EVALUATION OF A CUSTOMISED ORGANIC FERTILIZER IN RELATION TO LABILE CARBON DYNAMICS NUTRIENT RELEASE CHARACTERISTICS AND PRODUCTIVITY OF BANANA

by

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(2013-21-113)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"EVALUATION OF A CUSTOMISED ORGANIC FERTILIZER IN RELATION TO LABILE CARBON DYNAMICS, NUTRIENT RELEASE CHARACTERISTICS AND PRODUCTIVITY OF BANANA"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS

%	Per cent
@	At the rate of
AEU	Agro ecological unit
As	Arsenic
B	Boron
B:C	Benefit : Cost
C_{NL}	Non labile carbon
C:N	Carbon : Nitrogen
Ca	Calcium
Cd	Cadmium
CEC	Cation exchange capacity
C_{EX}	0.1 M NaOH extractable organic carbon
C_{FA}	Fulvic acid carbon
C_{HA}	Humic acid carbon
C_L	Labile carbon
COF	Customised organic fertilizer
CPI	Carbon pool index
Cr	Chromium
CRD	Completely randomised design
Cu	Copper
C_w	Water soluble organic carbon
D	Days of incubation
DSW	Degradable solid waste
EC	Electrical conductivity
Fe	Iron
FYM	Farm yard manure
g	Gram
g kg^{-1}	Gram per kilogram

GI	Germination index
H	Harvest stage
HI	Humification index
HR	Humification ratio
K	Potassium
kg ha^{-1}	Kilogram per hectare
L	Lability of carbon
LI	Lability index
M	Months of crop growth
Mg	Magnesium
mg kg^{-1}	Milligram per kilogram
Mn	Manganese
MSW	Municipal solid waste
N	Nitrogen
Ni	Nickel
OC	Organic carbon
OF	Organic fertilizer
P	Phosphorus
Pb	Lead
PHA	Percent of humic acids
PI	Polymerisation index
POP	Package of Practices
RBD	Randomised block design
S	Sulphur
SOC	Soil organic carbon
t ha^{-1}	Tons per hectare
TOC	Total organic carbon
WHC	Water holding capacity
Zn	Zinc

To
the revered memory of
my mother
Brenda

INTRODUCTION

1. INTRODUCTION

The history of waste generation is as old as that of mankind. With the burgeoning trend in urbanization and consumerism exhibiting a phenomenal increase in recent times, the diverse waste streams are posing formidable agro-ecological and socio-economic challenges particularly to the developing and underdeveloped countries (Sukholthaman and Sharp, 2016). The global municipal solid waste generation has escalated to an all-time high of 1.3 billion tonnes per year (Manohara and Belagali, 2017). Degradable organics constitute a major share of the waste generated with food waste dominating the lot in urban households of populous metros and cities. Several recycling and reuse options involving biotic flora and fauna are in vogue (Zhang and Sun, 2014). A major constraint of these technologies is the long time span required for the completion of decomposition (Lim *et al*., 2016) with the resultant inevitability of cumbersome transport to centralized processing plants, prolonged dumping of wastes, pollutant leachate contaminating ecologically fragile streams and water bodies, predisposing it to bird, dog and rodent menace posing nuisance and health hazard to the society at large. Solid waste management and safe disposal of wastes still remain a challenging task for policy planners and administrators.

Emission of carbon dioxide, the most potent greenhouse gas contributing to global warming has surpassed 400 ppm per year (Ortas *et al.*, 2017). Mineralization of soil organic matter is accompanied by the evolution of carbon dioxide. Soil degradation has become a major constraint restricting gains in agricultural output threatening food security in the global scenario. Depletion of soil organic carbon from the soil particularly in tropical soils has attained alarming proportions. Sustainable organic agriculture which is gaining popularity of late, relies primarily on organic matter addition to soil. Soil organic carbon plays a vital role in maintaining soil quality and sustaining soil health. Replenishing of organic matter serves as a repository of energy source for the proliferation of soil microbes. The soil organic carbon pool is categorized into different forms based on the turn over time. Labile carbon has a low residence time thus serving to the immediate energy demands of the rhizospheric microbes. Non labile carbon on the other hand has a high residence time which would help retain the soil organic carbon content for a fairly longer period, reduce the losses of soil organic carbon and help carbon sequestration thus reducing carbon dioxide emissions and global warming to a considerable extent.

A recent comprehensive study by the entire 17 soil research laboratories of Kerala state has revealed several inconsistencies in soil nutrient availability in the 23 agro ecological units of the state (Nair *et al.*, 2013). While the soils of Kerala are predominantly acidic in soil reaction with a very high status of phosphorus and iron, acute deficiency levels were observed for secondary nutrients like magnesium and calcium and micronutrients like boron. While soil test based nutrient recommendations ensure viable and economically feasible approach that renders direct availability of soil nutrient elements, it is well established that the dynamic interactive effects of the various essential elements have a far more decisive bearing on the differential temporal availability of these nutrients at various stages of crop growth. The type of crop and the duration of crop growth are also significant factors that merit due consideration in this respect as nutrient availability at critical stages of crop growth is vital for maximizing crop production. Southern laterites (AEU 8) of Kerala comprise of 38,727 ha in which coconut and banana are the predominant crops grown (Saifudeen *et al.*, 2013). Nendran banana is a high nutrient demanding crop cultivated extensively which has an export potential with high net returns.

