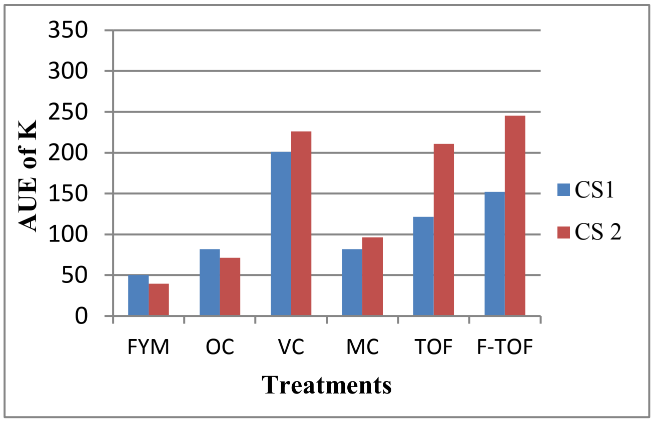

Fig. 89 AUE of K for different organic fertilizers under tomato crop in first and second cropping sequences

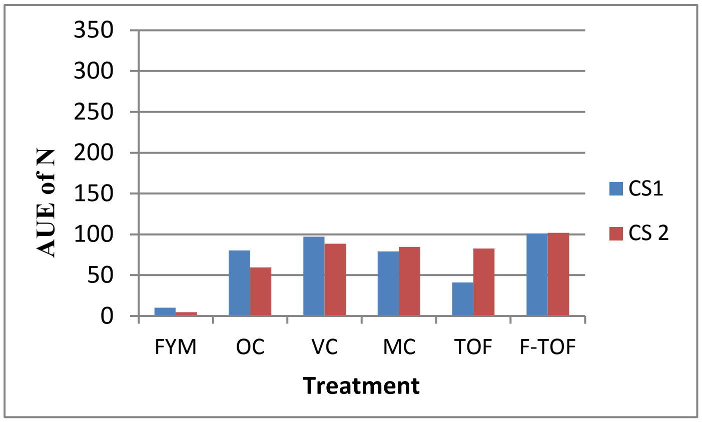

Fig. 90 AUE of N for different organic fertilizers under amaranthus crop in first and second cropping sequences

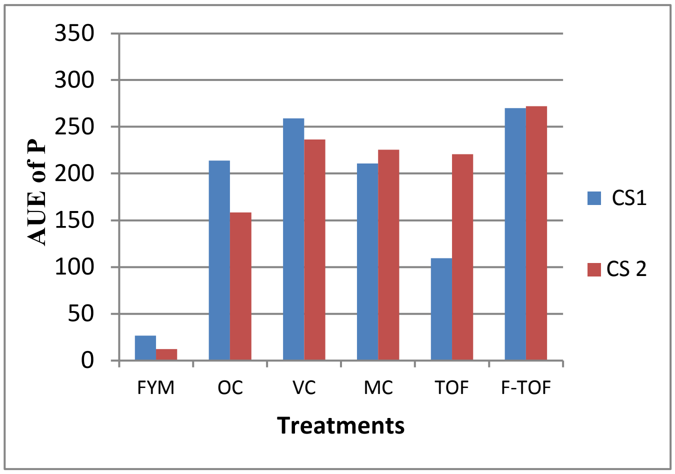

Fig. 91 AUE of P for different organic fertilizers under amaranthus crop in first and second cropping sequences

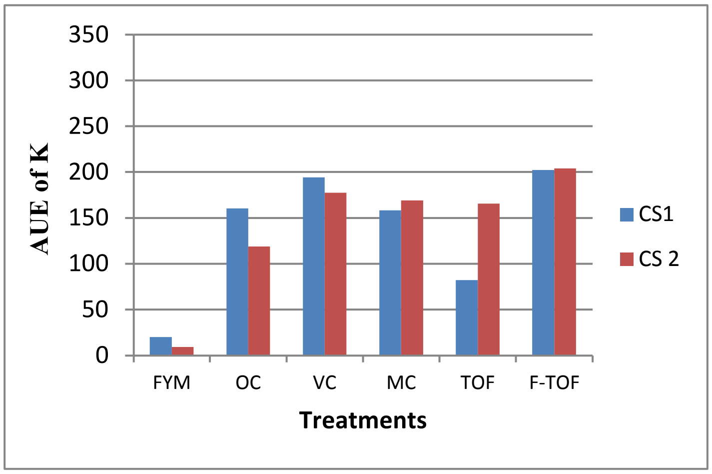

Fig. 92 AUE of K for different organic fertilizers under amaranthus crop in first and second cropping sequences

For tomato, the AUE of N for treatments such as T_2 (FYM +STBR), T_3 (OC +STBR), T_4 (VC +STBR), T_5 (MC +STBR), T_6 (TOF +STBR) and T_7 (F-TOF+STBR) were 20, 32.80, 80, 32.80, 48.53 and 60.80 kg per kg of N for first cropping sequence and 15.87, 28.53, 90.40, 38.53, 84.40 and 98.13 kg per kg N in the second cropping sequence of tomato (Fig. 87). From this it is understood that the yield increase per unit kg of nitrogen was highest for F-TOF application followed by VC and TOF. It was also noticed that the agronomic use efficiency of treatments where F-TOF, VC and TOF were used as amendments increased in the second cropping sequence than the first cropping sequence. This increase confirms the suitability F-TOF, VC and TOF for continuous application for economic crop production. Exactly similar behavior was noticed for AUE of P and K (Fig. 88 and 89) with application of these organic fertilizers. Thus thermochemical organic fertilizers (F-TOF and TOF) found to be ideal for continuous use in crop fields.

In the case of amaranthus, AUE for NPK nutrients was highest for F-TOF and that of organic fertilizers such as OC, VC, MC and TOF were comparable (Fig. 90, 91 and 92). It may be due the exhaustive nutrient uptake of amaranthus, organic fertilizers did not have much impact on its AUE.

5.4.8 Impact of continuous application thermochemical organic fertilizer on soil properties under tomato -amaranthus cropping sequence

The field trials conducted as cropping sequences of tomato and amaranthus revealed the effect of continuous application of thermochemical organic fertilizers / other organic fertilizers on the physical, chemical and biological properties of the soil and are discussed under this chapter

5.4.8.1 Physical properties

Application of organic manures along with inorganic fertilizers improves the physical condition of soil and improves the crop yield (Katkar *et al.,* 2012). The addition of organic fertilizers had decreased the bulk density of the soil after each crop. The decrease was more prominent for treatments receiving thermochemical organic fertilizers due to its very low bulk density and the high content of lignin which remained for more time in soil contributing to the decrease in bulk density. Similarly, application of other organic fertilizers has also decreased the bulk density of the soil compared to the control. The combined application of organic and inorganic fertilizers decreases the bulk density of the soil by addition of root and plant biomass and by increasing the macropores in the soil. The decomposition of organic matter releases polysaccharides and organic acids which act as a binding agent for aggregate formation in the soil (Sharma and Behera, 2020).

Similarly, the water holding capacity of F-TOF amended soil increased evidently which is also a reflection of decreased bulk density. The WHC of the treatment T_7 (F-TOF + STBR) increased by 43 % after the first cropping sequence and by 46 % at end of second cropping sequence compared to control (Fig. 93). Similarly for treatment T_6 (TOF + STBR) and T_8 (F-TOF alone), WHC capacity increased by 42 % and 44 % respectively, after the second cropping sequence. Addition of organic fertilizers has increased water holding capacity of the soil (Fig. 93) compared to the control treatment. Application of organic substances improves soil aggregation and total porosity and there by enhances the water-holding capacity of the soil (Celik *et al*., 2004; Leroy *et al.,* 2008). The improved physical properties enhance the crop growth by better root penetration and nutrient availability.

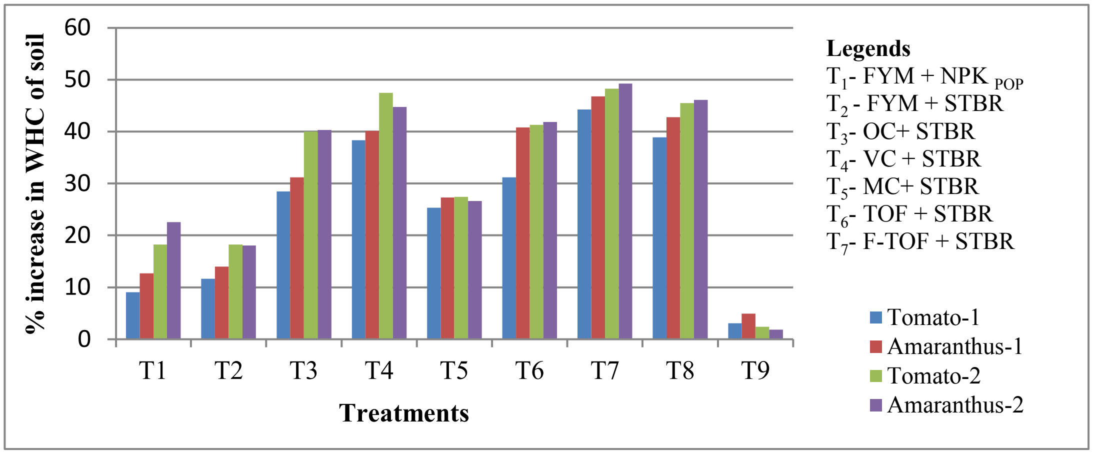

Fig. 93 Percentage increase in the WHC of post-harvest soil in tomato-amaranthus cropping sequence

5.4.8.2 Electrochemical and chemical properties

Thermochemical organic fertilizer was able to improve soil chemical properties also. It maintained a higher pH compared to other organic fertilizers, even when it was applied along with chemical fertilizers (Table 139). It has already observed that it could enhance soil pH when applied alone as evidenced from incubation/leaching studies.

The acidification of soil by the continuous application of mineral fertilizers where reported by Chang *et al.* (2007) and Gong *et al.* (2008). Even though the application of organic fertilizers has increased the pH of the soil than their initial value, with the continuous cropping under the application of mineral fertilizers decreased the soil pH towards the end of second cropping sequence. The decline was more evident in treatments that received FYM, OC, VC and MC, but not with F-TOF and TOF. Presence of elements of alkaline nature might have helped in maintaining such as a pH in soil.

F-TOF maintained highest EC for post-harvest soil throughout the cropping sequences.VC, MC and TOF also showed similar response indicating the similar effect of organic fertilizers in supplying and retaining nutrients in the soil. The lowest EC with the control treatment was mainly due to the nutrient depletion by cropping without any external addition of nutrients. Similar results regarding the effect of continuous application of organic fertilizers on soil properties were reported by Yadav *et al.* (2019).

Addition of organic fertilizers after each crop in the tomato-amaranthus cropping sequence was to replenish the SOC pools. Application of thermochemical organic fertilizers found to increase the TOC content of soil better than other organic fertilizers definitely due to its recalcitrance nature. The addition of F-TOF alone and F-TOF and TOF along with inorganic fertilizer has raised TOC of the post-harvest soil at the end of second cropping sequence by 48.48 %, 54.62 % and 54.26 %, respectively compared to initial status (Fig. 94). Similarly, the addition of other organic fertilizers has also raised the TOC content of post-harvest soil in the order VC > MC > OC > FYM. In the absolute control, TOC content of the soil decreased by 24.03 % at the end of the two continuous cropping sequences (Fig. 94).

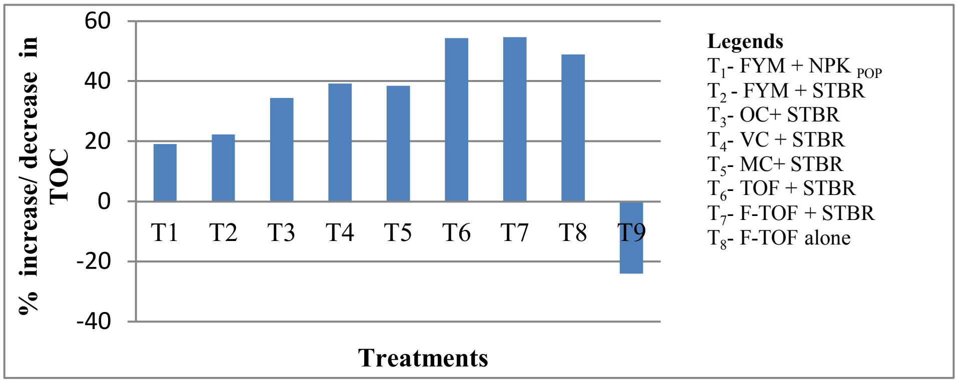

Fig. 94 Variation in the TOC content of the post-harvest soil at the end of second cropping sequence

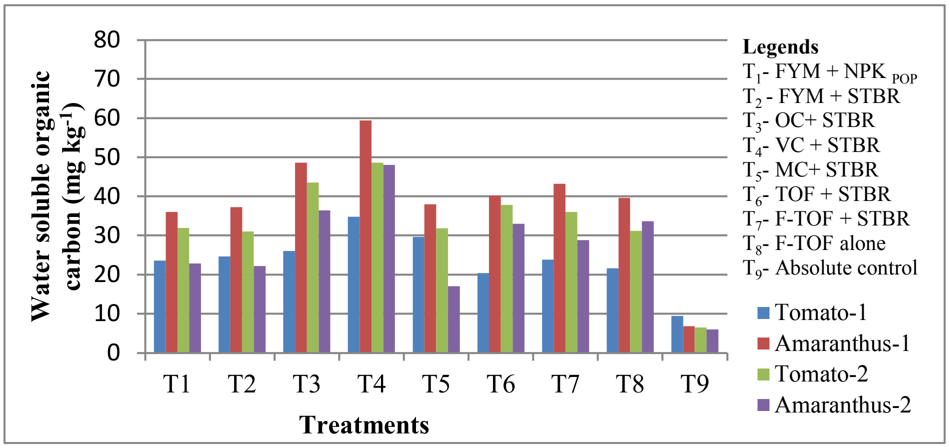

Fig. 95 WSOC in the post-harvest soil under tomato-amaranthus cropping sequence

The WSOC was highest for VC amended treatment indicating faster mineralization of complex organic molecules in to simpler molecules (Fig. 95). It is the C:N ratio that determines the C-mineralization. The higher N content in VC lowers its C:N ratio and favours the mineralization process to release water soluble simpler organic molecules. In all organic fertilizers added treatments there was increase in WSOC than their initial value. The amount of WSOC increases with mineralization of organic fertilizers and later decreases with stabilization and establishment of equilibrium. The amount of WSOC was highest in all treatments after the first cropping sequence, which declined in the end of the second cropping sequences due to the decomposition and stabilization of organic matter (Fig. 95). The WSOC can be leached from the soil or can be used by the microorganism or can be lost to atmosphere as CO_2. Among the organic fertilizers amended treatments, at the end of the second cropping sequence the lowest WSOC in the post-harvest soil was with MC and it was mainly to the higher stabilization of organic carbon due to higher load of microbial population (Table 154). However in the absolute control the decline in WSOC was due to the lack of addition of organic fertilizers and decline in the exiting soil organic matter where it is lost as CO_2 or immobilized by microorganism. Similar results regarding WSOC and stabilization of organic carbon with maturity were reported by Zhmora-Nahum *et al.* (2005).

Labile carbon is an indicator of soil health. Labile carbon is only a small proportion of TOC, but critical component of TOC that support the biogeochemical transformation of nutrients especially N and P (Xu *et al.,* 2011).Organic fertilizers mainly added to replenish the labile pool of carbon in the soil as it is the fraction readily available to microorganisms for consumption. Addition of F-TOF along with inorganic fertilizers (T_7) has maintained a highest labile carbon pool throughout the cropping sequence (Fig. 96). It was mainly due to their high TOC content and proportionate contribution to labile carbon pool.

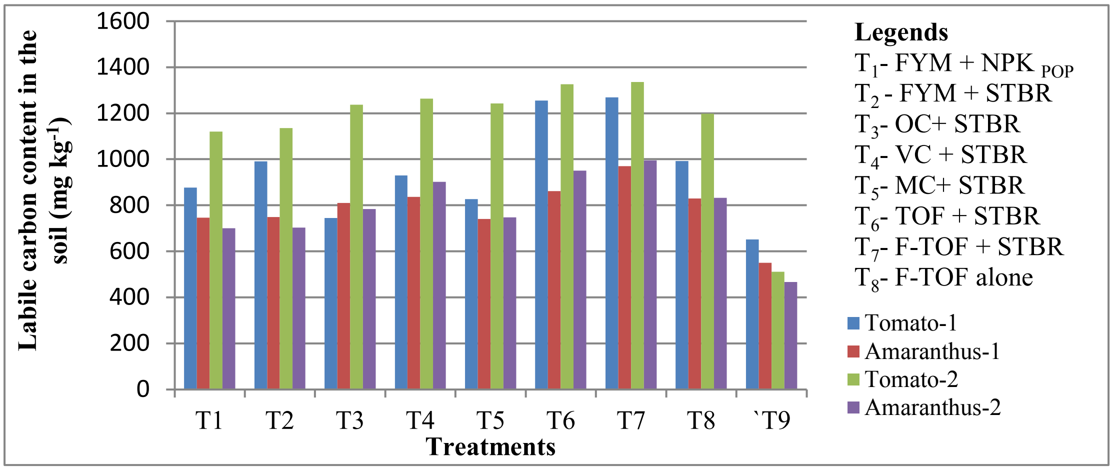

Fig. 96 Labile carbon in the post -harvest soil under tomato-amaranthus cropping sequence

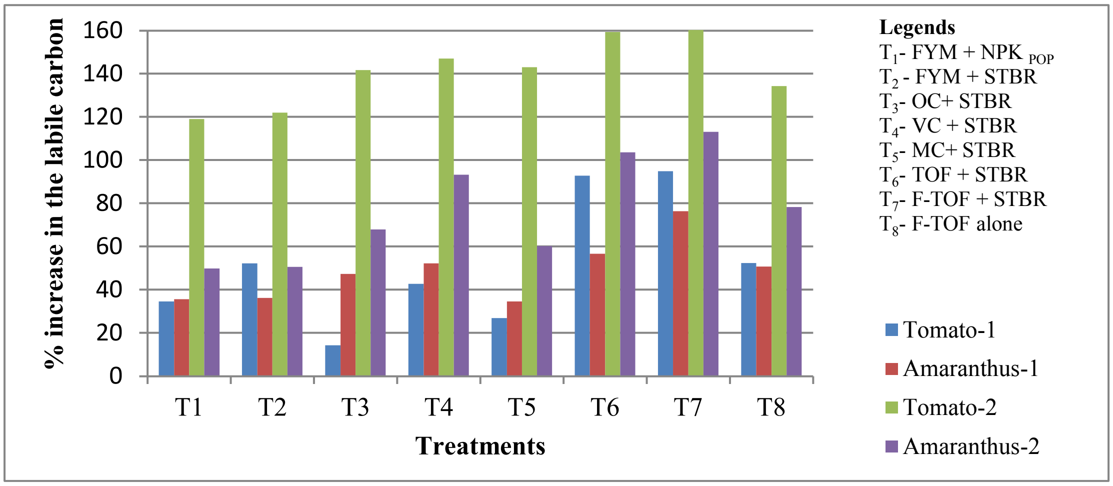

Fig. 97 Percentage increase in the labile carbon content of post-harvest soil over absolute control

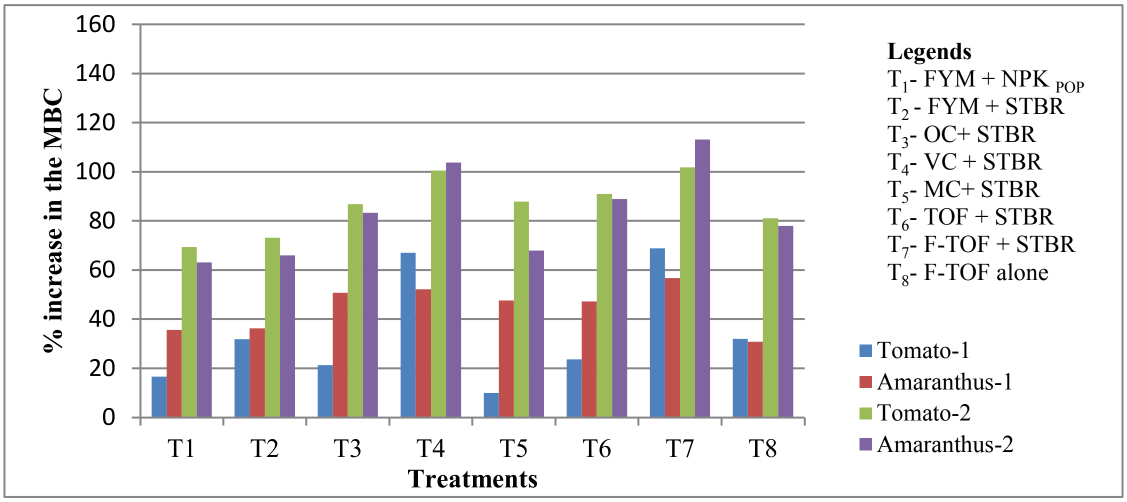

Fig. 98 Percentage increase in the MBC content of post -harvest soil over absolute control

At the end of the second cropping sequence the labile carbon content in the treatment F-TOF + STBR was 113 % higher than the control (Fig. 97) followed by TOF + STBR (103.61 %) and VC + STBR (93.25 %). It indicates ability of these organic fertilizers to replenish the labile carbon pool of the soil with the decomposition. The decline in the labile pools of absolute control treatment was mainly due to lack of sufficient substrate to replenish the pool.