Thus it becomes highly imperative to have a fertilizer with an organic matter based framework of both labile and non labile carbon fractions with a net nutrient mineralization synchronizing with critical crop demands in a sustainable and environment friendly manner capable of maintaining soil health and quality. It would only be a boon to ecofriendly solid waste management if such an organic fertilizer could be produced from the degradable solid waste, within the shortest time span possible. It is in this context that the organic fertilizer produced from degradable solid waste by abiotic and non enzymatic, rapid thermochemical processing technology (Sudharmaidevi *et al.*, 2017) which requires only an hour for conversion to fertilizer becomes all the more relevant. Moreover it has the prospect of being customised on site specific or crop specific basis.

The present study envisages physicochemical and biochemical characterisation, and assessment of maturity parameters of the organic fertilizer obtained from degradable solid waste by rapid thermochemical conversion technology and evaluation of the customised organic fertilizer in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana in agro-ecological unit (AEU) 8 of Kerala.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

A study entitled 'Evaluation of a customised organic fertilizer in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana' was undertaken at the College of Agriculture, Vellayani from October 2014 to August 2016 with the objective of evaluating the customised organic fertilizer obtained by rapid thermochemical conversion of degradable solid waste on the performance of banana in agro-ecological unit 8 of Kerala. This treatise is an attempt to present the gleanings of literature on characteristics and transformation of degradable organics to organic fertilizers, the modus of influence on the dynamics of the soil organic carbon pool and behavioural aspects of constituent nutrients in soil with special focus on banana crop performance.

2.1 TECHNOLOGICAL OPTIONS IN WASTE MANAGEMENT

A host of technological options for the management of waste streams predominated by degradable organics are practiced globally. Recycling of the degradable solid waste by conversion to organic fertilizers is desirable as it augments the fast declining soil organic carbon content and enhances soil fertility and productivity (Lal, 2015).

Utilising municipal solid waste (MSW) in agro based systems as nutrient source for crops and as soil ammendment is the most cost effective disposal option as compared to the conventional disposal methods of unscientific land filling and incineration (Lim *et al.*, 2015). The potential threat in such a situation is the phytotoxicity due to pathogens and environmental pollution due to heavy metal concentration, leachate and greenhouse gas emissions (Awasti *et al.*, 2015). The feasible and widely adopted technological recycling option is composting (Stern *et al.*, 2007; Abichou *et al.*, 2009; Iqbal *et al.,* 2010; Haight 2011; Scheutz *et al.,* 2011; Guo *et al.,* 2012).

Composting of organic wastes is a bio oxidative process involving the mineralization and partial humification of the organic matter leading to a stabilized final product, free of phytotoxicity and pathogens and with certain humic properties (Zucconi and de Bertoldi, 1987). It is a spontaneous biological decomposition process of organic materials in a predominantly aerobic environment. During the process, bacteria, fungi and other microorganisms including micro arthropods break down organic materials to stable, usable organic substances called compost. It is the biological reduction of organic waste to humus or humus like substances (Bernal *et al.*, 2009).

There are different methods of composting (Misra *et al.*, 2003). Conventional approaches used are based on anaerobic or aerobic decomposition with provision for aeration either by turning or maintaining static condition with perforated pipes (Fernandes and Sartaj, 1997). Passive composting provides stacking the material in piles or pits with little agitation. The EM and microbial consortium based composting process involve aerobic decomposition which comparatively expedite the process, but to a limited extent (Saravanan *et al.*, 2013). Vermicomposting technology employing the agency of earthworm for transformation is also practiced (Misra *et al.*, 2003; Pattanaik and Reddy, 2010). However most of these processes are time consuming and laborious, predisposing leachate formation leading to environmental pollution and health hazards.

The Department of Soil Science and Agricultural Chemistry, Kerala Agricultural University, India has developed a novel technology for the conversion of degradable organics to value added organic fertilizer through chemical decomposition at 100 ^{0}C (Sudharmaidevi *et al.*, 2017).

2.2 CHARACTERISATION OF DEGRADABLE ORGANICS AND ORGANIC FERTILIZERS

2.2.1 Characterisation of raw waste

With a population of 377 million, the total MSW generation in India is estimated to be 68.8 million tons per year and the per capita waste generation in urban India is 0.498 kilograms per day (Annepu, 2012). About 50 - 80 % of the MSW comprises of biodegradable organic waste (Hikkaduwa *et al.*, 2015) of which food waste is the dominant constituent. Per capita household waste in England is 403 kg per year and 51.4 % of MSW sent to landfill was biodegradables dominated by food waste (Pham *et al.*, 2015). Forty percent of the food produced in USA and Japan, 9 million tons in South Africa and 703,200 tons of food in Singapore are wasted annually (Pham *et al*., 2015). Annual food waste production in China was 90 million tonnes in 2010 (Zhang *et al*., 2014).

The average degradable material present in solid waste collected from representative houses of Aurangabad city was 83.50 % whereas the average non - degradable material present in cumulative solid waste collected from selected houses was 16.50 % (Late and Mule, 2013). A study done by Prakasam and Das (2016) revealed that MSW of Neyyatinkara municipality in Kerala, India comprised of 63% organic waste, 17% plastic, 12% paper, 3% metals and glass, 4% construction debris and 1% others.

The source separated household raw food waste collected had pH values ranging from below 4 - 5.5. The low pH was the result of generation of acids like lactic, acetic, butyric and propionic which would lead to bad odour as well (Sundberg *et al.*, 2011).

Simon *et al.* (2013) in a study on the physicochemical characteristics of organic kitchen waste in households of Manipal reported that the raw waste had a density of 797 kg m^{-3}, moisture content of 76.85 %, 38.68 % carbon, 1.5 % N, 0.32 % P and 0.23 % K . A moisture content of 70 % for the composting substrate was ascribed to be optimal by Petric and Selimbasic (2008).

Raw food waste collected for biogas production from a canteen of Beijing University contained 49.7 % C and 1.75% N with a C/N ratio of 28.4 (Yong *et al*., 2015). Petric *et al.* (2015) recommends a high C/N ratio of 25 to 40, even as high as 50 for material to be composted. At lower C/N ratio, N will be available in excess leading to loss as ammonia gas with resultant undesirable odour. Awasthi *et al.* (2014) observed that soluble basic salts would also be liberated at lower C/N ratio which is undesirable for plant growth. A malodourous characteristic would be rendered to the compost feedstock by a low initial C/N ratio (Mohee *et al.*, 2015).

Abdou *et al.* (2016) reported that cow pea haulms collected as raw material for composting had total N (2.5%), total P (0.16%), total K (1.93%), organic C (20.75 %), total Ca (0.06%), total Mg (0.01 %) and lignin (10.9 %).

2.2.2 Characterisation of organic fertilizers

The odour in composting is caused by the content of organic acids of low molecular weight produced during the process. Oviedo-Ocana *et al.* (2015) reported a characteristic odour of humid soil after 100 days of composting for one pile of biowaste applied compost and beyond day 128 for another pile of compost studied.

EC, a measure of salt content of compost is an indication of the quality of compost for use as fertilizer (Awasthi *et al.*, 2014; Jiang *et al.*, 2015). Chan *et al.* (2016) observed that consequent to the decomposition of complex organic matter as composting proceeds, the salt content increased considerably reflecting on an enhanced EC. However Huang *et al.* (2004) opined that volatilisation loss of ammonia and the precipitation of mineral salts could also lead to a decline in EC. A mature compost with low EC value is favourable for crop growth (Yong *et al.*, 2015). Researchers have spelt out different permissible index values. Lower EC limits of 4 dS m^{-1} (Awasthi *et al.*, 2014; Chowdhury *et al.*, 2015; Zhang and Sun, 2016 a, b), < 3.5 dS m^{-1} (Mohee *et al.*, 2015), 3 dS m^{-1} (Juarez *et al.*, 2015), 2.5 dS m^{-1} (Mulec *et al.*, 2016) have been reported.

Chan *et al.* (2016) opined that under optimal conditions, pH after an initial decline rises from acidic to neutral range. Volatalisation of NH^{4+}-N, H^+ released as a result of nitrification, large quantities of CO_2 and production of organic and inorganic acids decrease the pH (Huang *et al.*, 2004; Wang *et al.*, 2016). Accumulation of ammonia consequent to protein degradation increases pH (Hachicha *et al.*, 2009). While Hachicha *et al.* (2009) stipulates a pH range of 6.0 - 8.5 for mature compost, Juarez *et al.* (2015) recommends a range of 8.0 -8.5.

The particle size of the compost is vital in determining the physical fabric regulating gas and water exchange, determining the water holding capacity and porosity (Zhang and Sun, 2014).

The content of organic matter, N, K and lignin were 46%, 2.2%, 2.1% and 20% respectively as reported by Faverial and Sierra (2014) in a study on home composting of household biodegradable wastes. However higher N, P, K contents in compost were obtained by Swarnam *et al.* (2016). Rao *et al.* (2008) stated that N content increased from 0.78 to 1.29 % in urban waste compost and from 0.75 to 1.23% in agricultural compost.

Saha *et al.* (2010) observed that MSW compost prepared from source segregated biowaste and partially segregated wastes had significantly lower contents of heavy metals like Zn, Cu, Cd, Pb, Ni and Cr as compared to non segregated mixed waste composts. According to Raut *et al.* (2008), if the organic C content is higher than 40-43 %, composting is considered to be incomplete.

Alidadi *et al.* (2016) found an increase in lignin content after the 50th day of vermicomposting. They reported that this might be due to the bioconversion of cellulose substances to lignin by cellulase and lignocellulase enzymes. Organic matter humification is formation of aromatic materials and lignin is an aromatic constituent (Senesi, 1989).

Chaudhary *et al.* (2017) obtained values ranging from 0.36 - 1.50% for N, 0.05- 1.60% for P and 0.5- 2.26 % for K in various organic manures from rice straw, wheat straw, FYM and green manure.

Dimambro *et al.* (2007) observed that the cellulose content varied between 3.0% - 40.6% and lignin content varied from 11.7% - 31.0% in compost produced from segregated degradable wastes of different proportions. Higher presence of woody material and cardboard resulted in higher cellulose and lignin contents. The contents of major nutrient elements reported are N (1.0 - 2.2%), water extractable P (23 - 247 mg kg^{-1}) and K (1852 - 6615 mg kg^{-1}).

El-Mahrouk and Dewir (2016) observed that 100% squeezed grape food waste compost had a desirable pH of 7.82 , EC of 1.68 dS m^{-1} and N, P, K contents higher than cocopeat or vermiculite. The soluble cations (Ca^{2+}, Mg^{2+} and K^{+}) and anions (CO_3^{2-}, HCO_3^{-}) were higher when mixed with 40% chicken manure and sawdust compost. Irshad *et al.* (2013) reported that pH, total C, total N, extractable K and Na decreased with composting whereas EC, extractable P and B increased. Mineralized nutrients in composted manure is less for swine and high for poultry manure (Eghball *et al.,* 2002).