Application of thermochemical organic fertilizers has maintained a higher microbial biomass carbon in the post-harvest soil and it was mainly due its higher TOC and proportionate contribution the microbial biomass pool. Also there exist a positive correlation with labile C and MBC (Souza *et al.,* 2016). So increase in the labile carbon pools contributes to increase in the MBC pool. At the end of the second cropping sequences MBC content in the post-harvest soil of treatment T_7 (F-TOF + STBR) increased by 113 % compared to control (Fig. 98) followed by T_4 (103.67 %) and T_6 (88.9 %). It was mainly due sufficient supply labile carbon pool that has enhanced MBC content in the soil.

The higher recalcitrance nature of thermochemical organic fertilizer has maintained a higher ROC content in the post-harvest soil amended with TOF and F-TOF along with inorganic fertilizers. The recalcitrance nature of thermochemical organic fertilizer was mainly due to the higher lignin content. The recalcitrant organic carbon content in the soil after second cropping sequence was 176 % higher for (F-TOF compared to the control (Fig. 99) followed by TOF and MC with 152.5 % increase. Addition of organic amendments enhances the SOC content of the soil. During the cropping sequences, a higher NH_4-N and NO_3-N contents were noticed for F-TOF followed by MC under soil test based recommendation due the higher N content in the organic fertilizers.

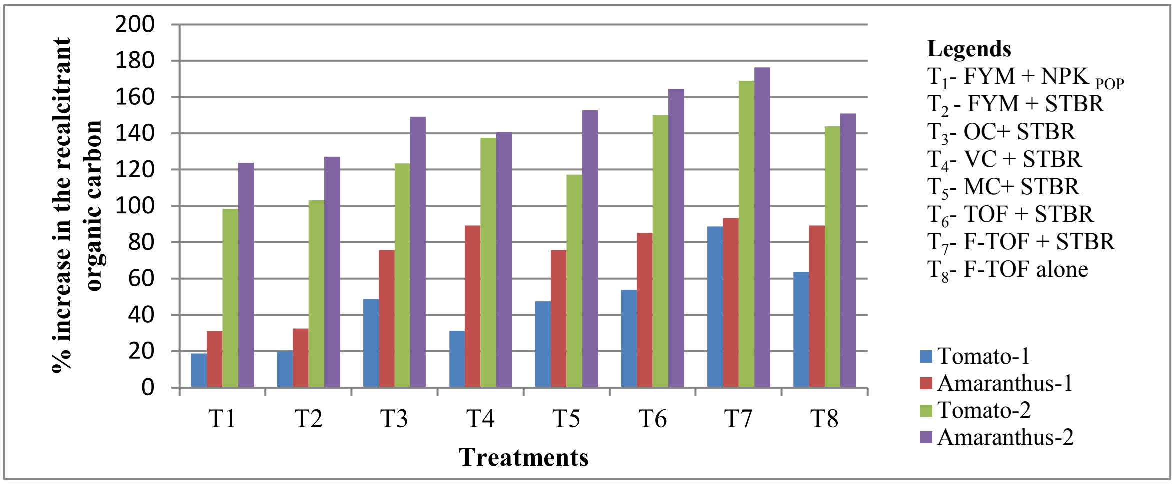

Fig. 99 Percentage increase in the ROC content of post-harvest soil over absolute control

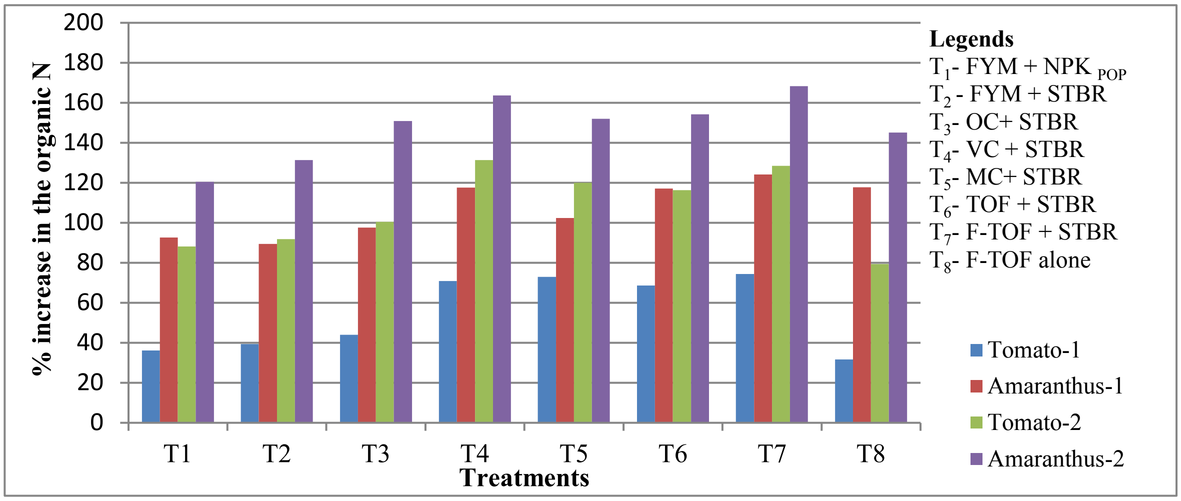

Fig. 100 Percentage increase in the organic N content of post-harvest soil over absolute control

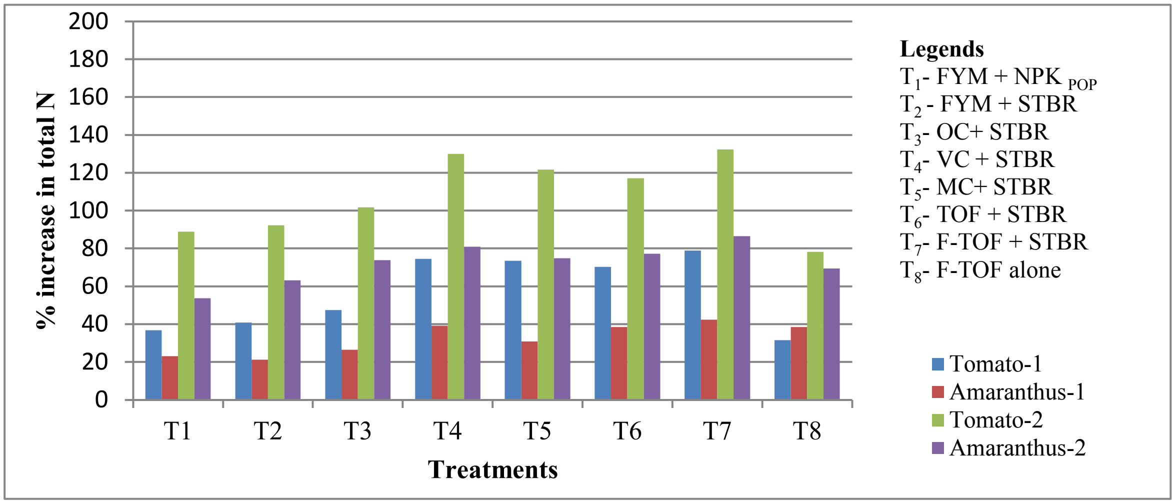

Fig. 101 Percentage increase in the total N content of post-harvest soil over absolute control

Organic N content in the soil is the non-mineralized N in the soil. So it is the N reserve in the soil for the mineralization. In the post-harvest soil organic N content was the highest at the end second cropping sequence (Table 144) for F-TOF under soil test based recommendation (T_7). For treatments receiving F-TOF, VC and TOF the organic N after the second cropping sequence increased by 168 %, 163.69 %, and 154.25 % over the control, respectively (Fig. 100). It indicates the slow release of nitrogen from these organic fertilizers.

During the cropping sequences the highest total N content was maintained in the treatment T_7 (F-TOF + STBR). The higher value indicates the ability of F-TOF to conserve and maintain a higher level of nitrogen in the soil. The highest percentage increase in the total N content in the soil was after tomato crop of the second cropping sequence (Fig. 101). At the end of the second cropping sequence the highest percentage increase in total N content was observed for F-TOF followed by VC, TOF and MC when applied along with chemical fertilizers as per soil test basis.

5.4.8.3 Nutrient availability

Availability of nutrients in the post-harvest soil indicates the amount nutrients unutilized by the crop and retained in the soil for the succeeding crops. Vermicompost had maintained highest P availability in the post-harvest soil throughout the cropping sequences. It was mainly due to the higher P content in the vermicompost (Table 145). During the cropping sequences, the percentage increase in P availability with treatment T_4 (VC+ STBR) was 64.25, 33.02, 52.14 and 100.02 % over the control, respectively, after each crop (Fig. 102). The availability of P increased after the first crop of first cropping sequence and declined after the second crop *i.e.,* amaranthus. This might due to crop removal as well as P fixation in the soil. But in the second cropping sequence, the availability increased after each crop. It shows that, from second cropping season onwards there was a built-up of P-reserve in the soil with the application of organic and inorganic fertilizers. At the end of second

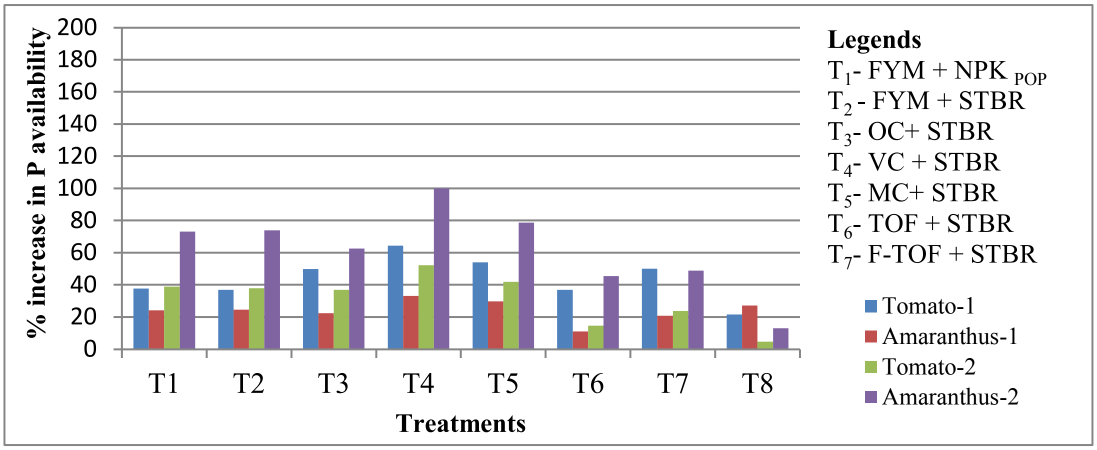

Fig. 102 Percentage increase in the P availability of post-harvest soil over absolute control

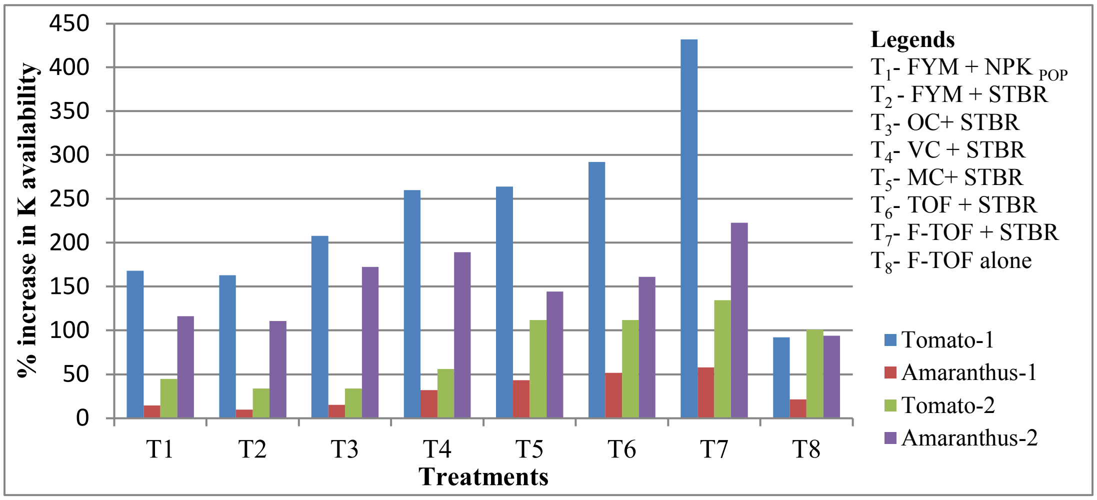

Fig. 103 Percentage increase in the K availability of post-harvest soil over absolute control

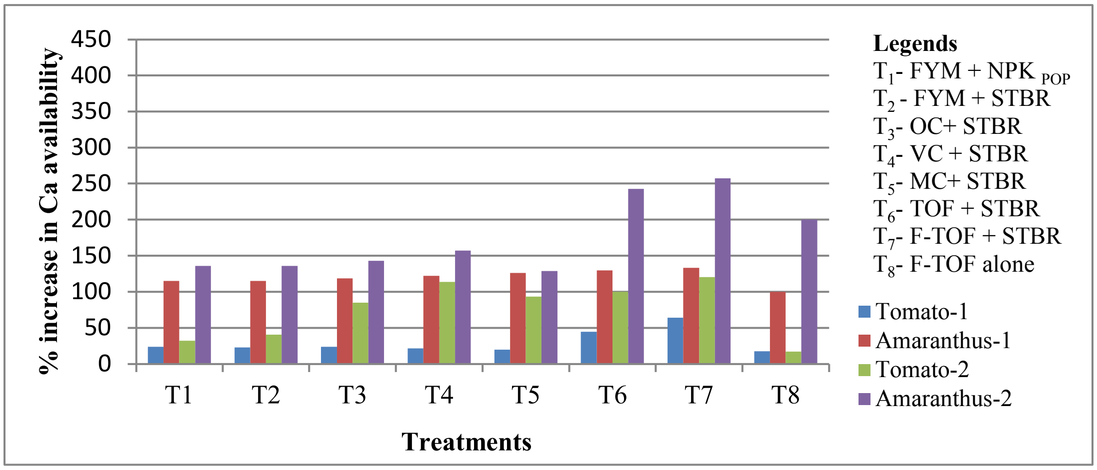

Fig. 104 Percentage increase in the Ca availability of post-harvest soil over absolute control

cropping sequence, all the treatments showed an increase in availability of P closely followed by MC and FYM.

F-TOF had maintained a higher available K, Ca and Mg contents in the post-harvest soil due to higher content in it throughout the cropping sequence (Table 145 and 146) This has reflected on the crop yield showing highest fruit yield in tomato (Table 100) and shoot yield in amaranthus (Table 120). The availability of K from F-TOF (T_7) at end of first cropping sequence was 132.40 kg ha^{-1} and it increased to 280 kg ha^{-1} at the end of second cropping sequence. Similarly, the availability of Ca from treatment T_7 at end of first cropping sequence was 315 kg ha^{-1} and it increased to 500 kg ha^{-1} at the end of second cropping sequence. In the first cropping sequence, a higher availability of Mg in the post-harvest soil was observed with addition of VC. It may be due to the higher Mg content and slow release of Mg from the VC which made it available even after the peak nutrient requirement of the crop plant. For treatment T_7 (F-TOF + STBR) the Mg the availability increased from 65 to 156 kg ha^{-1} at the end of first cropping sequence and slightly decreased to 144 kg ha^{-1} at the end of second cropping sequence. At the end of second cropping sequence the availability of K, Ca and Mg from T_7 (F-TOF + STBR) has increased by 223%, 257% and 162 % over the control, respectively (Fig. 103 to 105).

The main source of S for crop plants is organic fertilizers. The addition of organic fertilizers satisfies the nutrient requirement of crop plants due to their high S content. In post-harvest soil, the availability of S declined after each crop due to the utilization of S by the crop plants. The application of organic fertilizers has enhanced the availability of sulphur in the post-harvest soil (Table 147). At the end of the second cropping sequence, the highest availability of sulphur (Fig. 106) was from the VC (T_4) amended soil (170 % over the control) followed by F-TOF (T_7) amended soil (150 % over the control) and MC (T_5) amended soil (140 % over the control). The higher availability of S in the post-harvest soil indicates the slow release pattern of the organic fertilizers. Similar result regarding the increased in the availability of

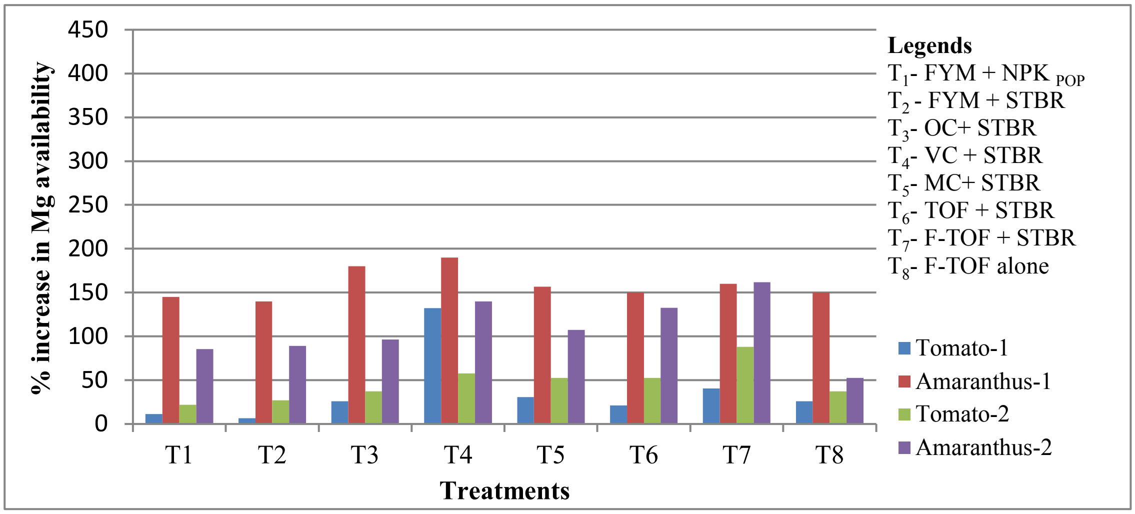

Fig. 105: Percentage increase in the Mg availability of post-harvest soil over absolute control

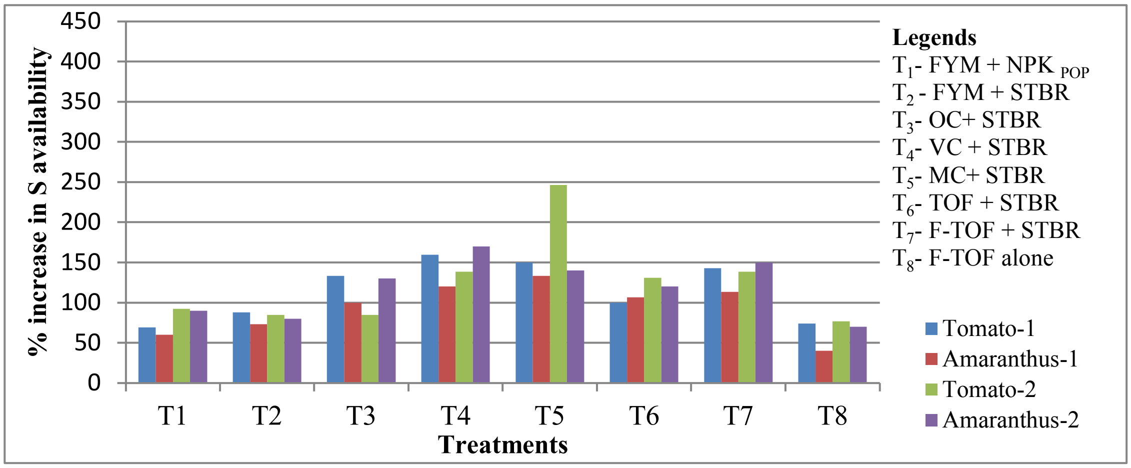

Fig. 106 Percentage increase in the S availability of post-harvest soil over absolute control

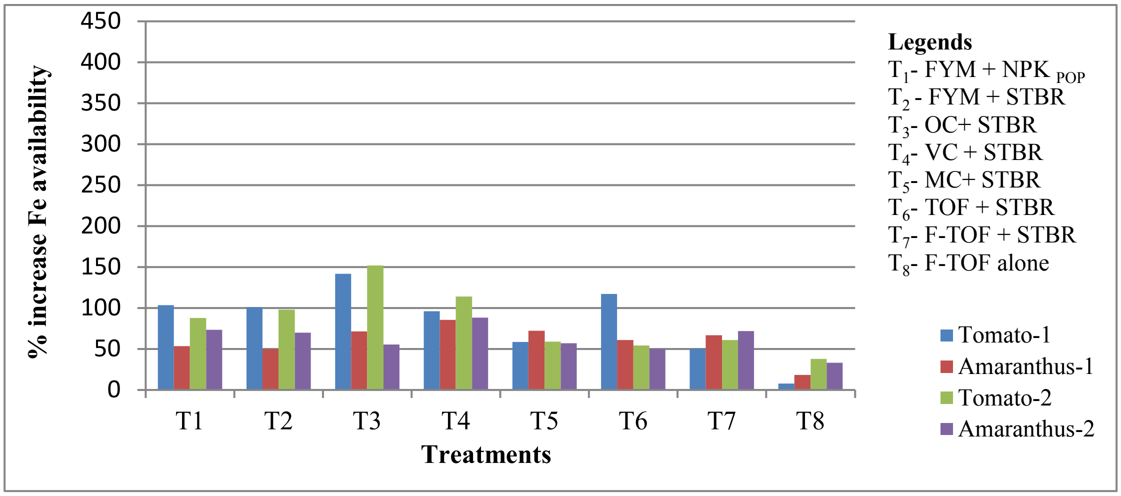

Fig. 107 Percentage increase in the Fe availability of post-harvest soil over absolute control