Azeem *et al.* (2014) found that the content of Cu, Fe, Zn and Mn in composted poultry litter and fast food waste (75:25) were 21.92 mg kg^{-1}, 210.25 mg kg^{-1}, 288.63 mg kg^{-1} and 172.05 mg kg^{-1} respectively.

2.2.3 Compost Maturity Parameters

Applying of organic wastes as such or without complete maturation may result in immobilization of essential nutrients and cause phytotoxicity with the resultant adverse effect on the ecosystem (Juarez *et al.,* 2015). Composting Association (2001) defined stability as 'the degree of biological decomposition that composting feedstocks have achieved'. Several physical, chemical, biochemical and biological parameters and indices have been developed to assess compost maturity (Cesaro *et al*., 2015). Maturity cannot be assessed by a single parameter alone and hence is determined by measuring two or more parameters (Wichuk and McCartney, 2013).

2.2.3.1 Physical and Chemical Parameters

These parameters comprise of several physico chemical characteristics like C/N ratio, NH_4/NH_3, CO_2 evolution, electrical conductivity, moisture content, water-soluble carbon, cation exchange capacity, self-heating capacity, oxygen uptake rate, total organic carbon, volatile organic carbon, production of humic and fulvic acids, germination index to measure phytotoxicity (Zeng *et al.,* 2009; Rashad *et al*., 2010; Qian *et al*., 2014; El-Ouaqoudi *et al.,* 2015; Oviedo-Ocana *et al*., 2015; Swarnam *et al.,* 2016). Physical characteristics like temperature, colour, odour and humidity also form part of the criteria for describing the maturity of compost (Oviedo-Ocana *et al.*, 2015).

Physical characteristics serve to give only a general idea regarding the degree of decomposition. Chemical methods have wide acceptance. The carbon to nitrogen (C: N) ratio of the compost is the most vital parameter in maturity assessment of compost (Awasthi *et al.,* 2014; Chen *et al.,* 2015). A decrease in the C/N ratio is a criteria of compost stability and maturity. The California Compost Quality Council (CCQC, 2001) stipulates that compost must first have a C/N ratio of less than or equal to 25 in order to be rated as acceptable. Awasthi *et al.* (2014)

confirms this. Iqbal *et al.* (2015) stated that a C/N ratio below 20 could be considered to be of acceptable maturity and a ratio of 15 or less was preferable.

The total Kjeldahl's nitrogen content can also be taken as an index for compost maturity (Chaudhary *et al.*, 2017). The nitrification index (NH_4-N/NO_3 – N) ratio is also employed to assess the degree of compost maturity (Zhang and Sun, 2014). Juarez *et al.* (2015) put forth 0.16 as the optimum value for the nitrification index of stable compost. Singh and Kalamdhad (2013) opined that the absence or decrease of NH_4-N as a qualifying criteria of a composting procedure.

Use of cation exchange capacity as a prospective criteria for evaluation of compost maturity has been put forth by Bernal *et al.* (2009). The formation of carboxyl functional groups, formed by the oxidation of lateral chains of the aromatic rings or the hydrolysis of esters or lactones, and phenolic functional groups in an organic mass with the progression of humification results in the enhancement of CEC. Rao *et al.* (2008) observed an increase of CEC from an initial value of 38 cmol(p+) kg^{-1} to 69 cmol(p+) kg^{-1} in compost produced from agricultural waste. Harada and Inoko (1980) have proposed a CEC > 80 cmol(p+) kg^{-1} as an index of maturity.

Proposing that particle size be used as a parameter for assessment of maturity, Zhang and Sun (2016 a,b) put forth an index range of 0.25 -2.00 mm. In general, organic C content, degree of organic matter humification, water soluble carbon, cation exchange capacity, ratios of C/N, humic acid to fulvic acid and amount of CO_2 evolved are used to describe compost maturity (Bernal *et al.*, 2009; Swarnam *et al.*, 2016).

While Garcia *et al.* (2005) obtained relatively lower C_w of 0.41–1.19% in compost produced from municipal wastes, Goyal *et al.* (2005) reported comparatively higher level of 2.06 – 4.09% C_w for organic wastes. Since the water soluble C at the end of composting depends on the raw materials used for composting, harder organic materials will have a higher value (Huang *et al.*, 2004).

The degree of polymerisation is also deemed to be a significant criteria for evaluating compost maturity and reflects the use of simple molecules to form complex ones and reduction in the non humic component of compost (Zhang and Sun , 2016 a,b).

2.2.3.2 Phytotoxicity Parameters

Phytotoxicity can be defined as a delay in germination, inhibition of plant growth or any other adverse effect caused by phytotoxin (Baumgarten and Spiegel, 2004). Phytotoxic effects can be due to ammonia, ethylene oxide, organic acids, phenols, salts, heavy metals (Barral and Paradelo, 2011). Moreover, phytotoxicity assessment is a valuable way to assess the maturity of the compost (Zucconi *et al.*, 1985). Determination of *in vitro* seed germination and plant growth are the most common techniques to assess the phytotoxicity of compost.

Guo *et al.* (2012) suggested that Germination index (GI) is a sensitive indicator of maturity and phytotoxicity of compost and Huang *et al.* (2006) proposed a GI value of 80% as critical limit. Germination index (GI) increased during the composting process and the compost samples at the end of the composting phase had GI values greater than 90 (Selim *et al.*, 2012). Bazrafshan (2016) obtained a negative correlation between GI of cress with NH_4^+-N, Cu and Zn content while positive correlation was observed with NO_3-N, P and K content. Negative correlations of GI with TOC and TN have also been reported by Young *et al.* (2016).

Qian *et al.* (2014) suggested that a comprehensive maturity evaluation indexing system consisting of chemical (C/N ratio) and biological (GI or Plant Growth Index) parameters is much more suitable and practical for the maturity assessment of compost.

Application of unstable and immature compost would fix N in the soil and affect crop development either by production of toxic substances or by draining off the rhizospheric oxygen (Guo *et al.*, 2012). Mulec *et al.* (2016) ascribes phytotoxicity to the NH_4^+ and concentration of heavy metals Zn and Cu. The rhizospheric competition for O_2 by crop roots and microbes would lead to accumulation of NO_2 and H_2S (Juarez *et al.*, 2015). It can very well be construed that immature composts will be luxurious in organic carbon content , C/N ratio, pH and salt content thus rendering it unsuitable for agro systems (Huang *et al*., 2004; Chen *et al*., 2015). Stable and mature composts on the other hand can be ideally used as a fertilizer catering to crop needs as well as helping carbon sequestration (Guo *et al*., 2012). Efforts of researchers are underway for converging at unified indices of global recognition for assessment of compost maturity (Onwosi *et al*., 2017).

2.3 NUTRIENT RELEASE PATTERN OF ORGANIC FERTILIZER

A thorough understanding of the immediate, short term and long term effects of the nutrient forms and release pattern is a prerequisite for effecting a better organic fertilizer management that would be of benefit to both crop production as well as the environment. There exists remarkable variation in these patterns both under optimum laboratory conditions and the heterogeneous, buffered field conditions (Nannipieri *et al*., 2003)

2.3.1 Under Laboratory Conditions

Cogger *et al.* (2016) found that the soil application of mixed compost enhanced the size (102 ± 17 mg N kg^{-1}) and the mean residence time (66 ±30 days) of the pool of mineralizable organic N in soil. Several researchers have obtained similar results (Fortuna *et al*., 2003; Spargo *et al*., 2011).

In a 360 day incubation experiment, Bhowmik *et al.* (2017) found that during the early stages, the C mineralized was derived largely from the active pool of C with a laboratory mean residence time ranging from 21 to 30 days. The hydrolysable and permanganate oxidisable carbon were significantly related with the cumulative nitrogen mineralized on day 90 of the incubation.

In a 140 day laboratory incubation study, Abbasi and Khaliq (2016) observed that the percentage conversion of added nitrogen into available N by different amendments varied between 21 and 80%, while conversion of applied N into NO_3-N ranged between 9 and 65%. Urea N when applied alone showed disappearance of 37% N at the end.

In a 97 day laboratory incubation experiment, Masunga *et al*. (2016) found that net N mineralization in clover amended soils was 54%, more than five times higher than in soils amended with composts or manure (4-9%). Redin *et al.* (2014) observed that the mineral N content in soil was almost depleted during the first 14 days and remained depleted until the end of incubation (day 120). The net N mineralization at day 120 was positively and linearly related to the residue N concentration, with residue with low N content inducing a net immobilization. Xiong *et al.* (2014) in a 346 day incubation study concluded that for litters with initial C:N ratios lower than 52, net N_{min} after 346 days was 100% higher when incubated with soil than when incubated alone. In a 120 day incubation experiment, Abbasi *et al.* (2015) reported a high N mineralization in soil only treatment on day 100 and the legumes exhibited continuous N mineralization, leaves of non-legumes showed four phases of mineralization –immobilization turn over *i.*e. initial negative from day 7 to 21, slow mineralization from days 21 to 60, rapid mineralization between days 60 and 80 and a decline in net mineralization between days 100 and 120. Li and Li (2014) reported that while N mineralization from poultry and pig manures followed a first order exponential model, a quadratic equation is best fit for mineralization of organic N from cattle manures, in a 161 day laboratory aerobic incubation study. In a soil incubation experiment for 30, 60 and 90 days and soil leaching experiment for 30 days, Omar *et al*. (2015) observed that urea amended with zeolite and compost significantly reduced NH_4^+ and NO_3^- release as compared with urea alone, thus reducing leaching of these ions.

In a 42 day incubation experiment, Kolawole (2016) observed an increase in pH. Mean values for available P was 1.2, 1.65 and 3.07 mg kg $^{-1}$ for tithonia compost in the three soil types while incubation with poultry manure gave 3.79, 1.92 and 6.06 mg kg^{-1} of P. However, incubation with residues decreased available N except for poultry manure. In a laboratory experiment to study the dynamics of phosphorus in soil under different organic amendment treatments incubated for 60 days, Saloid-P, Al-P, Fe-P, and Ca-P ranged from 3.28-22.41, 8.15-32.43, 11.77-35.38 and 161.83-215.30 mg kg^{-1} (Kumar *et al.,* 2015).

Leytem *et al.* (2006) in an 18 week laboratory study with calcareous soil incubated with manure from poultry fed with grain based diets containing different P forms found that there existed a linear relationship of percentage of water extractable P and phytic acid P in the manures ($r^2 = 0.94$), increases in Olsen P and monoester P were positively related and by 18 week, Olsen P was related to the amount of C or N added with the treatments.