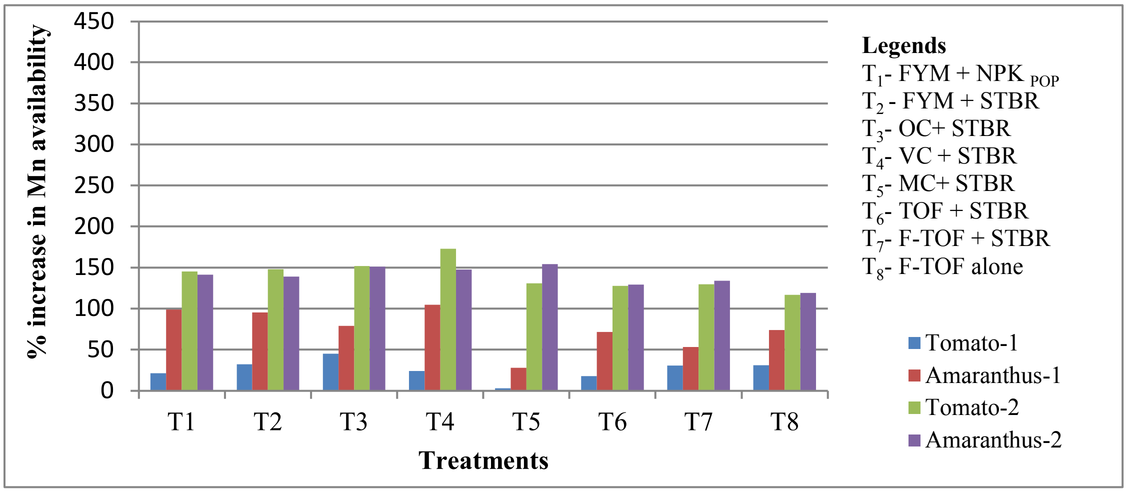

Fig. 108 Percentage increase in the Mn availability of post-harvest soil over absolute control

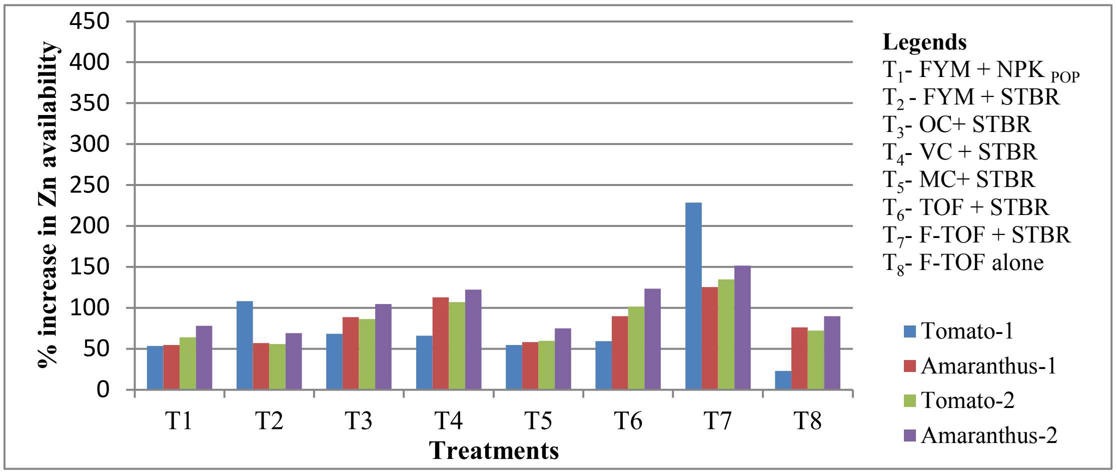

Fig. 109 Percentage increase in the Zn availability of post-harvest soil over absolute control

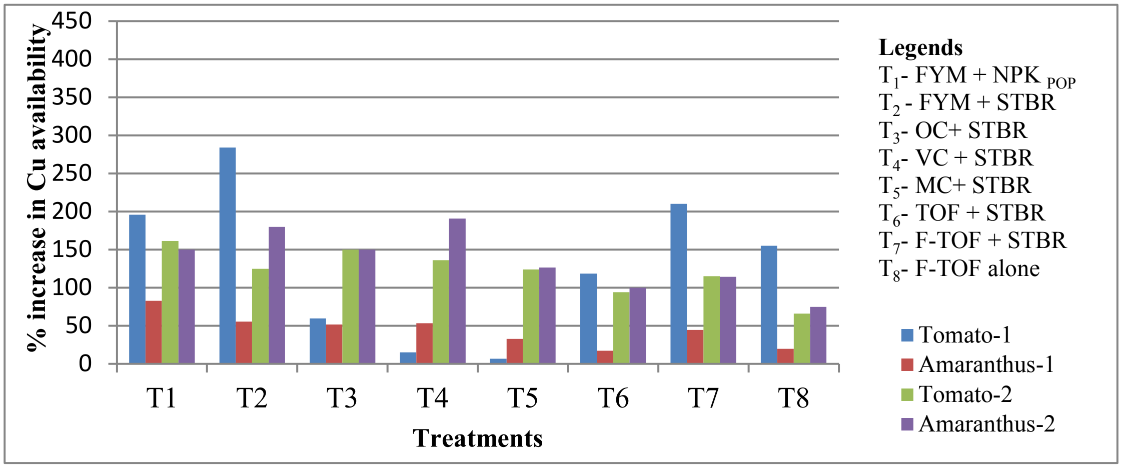

Fig. 110 Percentage increase in the Cu availability of post-harvest soil over absolute control

nutrients with the continuous application of organic fertilizers was reported by Abdou *et al.* (2016).

At the end of the second cropping sequences, the highest availability of Fe (Fig. 107) and Cu (Fig. 110) was from VC (88 % and 180 % increase over the control, respectively) and the highest Mn, availability (Fig. 108) was from MC (154 % increase over the control).For B (Fig. 98) and Zn (Fig. 109), a higher availability in the post-harvest soil was maintained by F-TOF due to the higher content of these micronutrients in it due to fortification. At the end of the second cropping sequences, the B availability from F-TOF under soil test based recommendation (T_7) has increased 277 % over the control (Fig. 111). The availability of micronutrients is mainly pH dependent and decided by the nutrient release pattern of organic fertilizers.

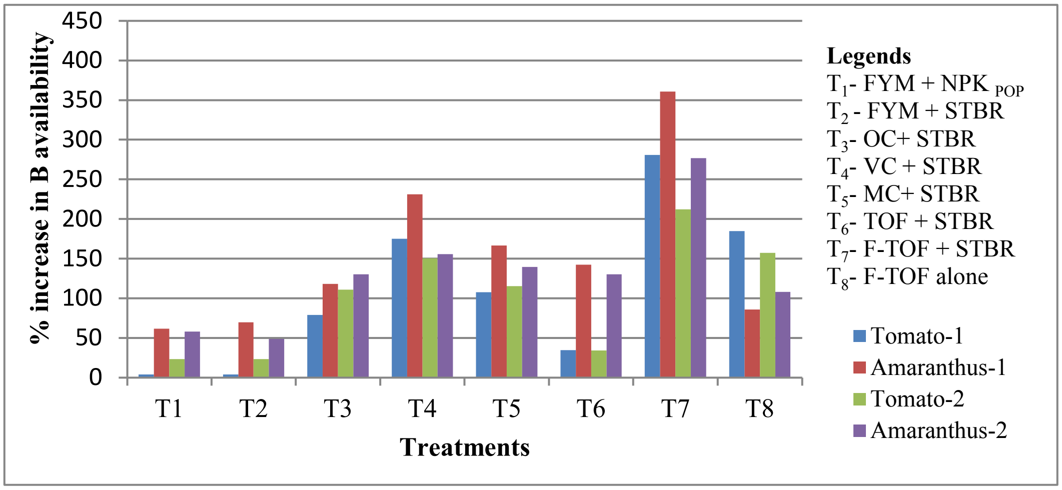

Fig. 111 Percentage increase in the B availability of post-harvest soil over absolute control

5.4.8.4 Biological properties

Biological properties mainly indicate the health of soil. Application of organic fertilizers VC, MC and F-TOF had maintained a higher microbial load in the soil compared to control and other organic fertilizers. Also the higher dehydrogenase activity was observed with VC, MC and F-TOF amended soil confirms the presence of higher microbial load. The nutrient transformation and nitrogen fixation process in the soil are mainly mediated by microorganisms and they have a very crucial role in the subsistence of ecosystem (Jacoby *et al*., 2017). The high N content of VC, MC and TOF might favoured the microbial proliferation and maintained higher biological activity. The biological activity in the soil mainly depends on the C:N ratio of the organic substrate added to the soil. High C:N ratio of the organic substrate or low nitrogen content limit the microbial activity due to lack of nitrogen for protein formation (Lin *et al.,* 2019).

5.4.8.5 Built up of carbon stock in the soil

Continuous cultivation of crop plants decreases the SOC content of the soil. The application of organic fertilizers along with inorganic fertilizers, replenishes the carbon pools in the soil. However, it requires long term continuous application to replenish the depleting carbon content and to increase carbon stock in tropical soils. Here, the application of organic fertilizers for each crop has gradually increased the organic carbon content of the soil in the surface and sub-surface layer compared to the control which receives no organic fertilizer. Carbon stock in the soil is a measure of amount of carbon sequestered and stored in the soil. Manna *et al.* (2005) reported that long term continuous application of organic fertilizers required to increase the carbon stock of cultivated lands.

The continuous application of F-TOF and TOF has enhanced the carbon stock in the surface layer by 17 % after the second cropping sequence compared to control (Fig. 98) and VC and OC have enhanced carbon stock by 12 % and MC by 11 %. The higher microbial activity had resulted in a very slow pace in improving the carbon stock under tropical situations. When compared to initial carbon stock of the soil, the addition of organic fertilizers has F-TOF and TOF had enhanced the carbon storage by 10 % , VC and OC by 5%, MC by 4 % and FYM by 1 %. In control, the carbon stock decreased by 6 % at the end of second cropping sequence due to the continuous cropping without application of organic and inorganic fertilizers.

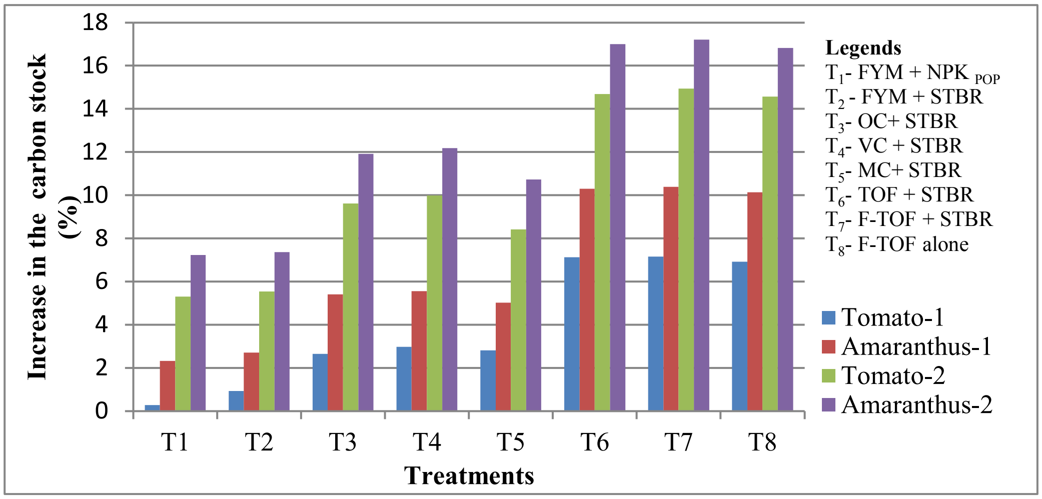

Fig. 112 Percentage increase in the carbon stock in the surface layer (0-15 cm) under different organic fertilizers compared to absolute control

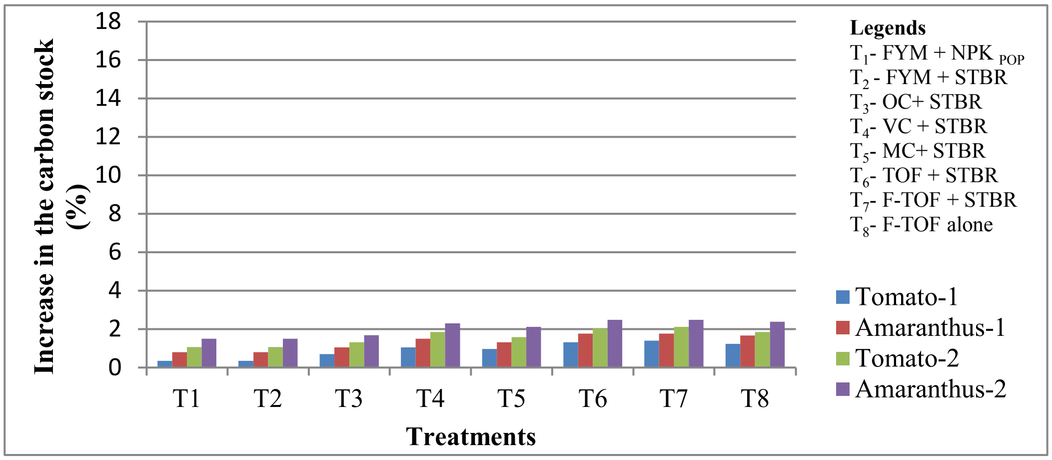

Fig. 113 Percentage increase in the carbon stock in the sub-surface layer (15-30 cm) under different organic fertilizers compared to absolute control

Similarly in the sub-surface layer (15-30 cm), application F-TOF and TOF has enhanced the carbon stock by nearly 2.47 % and VC by 2.30% and MC by 2.12 %. FYM application enhanced carbon stock in the sub surface layer by 1.5 % % and OC by 1.68 % (Fig. 99) compared to the control treatment where no organic fertilizer was added. When compared to initial carbon stock of the sub surface soil, the addition of F-TOF and TOF had enhanced the carbon storage by 1.58 % , VC by 1.4 %, MC by 1.23 %, OC by 0.79 % and FYM by 0.61 %. In control, the carbon stock in the sub surface layer decreased by 0.88 % at the end of second cropping sequence due to the continuous cropping without application of organic and inorganic fertilizers. Since the organic fertilizers were added in the surface soil, the increase in carbon stock in surface soil was higher compared to sub surface soil. The down ward movement of carbon pools has contributed to the increase in sub-surface soil. In both cases the increase was highest for F-TOF and TOF. The studies conducted revealed that cropping systems with different combinations of fertilizers and manures contribute to an increased SOC content in the soil (Rudrappa *et al.*, 2005).The percentage increase in the SOC content in different cropping system varied from 0.34 % to 40 %, in which the lowest contribution was from coconut- cassava cropping sequence and highest from rubber plantation (Gnanavelrajah *et al.,* 2008).Intensive agriculture with better management of water and nutrients had enhanced C-sequestration by higher crop productivity and greater return of crop residues, root biomass and root exudates to soil. Benbi and Brar (2009) reported that intensive agriculture with combined application of organic and inorganic fertilizers, for 25 years in Punjab has increased the SOC content of the soil by 38%.

5.4.8.6 Heavy metal loading in soil

The continuous application of organic fertilizers did not make any noticeable increase heavy metal content of the soil. The presence of Pb was noticed in post-harvest soil of both the cropping sequences and there was no significant difference among the treatments. Available Pb in the post-harvest soil decreased noticeably after the amaranthus crop for both the cropping sequences. It indicates the phytoextraction potential of amaranthus for the removal of Pb from soil (Table 139). Rahman *et al*. (2013) reported the potential of amaranthus in the quick removal of Pb from the contaminated soil. Application of organic fertilizer is the main source of trace metals to the soil and can also become a potential source of environmental pollution (Ding *et al.,* 2017). Presence of heavy metal limits the use of organic fertilizers in the soil. So it is important to understand the status and extent of soil contamination of trace metals from organic fertilizers to develop sustainable management strategies for agricultural soils (Gong *et al*., 2019). In order to reduce the risk in using organic fertilizers it is better to analysis of the heavy metal content of organic fertilizers to avoid its excess accumulation above the safe limits. It assures soil quality, safety to agricultural produce and a sustainable ecosystem. The ability of biochar to adsorb heavy metals was reported by Zhao *et al.* (2019) and such types of absorbent materials can be mixed with organic fertilizers to reduce the release of heavy metal to the soil.

5.5 CORRELATION STUDIES

Significant correlation among different parameters was observed in the second cropping sequence of tomato and amaranthus. Thus correlation analysis was only done for the second cropping sequence. The continuous application of organic fertilizers has enhanced soil carbon pools and total N content of soil which resulted in the higher crop yield. The significant positive correlation of yield with WSOC, MBC, TOC, labile carbon and total N content of soil substantiate the results. Continuous application of organic fertilizers also enhanced the availability of nutrients in the soil and thus resulted in a higher nutrient uptake in crop plants.

5.6 SYSTEM PRODUCTIVITY

In cropping system studies, the analysis of system productivity gives more meaningful information rather than analyzing individual crop performance.

Equivalent yield, production efficiency and equivalent energy are the three important parameters for understanding system productivity. Thus in the system, tomato was taken as the main crop and tomato equivalent yield of amaranthus was calculated. Using this total tomato equivalent yield of the cropping system and production efficiency of different treatments were calculated. Tomato equivalent yield of the cropping system was highest for the treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR) and they did not differ significantly. Similarly, the production efficiency of treatments T_7 and T_4 were found equally good. In the terms of equivalent energy, the highest energy production in the cropping system was from treatment T_7 followed by T_4. Eventhough the equivalent energy of the cropping system was highest for the treatment T_7, the equivalent yield as well as production efficiency of treatment T_7 and T_4 did not differ significantly. Thus it is clear from the experiment carried out that fortified thermochemical organic fertilizer is an ideal organic fertilizer for crop production.

5.7 ECONOMICS OF CULTIVATION

During the crop production application of organic and inorganic fertilizers increased tomato and amaranthus yield compared to the absolute control where no organic fertilizers were added. During the first cropping sequences, the treatment T_4 (VC +STBR) resulted the highest economic benefit for tomato I with a B:C ratio of 2.46. But the succeeding crops of the sequence *i.e.,* amaranthus-tomato-amaranthus gave the highest economic benefits for the treatment T_7 (F-TOF + STBR). F-TOF based treatment gave a B:C ratio in the order of $2.73_{\text{amaranthus I}}$, $2.45_{\text{tomato II}}$ and $2.68_{\text{amaranthus II}}$. Thus we can conclude that continuous application of F-TOF along with inorganic fertilizers have economic benefits during crop production and it can be used as an alternative to conventional and non-conventional organic fertilizers that are commonly used for crop production. Similar results regarding the economic benefit of thermochemical organic fertilizers were reported by Leno (2017) and Ramesha (2019).

The experiments carried out revealed the nutrient release pattern, temporal variation and extent of leaching losses and their retention from thermochemical organic fertilizer amended soil in comparison with FYM, vermicompost, microbial compost and ordinary compost. The field experiments revealed the performance of each organic fertilizer in relation to crop production and found that F-TOF is an ideal organic fertilizer for the Utilisols of Kerala considering its superiority in carbon storage and nutrient release.

SUMMARY

6. SUMMARY

A study entitled "Effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics and crop productivity in Ultisols" was conducted from April 2018 to January 2020 at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani with the objective to study the effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics, their retention and leaching and crop productivity in comparison with conventional organic fertilizers in Ultisols using tomato - amaranthus cropping sequence. A summary of salient results of the study are presented this chapter.

Production and characterisation of organic fertilizers

- Bio-waste collected from different sources were converted to ordinary compost (OC), vermicompost (VC), and microbial compost (MC) as per standard procedures and to thermochemical organic fertilizer as per the protocol standardized by Sudharmaidevi *et al.,* 2017.
- The organic fertilizers OC, VC, M , thermochemical organic fertilizer with (F-TOF) and without (TOF) fortification and FYM were tested for their physicochemical properties and they were in accordance with the standards specified by FCO.
- The pH of the organic fertilizers was in neutral range (6.5-7.5), where the pH of FYM, AC, VC and MC were > 7 and that of TOF and F-TOF < 7.
- EC of the organic fertilizers were < 2 ds m^{-1} and they were within the safe limit as prescribed by FCO. The highest EC was with F-TOF (1.59 dS m^{-1}) and lowest with FYM (0.20 dS m^{-1}).
- Among the organic fertilizers, thermochemical organic fertilizers (TOF and F-TOF) recorded higher carbon pools viz., TOC, WSOC, labile carbon and ROC compared to other organic fertilizers.

- Among the organic fertilizers, the total N content was highest for MC (2.61 %) followed by VC (2.42 %) and F-TOF (2.38 %) and lowest in FYM. The lowest C:N ratio was for MC (11.45) and the highest for TOF (23.73). The organic components such as cellulose and hemicellulose were highest with FYM and the lowest cellulose was with MC and hemicellulose with VC. The lignin content was highest in TOF followed by F-TOF and lowest in FYM.
- VC recorded the highest P (1.36 %) content and the lowest by TOF (0.49 %) while F-TOF recorded the highest K content (2.56 %) and the lowest by FYM. F-TOF had the highest contents for both Ca and Mg and FYM had the lowest values. Sulphur content was highest for FYM (550 mg kg^{-1}) and lowest for TOF (220 mg kg^{-1}).
- Boron content of organic fertilizers varied from 1.76 mg kg^{-1} for FYM to 4.64 mg kg^{-1} for F-TOF.
- Micronutrients Fe, Mn, Zn and Cu were highest in FYM (9580 mg kg^{-1}), VC (479.60 mg kg^{-1}), F-TOF (254 mg kg^{-1}) and OC (70.8 mg kg^{-1}), respectively and lowest in TOF.
- Among the heavy metals, Pb was detected in all the organic fertilizers while Cd was below detectable limits. The highest Pb content was with FYM (4.12 mg kg^{-1}) and the lowest was with OC (2.18 mg kg^{-1}).
- The bacterial and fungal count was highest in MC (8.48 and 5.27 log cfu g^{-1}, respectively) and lowest in TOF followed by F-TOF.
- Dehydrogenase activity was highest in MC followed by FYM and the lowest in thermochemical organic fertilizers (TOF and F-TOF).

Leaching study with soil columns

- The leachates from soil columns were collected at four weeks interval for a period of 24 weeks. The pH of the leachates ranged from 5.60 to 6.35 and was higher than that of control treatment.

- EC of the leachate was highest at the first week decreased toward the end of incubation
- The highest cumulative loss of DOC was from VC (14.54 mg L^{-1}) followed by OC, TOF and F-TOF and the lowest was from control.
- The highest cumulative loss of NH_4-N, NO_3-N and total N was from VC (28.82, 21.56, 185.86 mg L^{-1}, respectively) followed by MC, while the highest loss of organic N (5.29 mg L^{-1}) was from VC followed by OC.
- Cumulative leaching losses of P, K, Mg, Cu and B were highest from F-TOF while that of Ca and Mn from VC, Fe and Zn from OC and S from FYM. Pb and Cd content were not detected in leachate.
- After the leaching, at 24 W, pH of the surface layer soil decreased than their initial value for all the treatments. Among the treatments, F-TOF recorded highest pH at 0-15, 30-60 and 60-90 cm depths and MC at 15- 30 cm depth. In lower depths, pH increased than their initial values except for control.
- Leaching for 24 W had decreased the EC of the surface layer for all treatments than the 0 D and the highest EC at 24 W, was recorded by MC (0.26 dS m^{-1}) followed by F-TOF. However, in the lower depths (15-30, 30-60 and 60-90 cm) EC of organic fertilizers added treatments has increased compared to the initial values and the highest value was recorded by F-TOF.
- Due to leaching, TOC content of surface layer (0-15 cm) decreased and sub-surface layer (15-30 cm) increased than their initial value. However, the highest TOC in the surface and sub-surface layer was retained by F-TOF followed by TOF.
- Leached soil exhibited the highest WSOC content at 15-30 cm depth for all treatments except control. In the surface layer MC had the highest value for WSOC and for VC in lower layers.
- In the leached soil, labile carbon and MBC decreased in surface layer and increased evidently sub-surface layer (15-30 cm) except control. However the

highest for values for labile carbon and MBC in the both layers was maintained by F-TOF followed by TOF.

- In the leached soil, the highest value for ROC at 0-15 and 15-30 cm depths was recorded by TOF followed by F-TOF. At 15-30 cm depth, the treatments such as F-TOF, TOF, VC, MC and OC were statically on par with other for their ROC content.
- In the leached soil, NH_3-N was highest for VC at 0-15 cm and 60-90 cm. At 15-30 and 30-60 cm, the highest NH_3-N content was for MC and F-TOF, respectively. For NO_3-N, at 0-15 and 30-60 cm depth, MC recorded the highest value, while F-TOF for 15-30 cm and OC for 60-90 cm depth. For organic N, MC recorded the highest values up to 60 cm depth and at 60-90 cm depth; F-TOF recorded the highest organic N followed by VC. After leaching, total N content in the surface layer and sub-surface layer was highest for MC while from at 30-60 and 60-90 cm depth, F-TOF had the highest values.
- The highest value for total P at 0-15, 15-30 and 30-60 cm depths was recorded by VC followed OC and MC. At 60-90 cm depth, the highest value was for F-TOF followed by OC and VC. In the leached soil, the highest value of total K was maintained by F-TOF at all four depths.
- After leaching the highest total Ca and Mg content at all the four depths was recorded with F-TOF. In leached soil, the highest total S content in the surface layer (0-15 cm) was recorded with FYM followed by OC and F-TOF. Similarly, total Fe content at all the four depths was highest for FYM. After leaching, highest value for total Mn and Cu was recorded by VC. For total Zn, highest retention in surface layer was for F-TOF followed by VC.
- In the leached soil, availability of P and Mn was highest from VC amended soil, K, Mg, S, Fe, Zn, Cu and B from F-TOF and Ca from MC.

- In the leached soil, the total B as well as fractions of B such as readily available B, specifically adsorbed B, oxide bound B, organically bound B and residual B in the surface layer was highest F-TOF amended soil.
- Available Pb and Cd were not detected in the leached soil.

Incubation study

- In the organic fertilizers added treatments, the pH increased in the first week than the 0 D, but declined in the 4 W and again rose in 8 W which declined with the further incubation. Throughout the incubation, the highest pH was maintained by F-TOF.
- The treatments that received organic fertilizers did not show a consistent increase in EC, even though most of the treatments showed an increase up to 12 W and later decreased. Throughout the incubation, the highest EC was maintained by F-TOF and the peak value was recorded by F-TOF on 8 W.
- During the incubation the highest TOC content in the soil was maintained by TOF and F-TOF amended soil and it exhibited a gradual decreasing trend towards the end of the incubation.
- After one week of incubation WSOC decreased in TOF, F-TOF OC and control treatments but by 4 W all the treatments showed a decrease followed by an increase on 8 W except for control and later declined.
- Throughout the incubation period, the highest value for labile carbon was maintained by F-TOF. Labile carbon increased up to 4 W for control, FYM and MC, up to 8 W for VC, F-TOF and TOF and up to 12 W for OC.
- On 0 D and 1 W of incubation the highest value for microbial biomass carbon (MBC) was recorded by MC. But in the subsequent sampling highest value was recorded with F-TOF. MBC increased up to 12 W of

incubation for FYM and OC, while up to 8 W for VC, MC, TOF and F-TOF. Throughout the incubation period, the highest value for ROC was recorded by TOF followed by F-TOF.

- On 0 D, the highest NH_4-N content was for MC while the succeeding four sampling periods it was for VC and later for F-TOF. Throughout the incubation, the highest NO_3- N content was recorded by F-TOF followed by VC and MC. At all the sampling intervals the highest value for organic N was recorded by MC which was significantly superior to all other treatments, followed by VC and F-TOF except for the sampling intervals at 4 W and 16 W.
- During incubation, total N recorded highest with MC, total P with VC, total K, Ca, Mg, B and Zn with F-TOF. Highest value for total S and Fe was recorded by FYM. Mn and Cu content were highest with VC.
- For all treatments availability of P increased from 0 D up to 8 W and declined afterwards. Throughout the incubation, the availability P was highest from VC. Throughout the incubation, available K, Ca and Mg were highest from F-TOF. The availability of S was highest from F-TOF up to 4 W and at 24 W. While the availability was highest from FYM from 4 W up to 20 W.
- During the incubation, the highest availability Fe, Zn and Cu was from F-TOF. But for Mn, the availability was highest from F-TOF up to 4 W and afterward from VC. Throughout of the incubation, the highest value for all the fractions of B such as readily available B, specifically adsorbed B, oxide bound B, organically bound B and residual B was recorded by F-TOF.
- Available Pb and Cd were not detected in the incubated soil
- At 0 D and 1 W, bacterial population was highest for MC followed by VC. But from 4 W onwards, the highest bacterial count was maintained by F-

TOF. In all the treatments the bacterial population increased from 0 D up to 16 W, with control as exception.

- Fungal count was highest in MC at 0 D. From first week onwards, F-TOF maintained the highest fungal population throughout the incubation. It increased up to 8 W for all treatments and declined afterwards. Towards the end of incubation, again a rise in fungal population was noted for all treatment except for control. Similarly, the highest actinomycetes population was maintained in thermochemical organic fertilizer amended soil (TOF and F-TOF)
- During the incubation, from 4 W onwards, the highest dehydrogenase activity was recorded with treatment F-TOF followed by VC. But up to first week, MC had maintained the highest dehydrogenase activity. The lowest dehydrogenase activity throughout the incubation was recorded by control.

Field experiments on tomato – amaranthus cropping sequence

- In the first cropping sequence, VC amended treatment T_4 (VC + STBR) recorded highest fruit yield (40.97 t ha^{-1}) followed by F-TOF (T_7 : F-TOF + STBR) and in the second cropping sequence reverse was the order and they were statistically on par also.
- During both the cropping sequences, the highest yield for amaranthus (24.62 t ha^{-1} and 26.89 t ha^{-1}, respectively) was from the treatment T_7 (F-TOF + STBR) followed by T_4 (VC + STBR). The treatments T_7 and T_4 were statistically on par in second cropping sequence.
- The B:C ratio of tomato was highest for treatment T_4 (VC + STBR) during first cropping sequence, while B:C ratio for remaining crops were highest for treatment T_7 (F-TOF + STBR). However, the overall B:C ratio for the whole cropping sequences was highest for F-TOF followed by VC.

- The quality parameters of tomato and amaranthus were significantly influenced by the application of organic fertilizers.
- The highest lycopene and ascorbic acid content in tomato was recorded for the treatment T_7 (F-TOF + STBR) and it was statistically on par with treatment which received organic fertilizers along with POP or soil test based fertilizer recommendation of NPK.
- In amaranthus, the quality parameters such as crude fibre, ascorbic acid and carotene content were highest in treatment T_7 and nitrate content was highest in the treatment T_4 and these treatments were statistically on par with other treatments which received organic fertilizers along with POP or soil test based fertilizer recommendation of NPK. The oxalate content was least in the treatment T_7 and highest in treatment T_9 (Absolute control).
- Uptake of N, P, K, Ca, Mg, S, Zn and B in tomato was highest for F-TOF (T_7) while that of Fe, Mn, and Cu was for VC (T_4).
- For amaranthus, the uptake of N, P, K, Mg, Fe, Zn, Cu and B was highest for F-TOF (T_7) for both the cropping sequences. But the Ca uptake was highest for VC during the first cropping sequence while F-TOF had the highest during the second cropping sequence. Similarly for S, the highest uptake during first cropping sequence was for MC and in second cropping sequence for F-TOF. The uptake of Mn was highest with OC in first cropping sequence and with VC in second cropping sequence.
- Among the heavy metals tested only Pb was detected in plant parts and that too in roots only. For tomato, it was detected only in FYM treated plants while in amaranthus, all the treatments receiving organic fertilizers showed the presence of Pb. But the Pb content in the root was within the safe limit and Cd was not detected in plant samples.
- Continuous addition of organic fertilizers decreased the bulk density of the soil. At the end of second cropping sequence, the lowest bulk density

of (1.29 Mg m^{-3}) was recorded by the treatments that have received thermochemical organic fertilizers (TOF and F-TOF).

- For both the cropping sequences, the highest WHC in the post-harvest soil after each crop (29.50, 30.31, 30.89 and 31.02 %, respectively) was recorded by the treatment T_7 (F-TOF + STBR) followed by T_8 (F-TOF alone) and T_6 (TOF + STBR).
- For all the four crops, pH of post-harvest soil was highest for treatment T_8 (F-TOF alone) followed by T_6 (TOF + STBR) and T_7 (F-TOF + STBR).The lowest pH was recorded with absolute control and it exhibited a decreasing trend after each crop.
- For all the four crops, the EC of post-harvest soil recorded the highest value with treatment T_7 (F-TOF + STBR)
- The highest value for TOC, labile carbon, microbial biomass carbon and recalcitrant organic carbon in the post-harvest soil was recorded by the treatment T_7 (F-TOF + STBR).
- For both the cropping sequences, the highest value for water soluble organic carbon in the post-harvest soil after the harvest of each crop was recorded by the treatment T_4 (VC +STBR).
- At the end of second cropping sequence, the highest value for NH_4-N, NO_3-N, organic N and total N was recorded by the treatment T_7 (F-TOF + STBR)
- In the post-harvest soil for all the four crops, the highest available P was recorded by the treatment T_4 (VC +STBR) and T_7 (F-TOF + STBR for available K, Ca, B and Zn.
- In the post-harvest soil, the highest available Mg was recorded by treatment T_4 (VC + STBR) in first cropping sequence and T_7 (F-TOF + STBR) in second cropping sequence. For available S highest value at the end of second cropping sequence was from treatment T_4 (VC + STBR)

- In the end of second cropping sequence, the highest availability of Fe and Cu was from the treatment T_4 (VC + STBR) and that of Mn from T_5 (MC + STBR). Throughout the cropping sequence, the availability of Zn and B from post-harvest soil was highest for treatment T_7 (F-TOF + STBR).
- The available Pb from the post-harvest soil did not vary significantly among the treatments and Cd was not detected.
- At the end of second cropping sequence, the highest bacterial population was with treatment T_4 and actinomycetes populations with treatment T_7. While, throughout the cropping sequences, highest fungal population was maintained by treatment T_7. During the cropping sequences, the highest dehydrogenase activity was maintained between the treatment T_7 and T_4.

CONCLUSION

F-TOF is a good organic source to maintain the SOC of soil and is superior to VC, OC, MC and FYM in terms of carbon storage. Application of F-TOF has enhanced the C and N pools and availability of K, Mg, S, Fe, Zn, Cu and B in the soil as evidenced in the incubation study. Leaching study with soil column revealed that the highest retention of C, K, Ca, Mg, Zn and B by F-TOF and at the same time its favoured highest leaching loss of P, K, Mg, Cu and B. The nutrient content in the leachate actually indicated the potential availability of nutrients from different organic fertilizers for crop plants. Absence of plants resulted in the downward movement of nutrients along with leaching water. Since the nutrient loss was highest from F-TOF, there is a need to revisit the rate and mode of fortification of F-TOF which is widely marketed in the trade name “Suchitha”.

For crop production, the performance of F-TOF was very good giving highest yields from second crop of the first sequence onwards. However, it was statistically on par with VC and was superior to FYM, OC and MC. But in terms of soil carbon pools, carbon stock nutrient availability and dehydrogenase activity, its performance was superior to all the organic fertilizers tested. Thus, in long run F-TOF can be rated as the most suitable organic source for crop production, in tropical Ultisols, where depletion SOC and leaching loss of nutrients are the major problems. However, further long-term studies only could confirm F-TOF's role in crop production.

FUTURE LINE OF WORK

- Potential of fortified thermochemical organic fertilizer as an organic source on different crops to be studied and long term studies should be carried out to understand its potential in enhancing soil properties and carbon stock of the soil.
- Combination of TOF with bio-fertilizers and bio-pesticides can be studied to explore its potential in enhancing NUE and to control soil borne diseases.
- Alternative sources for fortification should be explored to avoid or reduce leaching losses
- Development of TOF based fertilizer formulations like nutrient tablets for the slow release of nutrients

REFERENCES

REFERENCES

Aalok, A., Tripathi, A. K., and Soni, P. 2008. Vermicomposting: a better option for organic solid waste management. *J. Human Ecol.* 24 (1): 59–64.

Abdel, N. G. and Hossein, A. H. A. 2001. Effect of different manure sources on some soil properties and sunflower plant growth. *Axeandria J. Res.* 46 (1): 227-251.

Abdou, G., Ewusi-Mensah, N., Nouri, M., Tetteh, F. M., Safo, E. Y. and Abaidoo, R. C. 2016. Nutrient release patterns of compost and its implication on crop yield under Sahelian conditions of Niger. *Nutr. Cycling Agroecosyst.* 105 (2): 117–128.

Abera, K., Crespo, O., Seid, J. and Mequanent, F. 2018. Simulating the impact of climate change on maize production in Ethiopia, East Africa. *Environ. Syst. Res.* 7 (1): doi:10.1186/s40068-018-0107-z

Abolusoro, P. F., Abolusoro, S. A., Adebiyi O. T. V. and Ogunremi, J. F. 2017. Evaluation of different manures application on fruit quality of tomato in the derived savannah ecological zone of Nigeria. *Horticult. Int. J.* 1 (2): 35–37.

Abou El-Magd, M. A., El-Bassiony, M. and Fawzy, Z. F. 2006. Effect of organic manure with or without chemical fertilizer on growth, yield and quality of some varieties of broccoli plants. *J. Appl. Sci. Res*. 2 (10): 791-798.

Adediran, J. A., Taiwo, L. B. and Sobulo, R. A. 2003. Effect of organic wastes and method of composting on compost maturity, nutrient composition of compost and yields of two vegetable crops. *J. Sustain. Agric.* 22 (4): 95–109.

Adegunloye, D.V., Adetuyi, F.C., Akinyosoye, F. A. and Doyeni, M. O. 2007. Microbial analysis of compost using cowdung as booster. *Pakistan J. Nutr.* 6 (5): 506-510.

Adeli, A., Read, J., Feng, G., McGrew, R. and Jenkins, J. 2017. Organic amendments and nutrient leaching in soil columns. *Agron. J.* 109 (4): 1294-1302.

Ahmad, A. A., Radovich, T. J. K., Nguyen, H. V., Uyeda, J., Arakaki, A., Cadby, J. and Teves, G. 2016. Use of organic fertilizers to enhance soil fertility, plant growth, and yield in a tropical environment. *Organic Fertilizers - From Basic Concepts to Applied Outcomes.* doi:10.5772/62529.

Ali, M. A., Molla, M. S. H., Alam, M. R., Mornin, M. A. and Mannan, M. A. 2009. Effect of combinations of chemical fertilizers and poultry manure on the productivity of crops in the cauliflower-stem amaranth -jute pattern. *Bangladesh J. Agric. Res.* 34 (1): 113 – 121.

Allan, J. D. and Castillo, M. M. 2007. Stream Ecology: Structure and Function of Running Waters. 2nd Edition, Chapman and Hall, New York. http://dx.doi.org/10.1007/978-1-4020-5583-6

Andersen, J. K., Boldrin, A., Christensen, T. H. and Scheutz, C. 2010. Greenhouse gas emissions from home composting of organic household waste. *Waste Manag*. 30: 2475–2482.

Antil, R. S. and Singh, M. 2007. Effects of organic manures and fertilizers on organic matter and nutrients status of the soil. *Arch. Agron. Soil Sci.,* 53: 519-528.

AOAC 1984. Official Methods of Analysis. Association of Official Analytical Chemists. 14th Edition, AOAC, Arlington.

Aula, L., Macnack, N., Omara, P., Mullock, J. and Raun, W. 2016. Effect of fertilizer nitrogen (N) on soil organic carbon, total n and soil pH in long-term continuous winter wheat (*Triticum aestivum* L.). *Commun. Soil Sci.* 47 (7): 863-874.

Ayilara , M. S., Olanrewaju, O. S., Babalola, O. O. and Odeyemi, O. 2020. Waste management through composting: challenges and potentials. *Sustainability* 12 (11): 4456-4479.

Azam, S., Shah, W. M., Syed, M. S. and Muhammad, S. S. 2013. Effect of organic and chemical nitrogen fertilizers on grain yield and yield components of wheat and soil fertility. *Sci. J. Agron. Plant Breeding* 1 (2): 37-48.

Azarmi, R., Ziveh, P. S. and Satari, M. R. 2008. Effect of vermicompost on growth, yield and nutrition status of tomato (*Lycopersicum esculentum*). *Pak. J. Bio. Sci.* 11: 1797-1802.

Baddi, G. A., Hafidi, M., Cegarra, J., Alburquerque, J. A., Gonzalvez, J., Gilard, V. and Revel, J. C. 2004. Characterization of fulvic acids by elemental and spectroscopic (FTIR and C-NMR) analyses during composting of olive mill wastes plus straw. *Bioresour. Technol.* 93: 285-290.

Barber, S. A. 2014. Soil nutrient bioavailability, 1st edn. Wiley, New Delhi.

Barker, A. V. 1997. Composition and uses of compost. In: Rechling, J. E. and Mackinnon, H.C. (eds): *Agricultural Uses of By-products and Wastes*, ACS Symposium, Orlando, FL, USA, p. 284

Barman, P., Sen, A. Phonglosa, A. and Bhattacharyya, K. 2017. Depth wise distribution of boron in some soils of red and laterite zone of West Bengal, India. *Int. J. Curr. Microbiol. App. Sci.* 6 (12): 4126-4137.

Barton, L., Wan, G. G. Y. and Colmer. T. D. 2006. Turfgrass (*Cynodon dactylon* L.) sod production on sandy soils: effects of irrigation and fertilizer regimes on N leaching. *Plant Soil* 248:147–164.