Samuel (2015) observed in a laboratory incubation study for 90 days that the organic and inorganic NPK at all rates enhanced soil NH_4-N, NO_3-N, total N and available P. In a 224 day incubation study it was found that C/N ratio of the amendment significantly correlated with N mineralization rate and C mineralization varied from 5 to 62 % of the organic C added. It is therefore a challenge to combine different types of organic fertilizers with mineral fertilizers (Mariaselvam *et al.*, 2015).

Rostami and Ahangar (2013) found that in a 4 month incubation study, the concentrations of Fe and Mn decreased primarily in the carbonate bound and residual fractions but was enhanced in the exchangeable, Fe-Mn oxide and organic matter bound fractions with cow manure application. Escobar and Hue (2008) found a rise in pH, EC, K and Mg whereas Ca, P, Mn decreased on incubation with chicken manure and green manure. Li and Li (2014) in a laboratory incubation study for 161 days found rapid N mineralization taking place between 56 to 84 days of incubation. First order exponential model can be used to describe N mineralization from chicken and pig manures while quadratic equation fitted that from cattle manure.

Cocoa pod ash @10 t ha^{-1} recorded highest pH and Ca at 30, 60 and 90 days in an incubation experiment conducted by Ayeni and Adeleye (2011). NPK fertilizer @ 200 kg ha^{-1} had the highest N, P and exchangeable acidity at 30, 60 and

90 days. Cocoa pod ash @ 10 t ha^{-1} had widest Ca: Mg ratio, indicating proneness to nutrient antagonism. Cocoa pod ash and poultry manure reduced K: Ca ratio. Abbasia *et al.* (2007) observed four phases of N mineralization –initial rapid release phase in10-20 days followed by slow phase in 30-40 days, a maximum mineralization in 55-90 days, and finally a declined phase in 120 days.

2.3.2 Under Field Conditions

In a field study of nutrient release patterns of plant litter decomposition, Tian *et al.* (1992) observed a progressive decline in the release of the nutrients N, P, Ca and Mg with time. Most of K contents were released before 41 days. The concentration and absolute weight of N, S and P in the leaf litter of all species increased with time and P levels had an influence on the mineralization or immobilization of other nutrients (Likens, 2013). Li-Hua *et al.* (2014) in a study of litter nutrient dynamics in a bamboo ecosystem for two years observed a negative exponential relationship between element initial and final concentrations which accounted for 57.9% (N), 95.0% (P), 99.8% (Ca) and 98.1% (Mg) variation.

Sharifi *et al.* (2014) observed that application of fresh manure resulted in greater quantity of readily available mineralizable N while composted manure contributed more to intermediate and stable mineralizable N pools in eight years history of ammendment application.

The availability of soil P within the soil solution is dependent on soil pH, concentration of Ca that can precipitate with P ions and the content of Fe and Al oxides and hydroxides that can sorb P (Ruttenberg, 2014). Organic fertilizer addition which modifies these chemical properties can influence P availability in the soil P pool. Application of organic manure to acidic soils enhances P availability by increasing soil pH, decreasing soil P retention capacity by increasing the concentration of ligands that compete with P for sorption sites and increasing net negative charges on the soil particles leading to a net increase in repulsive force for P (Faucon *et al.*, 2015). Aguiar *et al.* (2013) opined that the nature and kinetics of soil organic matter and P were associated and could form a baseline for foreseeing the effect of land use changes.

Addition of mineral organic fertilizer gave rise to highest soil pH value and application of compound fertilizer resulted in soil pH decrease (Xiao *et al.,* 2017). Higher intensity of pyrogenic organic matter addition increased soil exchangeable Mg by 24.2% but reduced available Fe, Mn, and Cu by up to 39.4%, 50.8%, and 30.0% (Wang *et al.*, 2017). Adekiya and Agbede (2016) observed that incorporation of poultry manure had the highest soil organic matter, N, P, K, Ca and Mg.

The electrical conductivity, soil P, K, Ca and Mg content were found to increase on addition of compost or compost plus fertilizer as compared with control soil and soil amended with fertilizer alone after 140 and 280 days (Adriano *et al.*, 2012). Bass *et al.* (2016) opined that treatments with organic amendments exhibited higher pH values and enhanced soil cation concentrations of K, Ca, NH_4 and NO_3. An increment in the soil carbon content was also evidenced to the tune of 0.11% and 0.18% in the organic amended plots. The increase in pH of organic amended soils is a pointer towards the beneficial effects of addition of organic materials on acid soils and scope of alleviating soil nutrient problems associated with high acidity, common in humid and sub humid environments (Yolou *et al.*, 2015).

Municipal waste compost application to soil is reported to enhance soil nutrients especially N as volatilisation and leaching losses from organic N sources will be less compared to mineral sources (Carbonell *et al.*, 2011; Siddiqui *et al.*, 2011) . Araujo *et al.* (2016) observed that there was a linear increment in the contents of P, K, Ca, Na, organic C, pH and CEC after six years of composted tannery sludge amendment.

Amending soils with biochar or compost effectively fixed Al and Fe instead of P, thus making P available by keeping the inorganic P in a bioavailable labile pool for a comparatively higher amount of time as against addition of triple super phosphate alone without organic amendments (Ch'ng *et al.*, 2014).

Abdou *et al.* (2016) in a study of nutrient release pattern of composted manure under field conditions found that 31, 74 and 97% of N, P and K were released at 63 days of addition in the first year. The corresponding values were 58, 60 and 99% during the second year at 84 days of decomposition. Fortified cow dung increased soil N, P, K contents by 25, 1 and 62% respectively and soil Ca and Mg contents by 2 and 8 % respectively (Ayoola and Makinde, 2014).

The microorganisms in the soil are an important source and drain of nutrients in the soil, promoting mineralization of organic matter making available inorganic nutrients NO_3^-, H_2 PO_4^-, SO_4^{2-} and CO_2 available to the plant. The dehydrogenase activity can be used as an indicator of microbial activity. Dehydrogenase enzyme was reported to be higher by over 730% in MSW treatment and by over 993% in treatment with cow manure as compared with unamended control soil (Bundela *et al*., 2010).

2.4 CARBON POOLS AND SEQUESTRATION

Comprising of a major part of the global C pool of 2500 Pg, the soil organic carbon (SOC) pool of 1550 Pg is 3.1 times the atmospheric pool and 4.5 times the biotic pool (Lal, 2004; Cotrufo *et al*., 2011). Resorting to sustainable soil and cultivation measures has a scope of sequestering 40-80 Pg of C in soils over the next 50 to 100 years (Houghton *et al.,* 1996).

Carbon sequestration refers to the process whereby atmospheric CO_2-C is transferred to soil C pools, namely organic C and secondary carbonates, with long residence times (Whalen *et al*., 2013).

The kinetics of the soil organic carbon pool relies greatly on the equilibrium achieved with regard to the carbon moving in and out through various pathways on which soil management measures have a direct bearing (Ding *et al,* 2012). Several researchers have found that balanced fertilization with Nitrogen (N), phosphorus and potassium in conjunction with organic fertilizers improved SOC status as well as plant growth (Cai and Qin, 2006; Mariott and Wander, 2006; Purakayastha *et al*., 2008). In organically managed top soils Gattinger *et al.* (2012) found that the SOC concentration in the top soil layer (0.18%), SOC stocks (3.5 Mg C ha^{-1}) and SOC sequestration rates (0.45 Mg C ha^{-1} yr^{-1}) were higher as compared to soils managed inorganically. Fan *et al.* (2014) concluded that there was an increment in SOC stock in the 0-60 cm depth ranging from 3.7% to 31.1% over 20 years with the addition of compost and inorganic N and P, but declined at proportions spanning rom 1.4% to 10.7% in plots without inorganic P or N addition.

The SOC stock consists of labile or active cycling pool and stable, passive/ recalcitrant pools with varying residence time (Xu *et al.*, 2011). Labile C pool is the fraction of soil organic carbon with rapid turnover rates which serve as the energy source for the microbes and thus influences nutrient cycling for maintaining soil quality and its productivity. Variation in magnitude of the soil labile organic carbon fraction in short and medium terms can be detected as they have only a comparatively lesser residence time and greater turnover rates (Haynes, 2005). The variation in labile carbon contents among different treatments would be a criteria for assessing their sensitivity for use as soil additives (Purakayastha *et al.*, 2008).

Since the highly recalcitrant organic matter is resistant to decomposition and has a very long turn over time of hundreds of years, the response of a very intermediary labile pool to variations in temperature and moisture conditions is significant in striking the soil C balance (Jia *et al.*, 2015). Labile C is sensitive to management practices and is a good indicator to study SOC changes on short term basis. The application of NPK fertilizers alone or in combination with organic manures had a positive effect on labile carbon (Chaudhary *et al.*, 2017).Enhancement of the labile carbon content in the soil under crop rotation was evidenced with addition of mixed compost or manure (Lucas and Weil, 2012; Culman *et al.,* 2013).

$KMnO_4$ oxidisable C is considered to be the ideal yard stick of organic carbon lability (Souza *et al.,* 2016). A rapid quantification of the labile carbon pool in soils is enabled by the permanganate oxidable carbon which was more closely related to the smaller sized (53-250 μm) particulate organic C as studied by Culman *et al.* (2012).

In a composting experiment with penicillin mycelial dreg, Zhang *et al.* (2016) observed a rapid decrease of dissolved organic carbon from 152.41 to 16.46 g kg^{-1} which had a predominance of humic and fulvic like substances during the first twelve days, which indicated a rapid conversion and breaking down of labile organic carbon. Similar results were reported by Li *et al.* (2016). The subsequent decrease in the dissolved organic carbon after the thermophilic stage, suggested the possibility of formation of complex substances with insolubility due to re-polymerisation (Shao *et al.*, 2009).

Balanced inorganic fertilizer application along with organic fertilizers was found to be of key significance in effecting a 2.3 - 52.6% and 9, 4 - 64.6% increase in SOC contents at 10 and 20 years of fertilizer application (Li *et al.*, 2015). Bhowmik *et.al.* (2017) observed that addition of organic amendments to organic management systems effected a reduced partitioning of C to the active pool with the simultaneous augmentation of the slow pool carbon which would in effect lead to soil carbon sequestration.