Basnet, M. and Shakya, S. M. 2016. Effect of different organic fertilizers on economic yield of cauliflower (*Brassica oleraceae* var. botrytis L.) at Ilam, Nepal. *Nepalese Hortic.* 11 (1): 7-12.

Basso, B. and Ritchie, J. T. 2005. Impact of compost, manure and inorganic fertilizer on nitrate leaching and yield for a 6-year maize–alfalfa rotation in Michigan. *Agric. Ecosyst. Environ*. 108: 329–341.

Batjes, N. H. 1996. Total carbon and nitrogen in the soils of the world. *Eur. J. Soil Sci.* 47: 151–163.

Beckwith, C. P., Cooper, J. Smith, K. A. and Shepherd, M. A. 1998. Nitrate leaching loss following application of organic manures to sandy soils in arable cropping; effects of application time, manure type, overwinter crop cover and nitrification inhibition. *Soil Use Manage.* 14: 123-130

Benbi, D. K. and Brar, J. S. 2009. A 25-year record of carbon sequestration and soil properties in intensive agriculture. *Agron. Sustain. Dev.* 29 (2): 257-26.

Bernal, M. P., Alburquerque, J. and Moral, R. 2009. Composting of animal manures and chemical criteria for compost maturity assessment: a review. *Bioresour. Technol.* 100: 5444-5453.

Bhalerao, N. M., Patil, N. M., Badgujar, C. D. and Patil, D. R. 2009. Studies on integrated nutrient management for tissue cultured Grand Naine banana. *Indian J. Agric. Res.* 43 (2): 107-112.

Bihari, B., Kumari, R. and Shambhavi, S. 2018. Release pattern of inorganic N, phosphorus and potassium as influenced by farmyard manure and pressmud compost under laboratory incubation study. *Int. J. Curr. Microbiol. App. Sci.* 7 (9): 2476-2483.

Bingham, F.T. 1982. Boron. In: Page, A.L., Ed., Methods of soil Analysis Part-2 Chemical and Mineralogical Properties, American Society of Agronomy, Madison, 431-448.

Blair, G. J., Lefroy, R. D. B., and Lisle, L. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Aust. J. Agric. Res.,* 46 (7): 1459-1466.

Bouldin and Lawson, Inc., 2000. Process of transforming household garbage into useful material. United States Patent 6017475. Date issued 25 January 2000.

Brady, N.C. 1990. *The Nature and Properties of Soils*, 10th edn, MacMillan Publishing Company, New York.

Brar, B. S., Singh, K., Dheri, G. S. and Kumar, B. 2012. Carbon sequestration and soil carbon pools in a rice–wheat cropping system: effect of long-term use of inorganic fertilizers and organic manure. *Soil Tillage Res.* 128: 30–36

Brar, S. B., Singh, J., Singh, G. and Kaur, G. 2015. Effects of long term application of inorganic and organic fertilizers on soil organic carbon and physical properties in maize–wheat rotation. *Agron.* 5 (2): 220–238.

Bratovcic, A., Zohorovic, M., Odobasic, A. and Sestan, I. 2018. Efficiency of food waste as an organic fertilizer. *Int. J. Engin. Sci. Res. Technol.* 7 (6): 528- 530.

Brauer, D., Aiken, G. E., Pote, D. H., Livingston, S. J. Norton, L. D., Way, T. R. and Edwards, J. H. 2005. Amendment effects on soil test phosphorus. *J. Environ. Qual.* 34:1682–1686.

Brown., K. H. 2013. Nitrogen fertilization effects on soil organic carbon storage and aggregation mechanisms within continuous corn cropping systems. MSc Thesis. Iowa State University, Ames, Iowa, 142p.

Bundy, L. G. and Meisinger, J. J. 1994. Nitrogen availability indices. In: Weaver, R. W., Angle, S., Bottomley, P., Bezdicek, D., Smith, S., Tabatabai, A. and Wollum, A. (eds), *Methods of Soil Analysis, Part 2: Microbiological and Biochemical Properties* (2nd ed.). SSSA, Madison, pp. 951–984.

Burchill, S., Hayes, M. H. B. and Greenland D. J. 1981. Adsorption. In Greenland D. J. and Hayes M. H. B. (eds) *The Chemistry of Soil Processes*. John Wiley & Sons, New York p. 221-400.

Burford, J. R. and Bremner, J. M. 1975. Relationships between the denitrification capacities of soils and total, water-soluble and readily decomposable soil organic matter. *Soil Biol. Biochem.* 7 (6): 389–394.

Burgos, P., Madejon, E. and Cabrera, F. 2006. Nitrogen mineralization and nitrate leaching of a sandy soil amended with different organic wastes. *Waste Manage. Res.* 24: 175–182.

Busby, R. R., Torbert, H. A. and Gebhart, D. L. 2007. Carbon and nitrogen mineralization of non-composted and composted municipal solid waste in sandy soils. *Soil Biol. Biochem.* 30: 1277–1283.

Calderón, F. J., McCarty, G. W., Van Kessel, J. A. S. and Reeves, J. B. 2004. Carbon and nitrogen dynamics during incubation of manured soil. *Soil Sci. Soc. America J.* 68 (5): doi:10.2136/sssaj2004.1592.

Casida, L. E., Klein, D. A. and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci*. 98: 371-376.

Celik, I., I. Ortas, and S. Kilic. 2004. Effect of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. *Soil Tillage Res.* 78: 59–67.

Chan, K. Y., Bowman, A. and Oates, A. 2001. Oxidizible organic carbon fractions and soil quality changes in an oxic paleustalf under different pasture leys. *Soil Sci.,* 166 (1), 61-67.

Chand S., Anwar M. and Patra D. D. 2006. Influence of long-term application of organic and inorganic fertilizer to build up soil fertility and nutrient uptake in mint mustard cropping sequence. *Commun. Soil Sci. Plant Anal.* 37 (1-2): 63-76.

Chang, E., Chung, R. and Tsai, Y. H. 2007. Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population. *Soil Sci. Plant Nutr.* 53: 132–140.

Chang, R., Yao, Y., Cao, W., Wang, J., Wang, X. and Chen, Q. 2019. Effects of composting and carbon based materials on carbon and nitrogen loss in the arable land utilization of cow manure and corn stalks. *J. Environ. Manage.* 233: 283–290.

Chantigny, M. H. 2003. Dissolved and water-extractable organic matter in soils: a review on the influence of land use and management practices. *Geoderma,* 113 (3-4): 357–380.

Chao, T. T. and Sanzolone, R. F. 1989. Fractionation of soil selenium by sequential partial dissolution: *Soil Sci. Soc. America J.* 53: 385-392.

Chatterjee, B. and Datta, S. 1951. Phosphate fixation by clay minerals montmorillonite and kaolinite. *J. Soil Sci.* 2 (2): 224–233.

Chatterjee, R., Jana J. C. and Paul P. K. 2013. Vermicompost substitution influences shelf life and fruit quality of tomato (*Lycopersicon esculentum* Mill.). *Am. J. Agric. Sci. Technol*. 1: 69–76.

Chen, H., Cao, C. F., Kong, L. C., Zhang, C. L., Li, W., Qiao, Y. Q., Du, S. Z. and Zhao, Z. 2014. Study on wheat yield stability in Huaibei lime concretion black soil area based on long-term fertilization experiment. *Scientia Agricultura Sinica*, 47: 2580–2590.

Chen, Y., Camps-Arbestain, M. and Shen, Q. 2018. The long-term role of organic amendments in building soil nutrient fertility: a meta-analysis and review. *Nutr. Cycl. Agroecosyst.* 111:103-125.

Chesnin, L. and Yien, C. H. 1951. Turbidimetric determination of available sulphates. *Soil Sci. Soc. Am. J.* 15: 149-151.

Chivenge, P., Vanlauwe, B. and Six, J. 2011. Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. *Plant Soil* 342:1–30.

Choudhari, V. K. and Kumar, S. P. 2013. Maize production, economics and soil productivity under different organic source of nutrients in eastern himalayan region, India. *Int. J. Plant Prod.* 7 (2): 167-186.

Choudhary, G. L., Choudhary, A. A., Khawale, V. S., Potkile, S. N. and More, S. R. 2008. Nutrient management studies in chickpea (*Cicer arietinum*). *J. Soils Crops* 18 (1): 174-177.

Chowdhury, A. K. M. M. B., Akratos, C. S., Vayenas, D. V. and Pavlou, S. 2013. Olive mill waste composting: a review. *Int. Biodeter. Biodegr*. 85: 108-119.

Chun-xi, L., Shou-chen, M. Yun, S. Shou-tian, M. and Ling-ling, Z. 2018. Effects of long-term organic fertilization on soil microbiologic characteristics, yield and sustainable production of winter wheat. *J. Integr. Agric.* 17 (1): 210-219.

Clark, S. and Cavigelli, M. 2005. Suitability of composts as potting media for production of organic vegetable transplants. *Compost Sci. Util.* 13:2, 150-155.

Cochran, W. G. und Cox, G. M. 1965. Experimental designs. *Biometrische Zeitschrift,* 7 (3): 203–203.

Cooperband, L., Stone, A., Fryda, M. and Ravet, J. 2003. Relating compost measures of stability and maturity to plant growth. *Compost Sci. Util.* 11: 113-124.

Costa, A. R., Sato, J. H., Ramos, M. L. G., Figueiredo, C. C., Souza, G. P., Rocha, O. C. and Guerra, A. F. 2013. Microbiological properties and oxidizable organic carbon fractions of an Oxisol under coffee with split phosphorus applications and irrigation regime. *Revista Brasileira de Ciência do Solo* 37: 55-65.

Cruz, D. N. E., Aganon, C. P., Patricio, M. G., Romero, E. S., Lindain, S. A. and Galindez, J. L. 2006. Production of organic fertilizer from solid waste and its utilization in intensive organic-based vegetable production and for sustaining soil health and productivity. In International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use, Bangkok, Thailand, 20p.

Czarnecki, S. and Düring, R. A. 2015. Influence of long-term mineral fertilization on metal contents and properties of soil samples taken from different locations in Hesse, Germany. *Soil* 1 (1): 23–33.

Darwin, C. R. 1881.The formation of vegetable mould, through the action of worms, with observations on their habits, London: John Murray, London, UK.

Das, R., Issac S. R. and Manorama Thampatti, K. C. 2020. Efficacy of enriched leaf litter composed as nutrient source in vegetable cowpea. *J. Soil Crops* 30 (1): 63-68.

Datt, N., Sharma, R. P. and Sharma, G. D. 2003. Effect of supplementary use of farmyard manure along with chemical fertilizers on productivity and nutrient uptake by vegetable pea (*Pisum sativum* var. arvense) and buildup of soil fertility in Lahaul valley of Himachal Pradesh. *Indian J. Agric. Sci*. 73 (5): 266-268.

Dere, A. L. and Stehouwer, R. C., Aboukila, E. and McDonald, K. E. 2012. Nutrient leaching and soil retention in mined land reclaimed with stabilized manure. *J. Environ. Qual*. 41:2001-2008.

Dey, S. R., Barman, R. and Kandpal, G. 2019. Effect of combined application of organic and inorganic fertilizer on growth attributes of wheat (*Triticum aestivum* L.). *J. Pharmacogn. Phytochem.* 8 (3): 576-578.

Dhaliwal, S. S. Naresh, R. K. Gupta, R. K. Panwar, A. S. Mahajan, N. C. Singh, R. and Mandal, A. 2019. Effect of tillage and straw return on carbon footprints, soil organic carbon fractions and soil microbial community in different textured soils under rice–wheat rotation: a review. *Rev. Environ. Sci. Biotechnol.* doi:10.1007/s11157-019-09520-1.

Dinesh, R, Srinivasan, V., Hamza, S. and Anandaraj, M. 2014. Massive phosphorus accumulation in soils: Kerala's continuing conundrum. *Curr. Sci.* 106 (3): 343-344.

Ding, Q., Cheng, G., Wang, Y. and Zhuang, D. 2017. Effects of natural factors on the spatial distribution of heavy metals in soils surrounding mining regions. *Sci. Total Environ.* 578: 577–585.

Dlamini S. N., Masarirambi M. T., Wahome, P. K. and Oseni T. O. 2020. The effects of organic fertilizers on the growth and yield of amaranthus (*Amaranthus hybridus* L.) grown in a lath house. *Asian J. Adv. Agric. Res.* 12 (1): 1-10.

Dolan, M. S., Clapp, C. E., Allmaras, R. R., Baker, J. M. and Molina, J. A. E. 2006. Soil organic carbon and nitrogen in a Minnesota soil as related to tillage, residue and nitrogen management. *Soil Tillage Res.* 89: 221–231.

Duynisveld, W. H. M., Strebel, O. and BSttcher, J. 1988. Are nitrate leaching from arable land and nitrate pollution of groundwater avoidable? *Ecol. Bull*. (Copenhagen) 39:116-125.

Eghball, B. 2003. Leaching of phosphorus fractions following manure or compost application. *Commun. Soil Sci. Plant Anal.* 34 (19): 2803–2815.

Eiland, F., Klamer, M., Lind, A. M., Leth, M. and Bååth, E. 2001. Influence of initial C/N Ratio on chemical and microbial composition during long term composting of straw. *Microb. Ecol.* 41 (3): 272–280.

Eldridge, S. M., Yin Chan, K., Donovan, N. J. 2018. Agronomic and economic benefits of green-waste compost for peri-urban vegetable production: implications for food security. *Nutr. Cycl. Agroecosyst.* 111: 155–173.

Fadhel, A. S, Raghad S., Mouhamad, Shaimaa A., Yousir, Ibrahim B., Razaq, Hasan H., Kamat and Iqbal M. 2016. Production and characterization of organic manure from liquorice residues. *Curr. Sci. Perspectives* 2 (3): 61-67.

Fageria, N. K., Dos Santos, A. B. and Cobucci, T. 2011. Zinc nutrition of lowland rice. *Comm. Soil Sci. Plant Anal.* 42: 1719-1727.

FAI (Fertilizer Association of India). 2018. *The Fertilizer (Control) Order, 1985.* New Delhi. http://www.astaspice.org/food-safety/astas-analytical-methods-manual.

Fang, C., Smith P., Moncrieff, J. B. and Smith, J. U. 2005. Similar response of labile and resistant soil organic matter pools to changes in temperature. *Nature* 433: 57–64.

Ferrando, R. 1981. Traditional and Non-Traditional Foods, FAO, Rome, pp 3-4 and 32-33.

Fonte, S. J., Yeboah, E., Ofori, P., Quansah, G. W. and Vanlauwe, B. 2009. Fertilizer and residue quality effects on organic matter stabilization in soil aggregates. *Soil Biol. Biochem.* 73: 961-966

Gachene, C. K. K. and Kimaru, G. 2003. Organic Fertilizers. In: Soil fertility and land productivity: A guide for extension workers in eastern Africa region. Technical Handbook 30, p. 46-63.

Gale, W. J., Cambardella, C, A. and Bailey, T. B. 2000. Root-derived carbon and the formation and stabilization of aggregates. *Soil Sci. Soc. Am. J.* 64:201-207.

Gao, C., El-Sawah, A. M., Ali, D. F. I., Hamoud, Y. A., Shaghaleh, H. and Sheteiwy, M. S. 2020. The Integration of bio and organic fertilizers improve plant growth, grain yield, quality and metabolism of hybrid maize (*Zea mays* L.) *Agronomy* 10: 319-344.

Gaur, A. C. and Singh, G. 1993. Role of IPNS in sustainable and environmentally sound agricultural development in India. PAO/RAPA Bull.199-313pp.

Georing, H. K. and Van Soest, P. J. 1970. *Forage Fibre Analysis.* U.S. Agricultural Research Service, Washington. 20p.

Ghosh, K., Chowdhury, M. A. H., Rahman, M. H. and Bhattacherjee, S. 2014. Effect of integrated nutrient management on nutrient uptake and economics of fertilizer use in rice cv. NERICA 10. *J. Bangladesh Agric. Univ.* 12 (2): 273–277

Ghuman, B. S. and Sur, H. S. 2006. Effect of manuring on soil properties and yield of rainfed wheat. *J. Indian Soc. Soil Sci*. 54 (1): 6-11.

Gnanavelrajah, N., Shrestha, R. P., Schmidt-Vogt, D. and Samarakoon, L. 2008. Carbon stock assessment and soil carbon management in agricultural land-uses in Thailand. *Land Degrad. Dev.* 19 (3): 242–256.

Goldman, E. and Green, L. H. 2008. Practical Handbook of Microbiology, 2nd edition. CRC Press, Boca Baton, Florida. 155p.

Gomez, K. A. and Gomez, A. A. 1984. Statistical Procedures for Agricultural Research. 2nd Edition, John Willey and Sons, New York, 680pp.

Gonet, S. S. and Debska, B. 2006. Dissolved organic carbon and dissolved nitrogen in soil under different fertilization treatments. *Plant Soil Environ*. 52: 55-63.

Gong, Q., Chen, P., Shi, R., Gao, Y., Zheng, S. A., Xu, Y. and Zheng, X. 2019. Health assessment of trace metal concentrations in organic fertilizer in Northern China. *Int. J. Environ. Res. Public Health* 16 (6): 1031-1052.

Gong, W., Yan, X., Wang, J., Hu, T. and Gong, Y. 2008. Long-term manuring and fertilization effects on soil organic carbon pools under a wheat–maize cropping system in North China Plain. *Plant Soil* 314: 67–76.

Grappelli, A., Galli, E. and Tomati, U. 1987. Earthworm casting effect on *Agaricus bisporus* fructification. *Agrochimica* 21: 457-462.

Greenberg, A. E., Clesceri, L. S. and Eaton, A. D. 1992. *Standard Methods for the Examination of Water and Waste Water,* 18th (Ed.). American Public Health Association, Washington. 75p.

Griffin, T. S., Honeycutt, C. W. and He, Z. 2003. Changes in soil phosphorus from manure application. *Soil Sci. Soc. Am. J.* 67: 645-653.

Guppy, C. N., Menzies, N. W., Blamey, F. P. C. and Moody, P. W. 2005. Do decomposing organic matter residues reduce phosphorus sorption in highly weathered soil? *Soil Sci. Soc. Am. J.* 69: 1405–1411.

Gupta, R. P. and Dakshinamoorthy, C. 1980. Procedures for Physical Analysis of Soil and Collection of Agrometeorological Data, Indian Agricultural Research Institute, New Delhi.

Gupta, U. C. 1967. A simplified method for determining hot water soluble boron in podzol soils. *Soil Sci.* 103 (6): 424-428.

Gutiérrez-Miceli, F. A., Santiago-Borraz, J., Montes Molina, J. A., Nafate, C. C., Abud-Archila, M., Oliva Llaven, M. A. and Dendooven, L. 2007. Vermicompost as a soil supplement to improve growth, yield and fruit quality of tomato (*Lycopersicum esculentum*). *Bioresour. Technol.* 98 (15): 2781-2786.

Hadas, A. and Portnoy, R. 1994. Nitrogen and carbon mineralization rates of composted manure incubated in soil. *J. Environ. Qual.* 23: 1184–1189.

Hagedorn, F., Spinnler, D. and Siegwolf, R. 2003. Increased N deposition retards mineralization of old soil organic matter. *Soil Biol. Biochem.* 35 (12): 1683–1692.

Hamdi, H., Jedidi, N., Ayari, F., Yoshida, M. and Ghrabi, A. 2003. Valuation of municipal solid waste compost of Tunis (Tunisia) – Agronomic aspect. Proceedings of the 14th Annual Conference of the Japan Society of Waste Management Experts, Vol. III, International Session. 62- 64.

Han, K. H., Choi, W. J., Han, G. H., Yun, S. I., Yoo, S. H. and Ro, H. M. 2004. Urea-nitrogen transformation and compost-nitrogen mineralization in three different soils as affected by the interaction between both nitrogen inputs. *Biol. Fertil. Soils* 39 (3): 193–199.

Han, S. H., Anb, J. Y., Hwang, J., Kima, S. B. and Park, B. B. 2016. The effects of organic manure and chemical fertilizer on the growth and nutrient concentrations of yellow poplar (*Liriodendron tulipifera* Lin.) in a nursery system. *Forest Sci. Technol.* 12 (3): 137-143.

Harris, J. A. 2003. Measurements of the soil microbial community for estimating the success of restoration. *Eur. J. Soil Sci.* 54: 801–808.

Hartz, T. K. Mitchell J. P. and Giannini, C. 2000. Nitrogen and carbon mineralization dynamics of manures and composts. *HortScience* 35 (2): 209-212.

Hattab, S., Bougattass, I., Hassine, R. and Dridi-Al-Mohandes, B. 2019. Metals and micronutrients in some edible crops and their cultivation soils in eastern-central region of Tunisia: a comparison between organic and conventional farming. *Food Chem.* 270: 293–298.

Hauer, F. R. and Lamberti, G. A. ed. 1996. Methods in stream ecology. Academic Press, San Diego, 674 p.

Haynes, R. J. 2005. Labile organic matter fractions as central components of the quality of agricultural soils: an overview. *Adv. Agron.* 85: 221-268.

Hazarika, B.N. and Ansari, S. 2010. Effect of integrated nutrient management on growth and yield of banana to organic manuring. *Trop. Agric.* 133: 117-229.

He, Z. L., Alva, A. K., Yan, P., Li, Y. C., Calvert, D. V., Stoffella, P. J. and Banks, D. J. (2000) Nitrogen mineralization and transformation from composts and biosolids during field incubation in a sandy soil. *Soil Sci.* 165 (2):161–169.

He, Y., Lehndorff, E., Amelunga, W., Wassmann, R. Albertob, M. C., Unoldd, G. V. and Siemense, J. 2017. Drainage and leaching losses of nitrogen and dissolved organic carbon after introducing maize into a continuous paddy-rice crop rotation. *Agric. Ecosyst. Environ*. 249: 91–100

Herbert, S.J. 1998. Crops, Dairy, Livestock News. Dept. of Plant and Soil Sci, Univ. of Massachusetts Amherst 3:1.

Hesse, P. R. 1971. *A Textbook of Soil Chemical Analysis.* Jone Murray Ltd, London. 520p.

Hou, X., Wang, X., Li, R., Jia, Z., Liang, L., Wang, J. and Wang, Z. 2012. Effects of different manure application rates on soil properties, nutrient use, and crop yield during dryland maize farming. *Soil Res.* 50(6): 507-514.

Hou, J., Evans, L. J. and Spiers, G. A. 1994. Boron fractions in soils. *Commun. Soil Sci. Plant Anal.* 25: 1841-1853.

Hu, X., Huang, X., Zhao, H., Liu, F., Wang, L., Zhao, X and Ji, P. 2021. Possibility of using modified fly ash and organic fertilizers for remediation of heavy-metal-contaminated soils. *J. Clean. Prod.* 124713: doi:10.1016/j.jclepro.2020.124713.

Hussain, M. Z., Robertson G.P., Basso , B. and Hamilton, S. K. 2020. Leaching losses of dissolved organic carbon and nitrogen from agricultural soils in the upper US Midwest. *Total Environ.* 734: 139379-139385.

Ilupeju, E. A. O, Akanbi, W. B., Olaniyi, J. O., Lawal, B. A., Ojo, M. A. and Akintokun, P. O. 2015. Impact of organic and inorganic fertilizers on growth, fruit yield, nutritional and lycopene contents of three varieties of tomato (*Lycopersicon esculentum* (L.) Mill) in Ogbomoso, Nigeria. *Afr. J. Biotechnol.*14 (31): 2424-2433.

Irshad, M., Eneji, A. E., Hussain, Z., and Ashraf, M. 2013. Chemical characterization of fresh and composted livestock manures. *J. Soil Sci. Plant Nutr.* 13 (1): 115-121.

Islam, M. A., Islam, S., Akter, A., Rahman, M. H., Nandwani, 2017. Effect of organic and inorganic fertilizers on soil properties and the growth, yield and quality of tomato in Mymensingh, Bangladesh. *Agriculture* 7: 18-20.

Jackson, M. L. 1973. *Soil Chemical Analysis* (2^{nd} Ed.). Prentice hall of India, New Delhi. 498p.

Jacob, G. 2018. Rhizosphere priming effects of conventional and non conventional organic manures on C and N dynamics. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 156p.

Jacob, G. and Sudharmaidevi, C. R., 2018. Temporal variation in chemical properties of soil amended with different types of organics under planted and nonplanted conditions. *Int. J. Agric. Sci.,* 10 (15): 6796-6800.

Jacoby, R., Peukert, M., Succurro, A., Koprivova, A. and Kopriva, S. 2017. The Role of soil microorganisms in plant mineral nutrition—current knowledge and future directions. *Front. Plant Sci.* 8: 1617.

Jagadeesh, B. R., 2000. Chemical and biochemical properties of soil subjected to permanent manurial and cropping schedule. *J. Indian Soc. Soil Sci*. 48 (2): 283-286.

Janaki, D. Poorniammal, R. and Rajangam, J. 2019 Effect of organic source of fertilizers along with inorganic on growth, yield and quality of chillies (*Capsicum annum* L) var PKM 1. 7 (3): 2755-2757

Javanmardi, J. and Kubota, C. 2006. Variation of lycopene, antioxidant activity, total soluble solids and weight loss of tomato during postharvest storage. *Postharvest Bio. Technol.* 41 (2), 151–155.

Jayakrishna, J. 2017. Evaluation of thermochemical digest of degradable waste for container cultivation of chilli. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 123p.

Jayakrishna, J. and Thampatti, K. C. M. 2016. Standardisation of growth medium based on thermo chemical digest produced from degradable solid waste by rapid conversion technology. *Int. J. Appl. Pure Sci. Agric.* 2 (10): 76–80.

Jenkinson, D. S. and Ladd, J. N. 1976. Microbial biomass in soil. Measurement and turn over. *Soil Biochem*. 5: 415-471.

Jensen, E.S. 1994. Mineralization–immobilization of nitrogen in soil ity of different mulch materials and their decomposition and N amended with low C/N ratio plant residues with different particle release under low moisture regimes. *Biol. Fertil. Soils* 26: 136–140.

Jimenez, B. and Wang, L. 2006. Sludge treatment and management, in Municipal wastewater management in developing countries: Principles and Engineering. Ed. by Ujang Z and Henze M, IWA Publishing, p. 364.

Jin, J., Martens, D. C. and Zelazny, L. W. 1987. Distribution and plant availability of soil; boron fractions. *Soil Sci. Soc. Am. J.* 51: 1228–1231.

Jing, H., Ying-hua, D., Ming-gang, X., Li-mei, Z., Xu-bo, Z., Bo-ren, W. Yang-zhu, Z,. S-duan G and Nan, S. 2017. Nitrogen mobility, ammonia volatilization, and estimated leaching loss from long-term manure incorporation in red soil. *J. Integr. Agric.* 16 (9): 2082–2092.

Jones, D. L. and Willett. V. B. 2006. Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. *Soil Biol. Biochem.* 38: 991-999.

Jones, D. L., Shannon, D., Murphy, D. V. Farrar J. 2004. Role of dissolved organic nitrogen (DON) in soil N cycling in grassland soils. *Soil Biol. Biochem*. 36:749–756.

Kahu, J. C, Umeh C. C , Achadu, A. 2019. Effetcs of different types of organic fertilizers on growth performance of *Amaranthus caudatus* (Samaru Local Variety) *and Amaranthus crue*ntus (NH84/452). *Asian J. Adv. Agric. Res.* 9 (2): 1-12

Kamal, A. M., Alam, M A., Uddin M. Z., Hossain M. M. and Islam, M. N. 2012. Impact of organic fertilizers on physical and chemical properties of soil as well as yield and quality of mango. *J. Bangladesh Soc. Agric. Sci. Technol.* 9 (1-2): 167-170.

Kaschl, A., Römheld, V. and Chen, Y. 2002. The influence of soluble organic matter from municipal solid waste compost on trace metal leaching in calcareous soils. *Sci. Total Environ.* 291(1-3): 45–57.

Katkar, R. N., Kharche, V. K., Sonune, B. A., Wanjari, R. H. and Singh. M. 2012. Long-term effect of nutrient management on soil quality and sustainable productivity under sorghum-wheat crop sequence in Vertisol of Akola, Maharashtra. *Agropedology* 22 (2):103–14.

KAU [Kerala Agricultural University]. 2016. *Package of Practices Recommendations: Crops* (15th Ed.). Kerala Agricultural University, Thrissur, 393p.

Kaur K., Kapoor, K. K. and Gupta, A. P. 2005. Impact of organic manure with and without mineral fertilizers on soil chemical biological properties under tropical conditions. *J. Plant Nutr. Soil Sci*. 168 (1): 117-122.

Kaviraj, and Sharma, S. 2003. Municipal solid waste management through vermicomposting employing exotic and local species of earthworms. *Bioresour. Technol.* 90 (2):169–173.

Kavitha, R. and Subramanian, P. 2007. Effect of enriched municipal solid waste compost application on soil available macronutrients in the rice field. *Arch. Agron. Soil Sci.* 53 (5): 497–506.

Kessel, C. V., Clough, T. and Groenigen, J. W. V. 2009. Dissolved organic nitrogen: an overlooked pathway of nitrogen loss from agricultural systems? *J. Environ. Qual.* 38:393-401.

Khan, A. A., Bibi, H., Ali, Z., Sharif, M., Shah, S. A., Ibadullah, H., Khan, K., Azeem, I. and Ali, S. 2017. Effect of compost and inorganic fertilizers on yield and quality of tomato. *Acad. J. Agric. Res.* 5 (10): 287-293.

Khoramnejadian, S. and Saeb, K. 2015. Accumulation and translocation of heavy metals by *Amaranthus retroflexus*. *J. Earth Environ. Health Sci*. 1: 58-60.

Kim, H. Y., Lim, S. S. Kwak, J. H., Lee, S. I, Lee, D. S., Hao, X., Yoon, K. S. and Choi, W. J. 2011. Soil and compost type affect phosphorus leaching from Inceptisol, Ultisol, and Andisol in a column experiment. *Commun. Soil Sci. Plant Analys.* 42: 2188–2199

Kleber, M. 2010. What is recalcitrant soil organic matter? *Environ. Chem.* 7 (4): 320–332.

Kokhia, M. 2015. Composting: Advantages and Disadvantages Proceedings of the Institute of Zoology 133-138p.

Kolahchi, Z. and Jalali, M. 2012. Kinetics of nutrient release from different organic residues using a laboratory system, *Arch. Agron. Soil Sci.* 58 (9):1013–1031.

Korsaeth, A., Bakken, L. R. and Riley. H. 2003. Nitrogen dynamics of grass as affected by N input regimes, soil texture, and climate: lysimeter measurements and simulations. *Nutr. Cycling Agroecosyst.* 66:181–199.

Kostyanovsky, K., Evanylo, G. K. Lasley, K. K. Daniels, W. L. and Shang, C. 2011. Leaching potential and forms of phosphrus in deep row applied biosolids underlying hybrid poplar. *Ecol. Eng.* 37:1765–1771.

Kumar S., Smith Stephen R.; Fowler Geoff; Velis Costas; Kumar S. Jyoti; Arya Shashi; Rena null; Kumar Rakesh; Cheeseman Christopher 2017. Challenges and opportunities associated with waste management in India. *R. Soc. Open Sci.* 4 (3): 160764

Kumar, P., Kamboj, D., Sharma, R. R. and Thind, V. 2019. Effect of integrated nutrient management on growth and yield of garlic (*Allium sativum* L.). *J Pharmacogn. Phytochem.* 8 (3): 2569-2572.

Kumar, S., Srivastava, A., and Gupta, A. 2015. Effect of organic amendments on availability of different chemical fractions of phosphorus. *Agric. Sci. Dig.* 35 (2): 83-88.

Kumar, T., Kumar, M., Singh, M. K., Kumar, V., Kumar, A., Kumar, S. and Singh, B. 2013. Impact of integrated nutrient management (INM) on growth and economic yield of okra. *Ann. Horticult.* 6 (1): 107-114.

Kumaran, S. S., Natarajan. S. and Thamburaj, S. 1998. Effect of inorganic and organic fertilizers on growth and yield of tomato. *South Indian Horticult.* 46 (3-4): 203-205.

Kumari, G., Mishra, B., Kumar, R., Agarwal, B. K. and Singh, B. P. 2011. Long- term effect of manure, fertilizer and lime application on active and passive pools of soil organic carbon under maize-wheat cropping system in an Alfisol. *J. Indian Soc. Soil Sci.* 59 (3): 245- 250.

Kuttimani, R., Velayudham, K., Somasundaram, E. and Muthukrishnan. P. 2013. Effect of integrated nutrient management on yield and economics of banana. *Global J. Biol. Agric. Health Sci.* 2 (4): 191-195.

Kuzucu, M., 2019. Effects of organic fertilizer application on yield, soil organic matter and porosity on Kilis oil olive variety under arid conditions *Eurasian J. Forest Sci*. 7 (1): 77-83.

Kwabiah, A. B., Stoskopf, N. C., Palm, C. A. and Voroney, R. P. 2003. Soil P availability as affected by the chemical composition of plant materials: Implications for P-limiting agriculture in tropical Africa. *Agric. Ecosyst. Environ.* 100: 53-61.

Ladisch, M. R., Lin, K.W., Voloch, M. and Tsao, G. T. 1983. Process considerations in the enzymatic hydrolysis of biomass. *Enzyme Microb. Technol.* 5 (2): 82-102.

Lajtha, K., Crow, S. E., Yano, Y., Kaushal, S.S., Sulzman, E. Sollins, P. and Spears, J. D. H. 2005. Detrital controls on soil solution N and dissolved organic matter in soils: a field experiment. *Biogeochemistry* 76: 261–281.

Lal, J. K., Mishra, B. and Sarkar, A. K. 2000. Effect of Plant Residues incorporation on specific microbial groups and availability of some plant nutrients in soil. *J. Indian Soc. Soil Sci.* 48:67-71.

Laurent, C., Bravin, M. N., Crouzet, O., Pelosi, C., Tillard, E., Lecomte, P. and Lamy, I. 2019. Increased soil pH and dissolved organic matter after a decade of organic fertilizer application mitigates copper and zinc availability despite contamination. *Sci. Total Environ.* 135927:doi:10.1016/j.scitotenv.2019.135927.

Lazicki, P., Geisseler, D. and Lloyd, M. 2020. Nitrogen mineralization from organic amendments is variable but predictable. *J. Environ. Qual.* 49 (2): 483-495.

Le, T. X. and Marschner, P. 2018. Mixing organic amendments with high and low C/N ratio influences nutrient availability and leaching in sandy soil. *J. Soil Sci Plant Nutr.* 218 (4): 952-964.

Leno, N., Sudharmaidevi, C. R., Byju, G. Manorama Thampatti, K. C., Priya U. K Jacob, G. and Pratheesh P. G. 2021. Thermochemical digestate fertilizer from solid waste: Characterization, labile carbon dynamics, dehydrogenase activity, water holding capacity and biomass allocation in banana. *Waste Manage.*123: 1-14.

Leno, N. 2017. Evaluation of a customised organic fertilizer in relation to labile carbon dynamics nutrient release characteristics and productivity of banana. Ph.D thesis, Kerala Agricultural University, Thrissur, 238p.

Leno, N. and Sudharmaidevi, C. R. 2017. Biometric and yield response of banana to organic fertilizer produced by rapid decomposition of solid wastes. *Trends Biosci.* 10 (45): 9284-9287.

Leno, N. and Sudharmaidevi, C.R. 2018. Micronutrient dynamics on addition of a rapid organic fertilizer produced from degradable waste in banana. *Int. J. Curr. Microbiol. App. Sci.* 7 (01): 1095-1102.

Leno, N., Sudarmaidevi, C. R., and Meera, A.V. 2016. Fertility evaluation and manurial effect of organic manure produced from degradable solid waste by rapid conversion technology. *Adv. Life Sci.* 5 (11): 4433-4436.

Leroy, B. L. M., Herath, H. M. S. K., Sleutel, S., De Neve, S., Gabriels, D., Reheul, D., and Moens, M. 2008. The quality of exogenous organic matter: short-term effects on soil physical properties and soil organic matter fractions. *Soil Use Manage.* 24 (2): 139–147.

Li, C., Ma, S., Shao, Y., Ma, S., and Zhang, L. 2018. Effects of long-term organic fertilization on soil microbiologic characteristics, yield and sustainable production of winter wheat. *J. Integr. Agric.* 17 (1): 210–219.

Li, X., Xing, M., Yang, J. and Huang, Z., 2011. Compositional and functional features of humic acid-like fractions from vermicomposting of sewage sludge and cow dung. *J. Hazard. Mater.* 185: 740–748.

Li, Y. C., Stoffella, P. J., Alva, A. K., Calvert, D. V. and Graetz, D. A. 1997. Leaching of nitrate, ammonium, and phosphate from compost amended soil columns. *Compost Sci. Utilization* 5 (2): 63-67.

Lidder, S. and Webb, A. J. 2013. Vascular effects of dietary nitrate (as found in green leafy vegetables and beetroot) via the nitrate-nitrite-nitric oxide pathway. *Br. J. Clin. Pharmacol.* 75 (3): 677–696.

Lim, P. N., Wu, T. Y., Shyang Sim, E. Y. and Lim, S. L. 2011. The potential reuse of soybean husk as feedstock of Eudrilus eugeniae in vermicomposting. *J. Sci. Food Agric.* 91 (14): 2637–2642.

Lim, S. L., Wu, T. Y., Sim, E. Y. S., Lim, P.N., Clarke, C. 2012. Biotransformation of rice husk into organic fertilizer through vermicomposting. *Ecol. Eng.* 41: 60–64.

Lim, S. S., Kwak, J. H., Lee, S. I., Lee, D. S., Park, H. J., Hao, X., Choi, W. J. 2010. Compost type effects on nitrogen leaching from Inceptisol, Ultisol, and Andisol in a column experiment. *J. Soils Sediments* 10: 1517–1526

Lin, L., Xu, F., Ge, X., and Li, Y. 2019. Biological treatment of organic materials for energy and nutrients production—anaerobic digestion and composting. *Adv. Bioenergy.* doi:10.1016/bs.aibe.2019.04.002

Lindsay, W. L. and Norvell, W. A. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.* 42 (3): 421-428.

Lipson, D. and Nasholm, T. 2001. Th e unexpected versatility of plants: Organic nitrogen use and availability in terrestrial ecosystems. Oecologia 128: 305–316.

Liu, E., Yan, C., Mei, X., Zhang, Y. and Fan, T. 2013. Long-term effect of manure and fertilizer on soil organic carbon pools in dryland farming in North West China. *PLos One* 8 (2): e56536.

Liu, J., Schulz, H., Brand, S., Miehtke, H., Huwe, B. 2012. Short-term effect of biochar and compost on soil fertility and water status of a Dystric Cambisol in NE Germany under field conditions. *J. Plant Nutr. Soil Sci.* 175: 698-707.

Lumpkin, H. 2003. Organic vegetable production: a theme for International Agricultural Research. *Proceedings of the seminar on the production and export of organic fruit and vegetables in Asia*. http://www.fao.org/DOCREP/006/A D429E/ad429e13.htm.

Lynch, J. M. 1992. In: Hoitink, H. A. J. and Keener, H. (eds), *Substrate availability in the production of composts.* Proceedings of the international composting research symposium, pp 24-35.

Ma, N. N., Li, T. L., Wu, C. C. and Zhang, E. P. 2010. Effects of long term fertilization on soil enzyme activities and soil physicochemical properties of facility vegetable field. *Chinese J. Appl. Ecol.* 21: 1766–1771.

Madejón, E., López, R., Murillo J. M. and Cabrera, F. 2001. Agricultural use of three (sugarbeet) vinasse composts: effect on crop and on chemical properties of a soil of the Guadalquivir River Valley (SW Spain). *Agric. Ecosyst. Environ.* 84: 55–67.

Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S., Shahid, M. and Ullah, S. 2017. Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *J. Soil Sci. Plant Nutr.* 17 (1): 22-32.

Majumder, B., Mandal, B., Bandyopadhyay, P. K., Gangopadhyay, A. and Mani, P. K. 2008. Organic amendments influence soil organic carbon pools and rice– wheat productivity. *Soil Sci. Soc. Am. J.* 72: 775–785.

Maltas, A., Kebli, H., Oberholzer, H. R., Weisskopf, P. and Sinaj, S. 2018. The effects of organic and mineral fertilizers on carbon sequestration, soil properties, and crop yields from a long-term field experiment under a Swiss conventional farming system. *Land Degrad. Dev.* 29 (4): 926–938.

Mamaril, C., Gonzales, V., Olegario, A. and Obcemea, W. 2000. Average nutrient composition of organic material (oven- dry basis) In: Integrated Plant Nutrition System in the Philippines: Review and Analysis. Compendium. P. 61.

Mandal, P., Chaturvedi, M. K., Bassin, J. K., Vaidya, A. N. and Gupta, R. K. 2014. Estimating the quantity of solid waste generation in Oyo. *Int J Recycl Org Waste Agricult.* 3: 133–13.

Manna, M. C., Hazra, J. N., Sinha N. B. and Ganguly, T. K. 1997. Enrichment of compost by bioinoculants and mineral amendments. *J. Indian Soc. Soil Sci.* 45: 831-833.

Manna, M. C., Swarup, A., Wanjari, R. H., Ravankar, H. N., Mishra, B., Saha, M. N., Singh, Y. V., Sahi, D. K. and Sarap, P. A. 2005. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. *Field Crop Res.* 93: 264–280.

Manzoni, S., Taylor, P., Richter, A., Porporato, A. and Agren, G. I. 2010. Environmental and stoichiometric controls on microbial carbon-use efficiency in soils. *New Phytologist.* 196:79-91.

Mariaselvam, A. A. Dandeniya, W. S., Indraratne, S. P and Dharmakeerthi, R. S. 2014. High C/N materials mixed with cattle manure as organic amendments to improve soil productivity and nutrient availability. *Tropical Agricult. Res.* 25 (2): 201- 213.

Marschner, B. and Kalbitz, K. 2003. Controls of bioavailability and biodegradability of dissolved organic matters in soils. *Geoderma* 13:211-235.

Martin, A. and Marinissen, J. C. Y. 1993. Biological and physico-chemical processes in excrements of soil animals. *Geoderma* 56: 331-347.

Maruthupandi, K. and Jayanthi, C. 2018. Integrated nutrient management of maize in rice-gingelly-maize cropping system through integrated farming system. *Chem. Sci. Rev. Lett.* 7 (26): 706-713.

Massoumi, A. and Cornfield, A. H. 1963. A rapid method for the determination of sulphate in water extracts of soil. *Analyst.* 88: 321-322

McGill W. B. and Cole C. V. 1981. Comparative aspects of cycling of organic C, N, S, and P through soil organic matter. *Geoderma* 26: 267–286.

McLaren A. D. and Peterson, G. H. 1965. In Bartholomew, W.V. and Clark, F. E. (eds.) *Physical chemistry and biological chemistry of clay mineral –organic nitrogen complexes.* Soil nitrogen, ASA Monogr. 10. ASA, Madison, WI, pp. 259-284.

Meera, A. V. 2017. Phytoremediation of inorganic contaminants in Vellayani wetland ecosystem. Ph.D thesis, Kerala Agricultural University, Thrissur, 234p.

Mengel, K. and Kirkby, E. A. 1980. Potassium in crop production. *Adv. Agron*. 33: 59-110.

Mengel, K., Schneider, B. and Kosegarten, H. 1999. Nitrogen compounds extracted by electroultrafiltration (EUF) or $CaCl_2$ solution and their relationships to nitrogen mineralization in soils. *J. Plant Nutr. Soil Sci*. 162: 139 -148.

Middleton, K. R. 2007. A new procedure for rapid determination of nitrate and a study of the preparation of the phenol-sulphonic acid reagent. *J. Appl. Chem*. 8 (8): 505–509.

Moghimi, N., Hosseinpur, A. and Motaghian, H. 2018. The Effect of vermicompost on transformation rate of available p applied as chemical fertilizer in a calcareous clay soil. *Commun. Soil Sci. Plant Anal.* 12: doi:10.1080/00103624.2018.1499110

Mohan, S. 2020. 6000 tonnes of dry wastes lie unattended across Kerala. The Indian Express, 14 April. 2020, p.11.

Moller, A., Kaiser, K. and Guggenberger, G. 2005. Dissolved organic carbon and nitrogen in precipitation, throughfall, soil solution, and stream water of the tropical highlands in northern Thailand. *J. Plant Nutr.* 168:649–659.

Mondal, M. A., Ahmed , K. M., Nabi , Al Noor , E. M. and Mondal, T. R. 2019. Performance of organic manures on the growth and yield of red amaranth (*Amaranthus tricolor*) and soil properties . *Res. Agric. Livest. Fish.* 6 (2): 263-269.

Mortvedt, J. J. 1996. Heavy metal contaminants in inorganic and organic fertilizers. In: Rodriguez-Barrueco C. (eds) *Fertilizers and Environment.* Developments in Plant and Soil Sciences, vol 66. Springer, Dordrecht. https://doi.org/10.1007/978-94-009-1586-2.

Morvan, T., Nicolardot, B., and Péan, L. 2005. Biochemical composition and kinetics of C and N mineralization of animal wastes: a typological approach. *Biol. Fertil. Soils,* 42(6): 513–522.

Munroe, G. 2007. Manual of on-farm vermicomposting and vermiculture. Organic Agriculture Centre of Canada, Nova Scotia.

Munsell, A. H. 1905. A color notation: a measured color system, based on the three qualities hue, value, chroma with illustrative models, charts, and a course of study arranged for teachers, G. H. Ellis Co, Boston, MA, p. 89.

Murphy, D. V., Macdonald, A. J., Stockdale, E. A. Goulding, K. W. T., Fortune, S., Gaunt, J. L.. Poulton, P. R., Wakefield, J. A., Webster, C. P. and Wilmer. W. S. 2000. Soluble organic nitrogen in agricultural soils. *Biol. Fertil. Soils,* 30:374–387.

Nada, W. M. 2015. Stability and maturity of maize stalks compost as affected by aeration rate, C/N ratio and moisture content. *J Soil Sci. Plant Nutr.* 15 (3): 751–764.

Nakhro, N. and Dkhar, M. S. 2010. Impact of organic and inorganic fertilizers on microbial populations and biomass carbon in paddy field soil. *J. Agron.* 9 (3): 102-110.

Nargave, T. and Mandloi, M. S. 2018. Impact of integrated nutrient management on nutrient uptake and economics of maize (*Zea mays* L.) *Int. J. Adv. Scient. Res.*, 3 (2): 1-3.

Nayak, A. K., Gangwar, B., Shukla, A. K., Mazumdar, S. P., Kumar, A., Raja, R. and Mohan, U. 2012. Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice–wheat system in Indo Gangetic Plains of India. *Field Crops Res.* 127: 129–139.

Nazir, R., Khan, M., Masab, M., Rehman, H. U., Rauf, N. U., Shahab, S. and Shaheen, Z. 2015. Accumulation of heavy metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water and plants and analysis of physico-chemical parameters of soil and water collected from Tanda Dam Kohat. *J. Pharm. Sci. Res.* 7: 89 - 97.

Nelson, D. W and Sommers, L. E. 1996. Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of America Book Series no.5, pp. 961-1010.

Ogunkunle, C. O. and Fatoba, P. O. 2013. Pollution loads and the ecological risk assessment of soil heavy metals around a mega cement factory in Southwest Nigeria. *Pol. J. Environ. Stud.* 22: 487–493.

Opala, P. A., Okalebo, J. R. and Othieno, C. O. 2012. Effects of organic and inorganic materials on soil acidity and phosphorus availability in a soil incubation study. ISRN Agron.1–10. doi:10.5402/2012/597216.

Osiname, O. A., Schults, B. T. and Corey, R. B. 1973. Soil tests for available copper and zinc in soils of Western Nigeria. *J. Sci. Food Agric*. 24: 1341-1349.

Oworu, O. O., Dada, O. A., Majekodunmi, O. E. 2010. Influence of compost on growth, nutrient uptake and dry matter partitioning of grain amaranths (*Amaranthus hypochondriacus* L.). *Libyan Agric. Res. Center J. Int.* 1 (6): 375–383.

Padbhushan, R. and Kumar, D. 2017. Fractions of soil boron: a review. *J. Agric. Sci.,* doi:10.1017/S0021859617000181

Pant, A. P., Radovich, T. .J. K., Hue, N. V. and Paull, R. E. 2012. Biochemical properties of compost tea associated with compost quality and effects on pak choi growth. *Sci. Hortic.* 148: 138–146.

Park, J. H., Lamb, D., Paneerselvam, P., Choppala, G., Bolan, N. and Chung, J. W. 2011. Role of organic amendments on enhanced bioremediation of heavy metal (loid) contaminated soils*. J. Hazard. Mater.* 185 (2-3): 549–574.

Patchaye M., Sundarkrishnan B., Tamilselvan S., Sakthivel N. 2018. Microbial Management of Organic Waste in Agroecosystem. In: Panpatte D., Jhala Y., Shelat H., Vyas R. (eds) Microorganisms for Green Revolution. Microorganisms for Sustainability, vol 7. Springer, Singapore.

Paul, E. A. and Clark, F. E. 1989. Soil microbiology and biochemistry, Academic Press, San Diego.

Piper, C. S. 1966. Aging of crystalline precipitates. *Analyst.* 77: 1000- 1011.

Poirier, N., Sohi, S. P., Gaunt, J. L., Mahieu, N., Randall, E. W., Powlson, D.S. and Evershed, R. P. 2005. The chemical composition of measurable soil organic matter pools. *Org. Geochem.* 36: 1174 - 1189.

Preetha, D., Sushama P. K. and Marykutty, K. C. 2005. Vermicompost + inorganic fertilizers promote yield and nutrient uptake of amaranth (Amaranthus tricolor L*.). J. Tropical Agric.,* 43(1-2): 87-89.

Preethu, D. C., Bhanu, P. B. N. U. H., Srinvasamurthy, C. A. and Vasanthi, B. G. 2007. Maturity indices as an index to evaluate the quality of compost of coffee waste blended with other organic wastes. Proceedings of the International Conference on sustainable solid waste management. Chennai, India 270-275.

Preusch, P. L., Adler, P. R., Sikora, L. J. and Tworkoski, T. J. 2002. Nitrogen and phosphorus availability in composted and uncomposted poultry litter. *J. Environ. Qual.* 31:2051–2057.

Purakayastha, T. J., Rudrappa, L., Singh, D., Swarup, A. and Bhadraray, S. 2008. Long-term impact of fertilizers on soil organic carbon pools and sequestration rates in maize-wheat-cowpea cropping system. *Geoderma* 144: 370–378

Qian, P. and Schoenau, J. J. 2002. Availability of nitrogen in solid manure amendments with different C:N ratios. *Can. J. Soil Sci.* 82: 219-225.

Qureshi, N. S. A., Rajput, A., Memon, M. and Solangi, M. A. 2014. Nutrient composition of rock phosphate enriched compost from various organic wastes. *J. Scientific Res.* 2 (3): 047-051.

Rahman, M. M., Azirun, S. M. and Boyce, A. N. 2013. enhanced accumulation of copper and lead in amaranth *(Amaranthus paniculatus),* Indian mustard *(Brassica juncea)* and sunflower *(Helianthus annuus). PLoS ONE,* 8 (5): e62941.

Raj, D. and Antil, R. 2011. Evaluation of maturity and stability parameters of composts prepared from agro-industrial wastes. *Bioresour. Technol.* 102: 2868-2873.

Rajeshwari, R. S., 2005. Integrated nitrogen management on growth and yield of maize (*Zea mays* L.). M.Sc. (Ag.) thesis, Univ. Agric. Sci., Dharwad.

Rajkhowa, D. J., Saikia, M. and Rajkhowa, K. M. 2003. Effect of vermicompost and levels of fertilizer on green gram. *Legume Res.* 26 (1): 63-65.

Rajya, L. P., Saravanan, S. and Lakshman, M. N. 2015. Effect of organic manures and inorganic fertilizers on plant growth, yield, fruit quality and shelf life of tomato *(Solanum lycopersicon* L.) C.V. PKM-1. *Int. J. Agric. Sci. Res.* 5 (2): 7-12.

Ramesh, P., Panwar, N. R., Singh, A. B. and Ramana, S. 2008. Effect of organic manures on productivity, nutrient uptake and soil fertility of maize (*Zea mays* L.) linseed (*Linum usitatissimum* L.) cropping system. *Indian J. Agric. Sci.* 78: 351-354.

Ramesha, G. K. 2019. Root phenomics and soil biological activity in response to thermochemical organic fertilizer application. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 140p.

Ranjan, B., Prakash V., Kundu S., Srivastva, A. K. and Gupta, H. S. 2004. Effect of long-term manuring on soil organic carbon, bulk density and water retention characteristics under soybean-wheat cropping sequence in North-Western Himalayas. *J. Indian Soc. Soil Sci.* 52 (3): 238-242.

Rawat, M., Ramanathan, A. L., Kuriakose, T. 2013. Characterisation of municipal solid waste compost (MSWC) from selected Indian cities-a case study for its sustainable utilization. *J Environ. Prot*. 4: 163–171.

Ren, T., Wang, J., Chen, Q., Zhang, F. and Lu, S. 2014. The effects of manure and nitrogen fertilizer applications on soil organic carbon and nitrogen in a high-input cropping system. *PLos One* 9 (5): e97732.

Riahi A. and Hdider C. 2013. Bioactive compounds and antioxidant activity of organically grown tomato (*Solanum lycopersicum* L.) cultivars as affected by fertilization. *Sci. Hort.* 151: 90–96.

Roig, A., Lax, A., Costa, F., Cegarra, J. and Hernandez, T. 1996. The influence of organic materials on the physical and physico-chemical properties of soil. *Agric. Medit.* 117: 309-318.

Roy, S. and Kashem, A. 2014. Effects of organic manures in changes of some soil properties at different incubation periods. *Open J. Soil Sci.* 4: 81-86.

Rudrappa, L., Purakayastha, T. J., Singh, D. and Bhadraray, S. 2005. Long-term manuring and fertilization effects on soil organic carbon pools in a Typic Haplustept of semi-arid sub-tropical India. *Soil Tillage Res*. 30: 1–13.

Sadasivam, S. and Manickam, A. 1992. In: Biochemical methods for Agricultural sciences. Wiley Eastern Limited , New Delhi, pp. 6-7; 11-12.

Saha, J. K., Panwar, N. and Singh, M. V. 2010. An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices. *Waste Manage.* 30 (2): 192–201.

Sahoo, U. K., Singh, S. L., Gogoi, A. Kenye, A. and Sahoo, S. S. 2019. Active and passive soil organic carbon pools as affected by different land use types in Mizoram, Northeast India. *PloS One* 14: doi:10.1371/journal.pone.0219969.

Saidy, A. R., Smernik, R. J., Baldock, J. A., Kaiser, K., Sanderman, J. and Macdonald, L. M. 2012. Effects of clay mineralogy and hydrous iron oxides on labile organic carbon stabilisation. *Geoderma,* 174: 104–110.

Sailajakumari, M. S. 1999. Effect of vermicompost enriched with rock phosphate in cowpea (*Vigna unguiculata* L. Walp.). M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, India. 110p.

Sanger, A., Geisseler, D. and Ludwig, B. 2010. Effects of rainfall pattern on carbon and nitrogen dynamics in soil amended with biogas slurry and composted cattle manure. *J. Plant Nutr. Soil Sci.* 173: 692-698.

Savini, I., Smithson, P. and Karanja, N. 2006. Effects of added biomass, soil pH and calcium on the solubility of Minjingu phosphate rock in a Kenyan Oxisol. *Arch. Agron. Soil Sci.* 52 (1):19-36.

Schimel, D. S. 1986. Carbon and nitrogen turnover in adjacent grassland and cropland ecosystems. *Biogeochemistry* 2: 345-357.

Shah, A. 2001. Quality of EM- fermented solution in relation to the nature of organic amendments MSc. (Ag.) thesis. Sindh Agriculture University, Tandojam, Pakistan, 198p.

Shak, K. P. Y., Wu, T. Y., Lim, S. L. and Lee, C. A. 2014. Sustainable reuse of rice residues as feedstocks in vermicomposting for organic fertilizer production. *Environ. Sci. Pollut. Res*. 21 (2): 1349–1359.

Shankar, K. S., Devi, Ch. A. and Rao, C. S. V. R. 2011. Phytoremediation of heavy metals with *Amaranthus dubius* in semi-arid soils of Patancheru, Andhra Pradesh. *Indian J. Dryland Agric. Res. Dev.* 26 (2): 71-76.

Sharma A. R. and Behera U. K. 2020. Good Agricultural Practices and Carbon Sequestration. In: Ghosh P., Mahanta S., Mandal D., Mandal B., Ramakrishnan S. (eds) Carbon Management in Tropical and Sub-Tropical Terrestrial Systems. Springer, Singapore.

Sharma, M. P., Bali, S. V. and Gupta, D. K. 2000. Crop yield and properties of Inceptisol as influenced by residue management under rice-wheat cropping sequence. *J. Indian Soc. Soil Sci.* 48 (3): 506-509.

Sharma, V. and Abraham, T., 2010. Response of black gram (*Phaseolus mungo* L.) to nitrogen, zinc and farmyard manure potassium and DAP spray. *Legume Res.* 33 (4): 295-298.

Shuman, L. M. and Hargrove, W. L. 1985. Effect of tillage on the distribution of manganese, copper, iron, and zinc in soil fractions. *Soil Sci. Soc. Am. J.* 49 (5), 1117 -1121.

Siemens, J. and Kaupenjohann, M. 2002. Contribution of dissolved organic nitrogen to N leaching from four German agricultural soils. *J. Plant Nutr. Soil Sci.* 165: 675–681.

Sigmund, G., Poyntner, C., Piñar, G., Kah, M. and Hofmann, T. 2018. Influence of compost and biochar on microbial communities and the sorption/degradation of PAHs and NSO-substituted PAHs in contaminated soils. *J. Hazard. Mater.* 345: 107–113.

Sikora, L. J. 1998. Benefits and Drawbacks to Composting Organic By-Products. In: Brown S., Angle J.S., Jacobs L. (eds) Beneficial Co-Utilization of Agricultural, Municipal and Industrial by-Products. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-5068-2_6

Sim, E. Y. S. and Wu, T. Y. 2010. The potential reuse of biodegradable municipal solid wastes (MSW) as feedstocks in vermicomposting. *J. Sci. Food Agric.* 90: 2153-2162.

Sims, J. T. 1990. Nitrogen mineralization and elemental availability in soil amended with cocomposted sewage sludge. *J. Environ. Qual.* 19: 669-675.

Sims, J. T. 1995. Organic wastes as alternative nitrogen sources. In: Bacon, P.E. (ed.): *Nitrogen Fertilization in the Environment*. Marcel Dekker, New York.

Singh, B. B. and Jones, J. P. 1976. Phosphorous sorption and desorption characteristics of soil as affected by organic residues. *Soil Sci. Soc. Am. J.* 40 (3): 389-394.

Singh, B. R. and Taneja, S. N. 1977. Effects of gypsum on mineral nitrogen status in alkaline soils. *Plant Soil* 48: 315–321.

Singh, D. V., Mukhi, S. K. and Mishra, S. N. 2016. Impact of integrated nutrient management on tomato yield under farmers field conditions. *Int. J. Agric. Environ. Biotechnol.* 9 (4): 567-572.

Singh, K. P., Malik, A. and Sinha, S. 2005. Water quality assessment and apportionment of pollution sources of Gomti river (India) using multivariate statistical techniques—a case *study. Analytica Chimica Acta* 538 (1-2): 355–374.

Singh, N. J. and Patel, K. P. 2016. Influence of plant nutrient (organic and inorganic) on nutrient dynamics in the soils of Golagamdi, Vadodara District, Gujarat. *Environ. Ecol.* 34 (4): 2414- 2419.

Singh, R. P. and Varshney, G. 2013. Effects of carbofuran on availability of macronutrients and growth of tomato plants in natural soils and soils amended with inorganic fertilizers and vermicompost. *Commun. Soil Sci. Plant Anal.* 44: 2571–2586.

Smith, J. L., Papendick, R. I., Bezdicek, D. F. and Lynch, J. M. 1992. Soil organic matter dynamics and crop residue management. In: Metting F.B.J. (eds): *Soil Microbial Ecology: Applications in Agricultural and Environmental Management*. Marcel Dekker Inc., New York, 65–94 pp.

Souza, G. P., Figueiredo, C. C. and Sousa, D. M. G. 2016. Relationships between labile soil organic carbon fractions under different soil management systems. *Scientia Agricola* 73 (6): 535–542.

Sparks D.L. 2003 Environmental Soil Chemistry Academic Press, California, U.S.

Srikanth, K., Srinivasamurthy, C. A., Siddaramappa, R. and Parama, V. R. 2000. Direct and residual effect of enriched composts, FYM, vermicompost and fertilizers on properties of an Alfisols. *J. Indian Soc. Soil Sci.* 48 (3): 496-499.

Srivastava, R. P. and Kumar, S. 2009. Fruit and Vegetable Preservation: Principles and Practices. IBDC, New Delhi. pp: 360.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., de Macêdo, J. L. V., Blum, W. E. H. and Zech, W. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant Soil* 291 (1-2): 275–290.

Stenger, R., Priesack, E. and Beese, F. 1995. Rates of net nitrogen mineralization in disturbed and undisturbed soils. *Plant Soil*, 171 (2): 323– 332.

Stewart, C. E., Paustian, K., Conant, R. T., Plante, A. F. and Six, J. 2007. Soil carbon saturation: concept,evidence and evaluation. *Biogeochemistry*, 86: 19-31.

Stott, D. E., Stroo, H. F, Elliot, L. F., Papendick, R. I. and Unger, W. 1990. Wheat residue loss from fields under no-till management. *Soil Sci. Soc. Am. J.* 54: 92–98.

Streeter, T. C., Bol, R. and Bardgett, R. D. 2000. Amino acids as a nitrogen source in temperate upland grasslands: The use of dual labelled (13C, 15N) glycine to test for direct uptake by dominant grasses. *Rapid Commun. Mass Spectrom*. 14: 1351–1355.

Subbarayappa, C. T., Santhosh, S. C., Srinivasa, N., and Ramakrishnaparama, V. 2009. Effect of integrated nutrient management on nutrient uptake and yield of cowpea in southern dry zone soils of Karnataka. *Mysore J. Agric. Sci.* 43 (4): 700-704.

Sudharmaidevi, C. R., Thampatti, K. C. M. and Saifudheen, N. 2015. A novel technology for rapid conversion of degradable waste to fortified manure. In: Wong,J.W.C, Tyagi, R. D., Nelles, M. and Selvan, A. (eds), Knowledge Transfer for Sustainable Resource Management. Proceedings of an International Conference on Solid Waste Management. Hong Kong Special Administrative Region, China, p. 237.

Sudharmaidevi, C.R., Thampatti, K.C.M. and Saifudeen, N. 2017. Rapid production of organic fertilizer from degradable waste by thermochemical processing. *Int. J. Recycl. Org. Waste Agricult.* 6:1–11.

Sutaria, G. S., Ramdevputra, M. V., Akbari, K. N., Vora, V. D. and Padmani, D. R. 2010. Effect of tillage and nutrient management on yield ofgroundnut and soil fertility. *Legume Res.* 33 (2): 131-133.

Suthar, S. 2009. Bioremediation of agricultural wastes through vermicomposting. *Biorem. J.* 13 (1): 21–28.

Swanston, C., Homann, P.S., Caldwell, B. A., Myrold, D. D, Ganio, L. and Sollins, P. 2004. Long-term effects of elevated nitrogen on forest soil organic matter stability. *Biogeochemistry* 70: 229–252.

Tan, X. B., Lam, M. K., Uemura, Y., Lim, J.W., Wong, C.Y., Ramli, A., Kiew, P.L. and Lee, K. T. 2018. Semi-continuous cultivation of Chlorella vulgaris using chicken compost as nutrients source: Growth optimization study and fatty acid composition analysis. *Energy Convers. Manag*. 164: 363–373.

Teutscherova, N., Vazquez, E., Santana, D., Navas, M., Masaguer, A. and Benito, M. 2017. Influence of pruning waste compost maturity and biochar on carbon dynamics in acid soil: incubation study. *Eur. J. Soil Biol.* 78: 66–74.

Thakur, R., Sawarkar, D., Kauraw, D. L. and Singh, M. 2010. Effect of inorganic and organic sources on nutrients availability in a Vertisol. *Agropedology.* 20 (1): 53-59.

Theunissen, J., Nhakidemi, P. and Laublsher, C.P. 2010. Potential of vermicompost produced from plant waste on the growth and nutrient status in vegetable production. *Int. J. Phys. Sci.* 5: 1964–1973.

Tibu C, Annang, T. Y., Solomon, N. and Yirenya-Tawiah, D. 2019. Effect of the composting process on physicochemical properties and concentration of heavy metals in market waste with additive materials in the Ga West Municipality, Ghana. *Int. J. Recycl. Org Waste Agric*. 8: 393–403.

Tiquia, S. M., Richard, T. L. and Honeyman, M. S. 2002. Carbon, nutrient, and mass loss during composting. *Nutr. Cycl. Agroecosyst*. 62: 15–24.

Tisdale, J. M. and Oades, J. M. 1982. Organic matter and water-stable aggregates in soil. *J. Soil Sci*. 33: 141.

Tolanur, S. I. and Badanur, V. P. 2003, Changes in organic carbon, available N, P and K under integrated use of organic manure, green manure and fertilizer on sustaining productivity of pearl millet pigeonpea system and fertility of an Inceptisol. *J. Indian Soc. Soil Sci.* 5 (1): 37- 41.

Tolanur, S. I. 2009. Effect of different organic manures, green manuring and fertilizer nitrogen on yield and uptake of macro nutrients by chickpea in Vertisol. *Legume Res.* 32 (4): 304-306.

Tomati, U., Grappelli, A. and Galli, E.: 1987. The presence of growth regulators in earthworm-worked wastes. In: Bonvicini Paglioi M. and Omodeo, P. (eds.), *On Earthworms.* Proceeding of international smposium on earthworms, selected symposium and monograph. A Unione Zoologica Italiana, 2, Mucchi, Modena Pp. 423-435.

Trinsoutrot, I., Recous, S., Bentz, B., Line`res, M., Che`neby, D. and Nicolardot, B. 2000. Biochemical quality of crop residues and carbon and nitrogen mineralization kinetics under nonlimiting nitrogen conditions. *Soil Sci. Soc. Am. J.* 64, 918-926.

Updegraff, D. M. 1969. Semimicro determination of cellulose in biological materials. *Annal. Biochem.* 32: 420- 424.

Van Groenigen, J. W., Georgius, P. J. van Kessel, C. Hummelink, E.W.J. Velthof, G. L. and Zwart. K. B. 2005. Subsoil 15N-N2O concentrations in a sandy soil profile after application of 15N-fertilizer. *Nutr. Cycling Agroecosyst.* 72: 13–25.

Vanilarasu, K. and Balakrishnamurthy, G. 2014. Influences of organic manures and amendments in soil physiochemical properties and their impact on growth, yield and nutrient uptake of banana. *Bioscan* 9 (2):525-529.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R. and Six, J. 2011. Agronomic use efficiency of N fertilizer in maizebased systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant Soil* 339: 35–50.

Vasak, F., Cerny, J., Buráňová, S, Kulhánek, M. and Balík, J. 2015. Soil pH changes in long-term field experiments with different fertilizing systems. *Soil Water Res.* 10 (1): 19–23.

Vasanthi, D. and Subramanian, 2004, Effect of vermicompost on nutrition uptake and protein content in black gram. *Legume Res.* 27 (4): 293-295.

Verma, G. and Mathur, A. K. 2009, Effect of INM an active pools of soil organic matter under maize-wheat system of a Typic Haplustept. *J. Indian Soc. Soil Sci.* 57 (3): 317-322.

Vijaya Sankar B. M., Mastan Reddy, C., Subramanyam, A. and Balaguruvaiah 2007. Effect of integrated use of organic and inorganic fertilizers on soil properties and yield of sugarcane. *J. Indian Soc. Soil Sci.* 55 (2): 161–166.

Vityakon, P., Meepech, S., Cadisch, G. and Toomsan, B. 2000. Soil organic matter and nitrogen transformation mediated by plant residues of different qualities in sandy acid upland and paddy soils. *Wageningen J. Life Sci.* 48: 75-90.

von Lützow M., Kögel-Knabner, I., Ekschmitt, K., Flessa, H., Guggenberger, G., Matzner, E. and Marschner, B. 2007. SOM fractionation methods: relevance to functional pools and to stabilization mechanisms. *Soil Biol. Biochem.* 39: 2183–2207.

Wakene, N., Heluf, G. and Friesen, D. K. 2005. Integrated use of farmyard manure and NP fertilizers for maize on farmers' fields. *J. Agric. Rural Dev. Trop.* 106 (2): 131-141.

Walkley, A. and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29–38.

Wang, H., Xu, J., Liu, X., Zhang, D., Li, L., Li, W. and Sheng, L. 2019. Effects of long-term application of organic fertilizer on improving organic matter content and retarding acidity in red soil from China. *Soil Tillage Res.* 195: 104382. doi:10.1016/j.still.2019.104382

Wang, X. X., Zhao, F., Zhang, G., Zhang, Y. and Yang, L. 2017. Vermicompost improves tomato yield and quality and the biochemical properties of soils with different tomato planting history in a greenhouse study. *Front. Plant Sci*. 8: 1978. doi: 10.3389/fpls.2017.01978.

Wei, B. and Yang, L. 2010. A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. *Microchem. J.* 94 (2): 99-107.

Wu, J., Huang, M., Xiao, H. A., Su, Y. R., Tong, C. L., Huang, D. Y. and Syers, J. K. 2007. Dynamics in microbial immobilization and transformations of phosphorus in highly weathered subtropical soil following organic amendments. *Plant Soil*, 290 (1–2): 333–342.

Xiao-yu, H., Wei, G., Yu-jun, W., Shao-wen, H., Ji-wei, T. and Ji-yun, J. 2012. Effects of combined application of organic manure and chemical fertilizers on yield and quality of tomato and soil nitrate leaching loss under greenhouse condition. *J. Agro-Environ. Sci.* 3: 234-241.

Xu, M., Lou, Y., Sun, X., Wang W., and Baniyamuddin M. 2011. Soil organic carbon active fractions as early indicators for total carbon change under straw incorporation. *Biol Fertil. Soils* 47: 745–752.

Yadav, S. K., Benbi, D. K. and Prasad, R. 2019. Effect of continuous application of organic and inorganic sources of nutrients on chemical properties of soil. *Int. J. Curr. Microbiol. App. Sci.* 8 (4): 2455-2463.

Yoo, J. H., H.M. Ro,W. J. Choi, S. H. Yoo, and K. H. Han. 2006. Phosphorus adsorption and remova by sediments of a constructed marsh in Korea. *Ecol. Engin.* 27 (2): 109–117.

Zhang, J. C., Zhang, L., Wang, P., Huang, Q. W., Yu, G. H., Li, D. C and Ran, W. 2013. The role of non-crystalline Fe in the increase of SOC after long-term organic manure application to the red soil of southern China. *Eur. J. Soil Sci.* 64 (6): 797–804.

Zhang, W., Xu, M., Wang, B. and Wang X. 2009. Soil organic carbon, total nitrogen and grain yields under long-term fertilizations in the upland red soil of southern China. *Nutr. Cycl. Agroecosyst.* 84: 59–69.

Zhanga, J. B., Zhua, T. B., Caia, C S., Qinb, Z. W. and Muller, C. 2012. Effects of long-term repeated mineral and organic fertilizer applications on soil nitrogen transformations. *Eur. J. Soil Sci.* 63: 75-85.

Zhao, J., Shen, X. J. and Domene, X. 2019. Comparison of biochars derived from different types of feedstock and their potential for heavy metal removal in multiple-metal solutions. *Sci. Rep.* 9**:** https://doi.org/10.1038/s41598-019-46234-4

Zhao, M., Zhou, J. and Kalbitz, K. 2008. Carbon mineralization and properties of water-extractable organic carbon in soils of the south Loess Plateau in China. *Eur. J. Soil Biol.* 44 (2): 158–165.

Zia, M. S., Khalil, S., Aslam, M. and Hussain, F. 2003. Preparation of compost and its use for crop-production. *Sci. Technol. Dev*. 22: 32-44.

Zmora-Nahum, S., Markovitch, O., Tarchitzky, J. and Chen, Y. 2005. Dissolved organic carbon (DOC) as a parameter of compost maturity. *Soil Biol. Biochem.* 37 (11): 2109–2116.

APPENDIX - I

A: Criteria for weighing factor to fertility parameters and score value to compost (Saha *et al.,* 2010)

Fertility parameters	**Score values (Sj)**					**Weighting factor (Wj)**
	5	4	3	2	1	
TOC %	>20	15.1-20.0	12.1-15	9.1-12	<9.1	5
TN %	>1.25	1.01-1.25	0.81-1.0	0.51-0.20	<0.51	3
TP %	>0.60	0.41-0.60	0.21-0.40	0.11-0.20	<0.11	3
TK %	>1.0	0.76-1.0	0.51-0.75	0.26-0.50	<0.26	1
C:N	<10.10	10.1-15	15.1-20	20.1-25	> 25	3

B: Criteria for assigning weighing factor to heavy metals parameters and score value to analytical data of compost (Saha *et al.,* 2010)

Heavy metals (mg kg$^{-1)}$	**Score values (Sj)**						**Weighting factor (Wj)**
	5	4	3	2	1	0	
Zn	<151	151-300	301-500	501-700	701-900	>900	1
Cu	<51	51-100	101-200	201-400	401-600	>600	2
Cd	<0.3	0.3-0.6	0.7-1.0	1.1-2.0	2.0-4.0	>4	5
Pb	<21	51-100	101-150	151-250	251-400	>400	3
Ni	<10.1	21-40	41-80	81-120	121-160	>160	1
Cr	<51	51-100	101-150	151-120	251-350	>350	3

APPENDIX II

Weather parameters during the field experiment (November 2018 - November 2019)

Standard week	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (mm)	Evaporation (mm)
45	31.1	24.3	93.6	8.5	2.5
46	31.7	23.8	92.1	7.3	2.8
47	31.6	24.1	93	7.4	2.8
48	31.9	23.7	93.3	0.0	3.1
49	31.9	23.7	92.9	2.5	2.9
50	32.2	23.8	94.3	3.7	2.5
51	32.0	22.9	92.4	0.3	3.1
52	32.0	23.5	92.4	0.8	3.3
1	32.0	19.6	92	0.0	3.3
2	31.6	22.1	92	0.0	3.5
3	32.2	20.9	91.6	0.0	4
4	32.0	21.2	92.1	0.0	3.8
5	32.5	22.1	92.6	0.3	4.2
6	32.9	24.3	88.9	0.1	4.4
7	33.3	24.1	86.7	0.0	4.6
8	35.3	23.4	87.4	0.0	4.7
9	34.4	24.2	85.0	0.0	4.5
10	34.6	24.8	85.4	0.0	5.2
11	34.4	24.4	85.3	0.0	5.8
12	34.2	24.8	84.9	0.0	5.7
13	34.8	25.4	85.7	0.0	4.6
14	35.18	26	83.7	0.0	5.3
15	35.0	25.9	78.6	0.0	4.9
16	34.9	25.6	82.8	1.6	5.2

17	35.1	25.6	84.6	1.0	5.6
18	34.0	25.9	82.7	2.3	4.5
19	34.3	26.2	80.3	0.0	4.3
20	34.5	26.2	81.3	0.0	2.1
21	33.5	26.5	87.4	11.9	2.5
22	33.6	26.7	90.4	3.6	2.8
23	32.2	25.3	89.3	23.5	4
24	31.1	24.8	93.3	16.3	2.8
25	31.9	24.9	90.0	4.1	1.9
26	32.1	26.1	87.1	0.0	2.5
27	32.2	25.9	90.3	4.6	1.9
28	30.8	25.4	90.3	6.0	1.7
29	30.1	23.7	94.1	14.4	2.1
30	30.4	24.3	92.3	1.1	2.8
31	31.5	25.6	89.3	2.5	3.5
32	30.0	23.6	94.6	28.3	1.9
33	30.4	24.1	91.6	2.6	2.5
34	32.0	24.2	92.1	5.8	3.2
35	30.7	23.9	93.1	13.1	2.3
36	30.2	24.8	95.6	21.1	1.4
37	32.2	24.3	86.5	2.7	1.1
38	30.1	24.2	92.8	4.9	3.3
39	31.9	25.8	93.0	17.7	2.4
40	31.8	24.1	91.3	1.0	3.1
41	30.8	24	91.7	19.0	2.8
42	30.4	23.9	949	18.0	3.2
43	30.3	23.8	91.3	6.1	3.2
44	30.6	24	90.2	15.1	1.2
45	31.2	26.4	89.3	0.0	1.1
46	32.6	24.8	90.7	1.3	3.3

EFFECT OF THERMOCHEMICAL ORGANIC FERTILIZER ON SOIL CARBON POOLS, NUTRIENT DYNAMICS AND CROP PRODUCTIVITY IN ULTISOLS

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ABSTRACT

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ABSTRACT

A study entitled "Effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics and crop productivity in Ultisols" was conducted from 2018 to 2020 at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani with the objective to study the effect of thermochemical organic fertilizer on soil carbon pools, nutrient dynamics, their retention and leaching, and crop productivity in comparison with conventional organic fertilizers in Ultisols using tomato - amaranthus cropping sequence.

The study includes production and characterization of organic fertilizers, leaching study using soil columns, an incubation experiment and field experiments using tomato - amaranthus cropping sequence. For the leaching study and incubation, the treatments were addition of FYM, ordinary compost (OC), vermicompost (VC), microbial compost (MC), unfortified (TOF) and fortified thermochemical organic fertilizer (F-TOF) @ 50 g per soil column/ pot and an absolute control. For the field experiment on tomato-amaranthus cropping sequence, the treatments were T_1 – FYM + POP recommendation of NPK, T_2 - FYM + soil test based recommendation of NPK (STBR), T_3 - OC + STBR, T_4 - VC + STBR, T_5 - MC + STBR, T_6 - TOF + STBR, T_7 - F-TOF + STBR, T_8 - F-TOF alone and T_9 - absolute control.

The organic fertilizers required for the study viz., OC, VC, MC, TOF and F-TOF were produced from bio-waste from vegetable markets and food waste from college hostels and FYM was purchased. The physical and chemical properties of organic fertilizers were in accordance with the standards of FCO. VC, OC, MC and FYM were neutral to slightly alkaline in reaction while TOF and F-TOF were slightly acidic. The lignin content (27.9 %) and the carbon pools viz., TOC (43.90 %), WSOC (1642 mg kg^{-1}), labile carbon (1776 mg kg^{-1}) and recalcitrant organic carbon (32.45 mg kg^{-1}) were highest for TOF followed by F-TOF. The N content was

highest for MC (2.61 %), P for VC (1.36 %) and K (2.56 %), Ca (1.12 %), Mg (0.78 %), Zn (254 mg kg^{-1}) and B (4.64 mg kg^{-1}) for F-TOF while S (550 mg kg^{-1}), Fe (9580 mg kg^{-1}) and Pb (4.16 mg kg^{-1}) for FYM. All the organic fertilizers contained Pb, but within permissible limit, while, Cd was not detected in any of them.

The soil column study was conducted to assess the extent of leaching loss of nutrients from F-TOF amended soil in comparison with other organic fertilizers and their nutrient retention ability in soil. Soil columns amended with organic fertilizers in the surface layer were subjected to leaching on 1st, 4th, 8th, 12th, 16th, 20th and 24th weeks with double the pore volume of water. During the leaching, the mineralized nutrients moved downwards and deposited at different depths in the soil column in accordance with their mobility and the rest was lost in leaching water. Leachates from organic fertilizer amended soils showed slightly acidic pH, which decreased up to 8th week followed by an increase towards 12th week. EC was highest at first week followed by a decrease towards 24th week. The highest cumulative loss of N (172.34 mg L^{-1}), Ca (273.86 mg L^{-1}) and Mn (3.97 mg L^{-1}) was from VC while that of P (7.22 mg L^{-1}), K (333.36 mg L^{-1}), Mg (144.41 mg L^{-1}), Cu (0.080 mg L^{-1}) and B (0.166 mg L^{-1}) was from F-TOF. For S the loss (4.19 mg L^{-1}) was highest from FYM, and Fe (4.71 mg L^{-1}) and Zn (4.58 mg L^{-1}) from OC. The leachate did not contain Pb and Cd.

The leached soil in the soil columns maintained a higher level of nutrients compared to the level prior to the addition of organic fertilzers even after leaching for 24 weeks. In the surface soil, highest quantity of total N was retained by MC; P, Mn and Cu by VC and K, Ca, Mg, Zn and B by F-TOF while FYM retained highest quantity of S and Fe. Evaluating the available nutrient status of the leached soil, it was found that F-TOF had highest availability for K, Mg, S, Fe, Zn, Cu and B. Availability of P and Mn was highest in VC amended soil and Ca from MC. Availability of Pb and Cd were not detected in the leached soil.

The incubation study for a period of 24 weeks revealed the nutrient release pattern of organic fertilizers. The peak release of most of the nutrients from organic fertilizers was from 8th to 16th week and for S it extended up to 20th week. The availability of K, Ca, Mg, Fe, Zn and B was highest from F-TOF amended soil while VC maintained the highest values for P, Mn and Cu and FYM for S. The different fractions of B were highest for F-TOF amended soil and the peak was during 12th week of incubation. Available Pb and Cd were not detected in the incubated soil. Organic fertilizers amended soil maintained a higher microbial count and exhibited a higher dehydrogenase activity compared to the control and the highest value was observed with F-TOF amended soil.

During the field experiments, in the first cropping sequence, VC amended treatment T_4 (VC + STBR) recorded significantly highest fruit yield (40.97 t ha^{-1}) for tomato followed by T_7 (F-TOF + STBR) while in the second cropping sequence F-TOF gave the highest yield which was statistically on par with VC. While for amaranthus, F-TOF recorded the highest yield during both the cropping sequences (24.62 t ha^{-1} and 26.89 t ha^{-1}, respectively) followed by VC and both the treatments were statistically on par in the second cropping sequence.

The quality parameters of tomato and amaranthus were highest for the treatment T_7 (F-TOF + STBR) but was statistically on par with other treatments which received organic fertilizers along with POP or soil test based NPK fertilizers. Evaluating the economic benefits, the performance of VC was the best for the first tomato followed by F-TOF while for second tomato F-TOF was the best. For amaranthus, F-TOF performed best during both the sequences. When the overall B:C ratio for the whole cropping sequence was taken F-TOF was the best followed by VC.

Uptake of N, P, K, Ca, Mg, S, Zn and B in tomato was highest for F-TOF while that of Fe, Mn, and Cu was for VC. For amaranthus, the uptake of N, P, K, Mg, Fe, Zn, Cu and B was highest for F-TOF for both the cropping sequences. Among the heavy metals tested only Pb was detected in plant parts and that too in roots only. For tomato, it was detected only in FYM treated plants while in amaranthus, all the treatments receiving organic fertilizers showed the presence of Pb. But the Pb content in the root was within the safe limit. The availability of Pb in the post-harvest soil was trace and there was no significant difference between the treatments. Cd was not detected in soil as well as plant samples.

The continuous application of organic fertilizers had improved the physical, chemical and biological properties of the soil. At the end of the second cropping sequence, the lowest bulk density and highest water holding capacity was recorded by the treatment receiving F-TOF + STBR. The highest value for TOC, labile carbon, microbial biomass carbon and recalcitrant organic carbon in the post-harvest soil during the cropping sequence was maintained by F-TOF. The N pools, NH_4-N, NO_3-N, organic N and total N at the end of second cropping sequence was also highest for F-TOF. In the case of availability of P, S, Fe, Mn and Cu in the post-harvest soil, better performance was showed by VC while F-TOF showed higher availability for K, Ca, Mg, Zn and B. Biological properties are a better indication of soil health and application of VC, MC and F-TOF maintained a higher microbial load in soil. The highest dehydrogenase activity was maintained by F-TOF. Continuous application of F-TOF and TOF increased the carbon stock of surface and sub-surface soil than other organic fertilizers.

F-TOF is superior to VC, OC, MC and FYM in terms of increasing carbon pools and carbon stock of the soil. The nutrient release was highest from F-TOF for most of the nutrients compared to other organic fertilizers, which might have resulted more leaching losses. However, the nutrient retention was also highest for F-TOF, even after the leaching for 24 weeks, suggesting a revisit on the rate and mode of fortification for F-TOF, popularly marketed in the trade name “Suchitha”. For crop production, the performance of F-TOF found equally good as that of vermicompost and was superior to FYM, OC and MC.