The proportion of soil labile C pool varies significantly with ecosystems. It was observed that the soil organic carbon of agro ecosystems had a relatively higher labile carbon pool than in forest ecosystems (Ratnayake *et al.*, 2013). The carbon management index (CMI) is a rather delicate index of the transformation in the kinetics of soil carbon of a system in comparison with a more stable reference soil (Blair *et al.,* 1995; Nogueirol *et al.,* 2014). A greater value for CMI implies that the soil agro system is being alleviated and replenished for sustenance as against a lesser CMI value which indicates a degradation of the soil system (Chaudhary *et al.*, 2017). Prakash *et al.* (2016) observed that the addition of FYM and fertilizer P in an integrated manner resulted in higher soil organic carbon, $KMnO_4$ oxidisable labile carbon pool and a higher carbon management index (CMI) in a seven year study from 2006-2013 on a rice–wheat cropping system. Similar results were reported by Moharana *et al.* (2012) and Chowdhury *et al.* (2015). Lucas and Weil (2012) reported that labile carbon could be used to predict crop yield and response to SOM management when winter rye was planted as a cover crop in a no tillage system.

In light of the intimate influence between CO_2 content in the air and the land management practices, studies regarding the type and forms of fertilizers that would be effective and efficient in reducing the CO_2 emissions to atmosphere are gaining wide consideration (Dadhi and Brar, 2016). Hence the SOC which would act as a storehouse is of prime importance for the atmospheric CO_2 cycle (Xiao *et al.,* 2017). Of late it is proved that addition of organic fertilizers has led to carbon sequestration in many kinds of soils (Fan *et al*., 2014; Mahmoodabadi and Heydarpour, 2014).

2.5 EFFECT OF ORGANIC FERTILIZERS ON CROP PRODUCTION

2.5.1. Plant Growth and Yield

A synergistic effect was evident to the conjunctive soil addition of organic amendments and inorganic fertilizers. Agegnehu *et al.* (2016) reported that with the addition of compost and 23 kg N ha^{-1} resulted in twice the barley grain yield (3321 kg ha^{-1}) as against the yield (1560 kg ha^{-1}) with the same N fertilizer rate alone.

Chhuria *et al.* (2016) reported higher bunch weight, number of hands per bunch and number of fingers per bunch in tissue cultured banana cv. Grand Nain grown with recommended dose of fertilizers, biofertilizers and vermicompost.

Gajbhiye *et al.* (2016) obtained highest pooled yield of 4.8 kg per tree on addition of recommended fertilizer dose along with 10 kg FYM. Poultry manure application at three weeks before transplanting increased tomato fruit yield by 4.0, 2.8 and 1.5 t ha^{-1} as compared with 6, 3 and 0 weeks after transplanting (Adekiya and Agbede, 2016). Manure and cover crop combination registered a positive effect on the potato tuber yield after lucerne and field pea (Nyamdavaa and Friedel, 2016). Ezeocha (2014) recorded 13.5% enhancement in starch yield of aerial yam at 4 tonnes per hectare of poultry manure addition. Damatto *et al*. (2011) found that 129 kg compost per plant corresponding to 290.5 g of K_2O per plant resulted in bunches with highest weight in banana 'Prata-ana' in Brazil.

Highest potato yield in response to increased fertilizer N application was 36 Mg ha^{-1} (at 250 kg N ha^{-1}) without compost and 39 Mg ha^{-1} at 213 kg N ha^{-1} for compost application (Carter *et al*., 2004). Bass *et al.* (2016) in a study on the effect of organic fertilizer on banana yield observed that there was a significant difference in bunch weight in organic amendment applied plants than from the control plants. This was despite without significant difference in bunch volume but having a significantly higher fruit diameter.

Vanilarasu and Balakrishnamurthy (2014) reported that the combined application of organic manures, amendments and green manures recorded the highest bunch weight (27.96 kg) , finger weight (280.25 g) as against inorganic treatments and control.

With the combined application of NPK fertilizers and FYM, the yield of banana increased to 50.3 t ha^{-1} which was equivalent to 59.4% increase over the yield obtained with N alone and 36.4% increase over that obtained with NPK alone. The values for combined application of NPK and composted press mud were 46.4 t ha^{-1}, 47% and 25.9% respectively (Rajput *et al*., 2015).

Youssef and Eissa (2016) observed that the mixture of rabbit manure, rock phosphate and feldspar with Bio-N-P-K enhanced the tomato fruit yield by 30% in comparison with inorganic fertilizer addition.

Yolou *et al.* (2015) observed that both the MSW compost and the NPK fertilizer significantly improved stover and grain yield and yield attributes as compared with control treatment. Masood *et al*. (2014) also reported the positive outcome of short term supply of organic manures in maize. Mbau *et al.* (2014) reported higher grain yield in maize on compost treated plots as against those treated with mineral fertilizer. Kuttimani *et al.* (2013) reported that full dose of NPK combined with 40% Wellgro soil produced highest yield of 72.8 and 77.1 t ha^{-1} in consecutive years. Patil and Shinde (2013) obtained 85, 80 t ha^{-1} yield with application of half dose (100-80-100 g plant^{-1}) of NPK along with FYM, Azotobacter (50 g plant^{-1}), phosphate solubilizing bacteria (50 g plant^{-1}) and vesicular arbuscular mycorrhiza (250 g plant^{-1}).

Araujo *et al*. (2016) observed that the cowpea yield exhibited a quadratic response to rates of composted tannery sludge amendment with a highest cowpea yield at 8.3 Mg ha^{-1}. The highest (6.95 t ha^{-1}) and lowest grain yield (3.17 t ha^{-1}) in maize was obtained from compost 5 t ha^{-1} + urea 75 kg ha^{-1} and control respectively (Laekemariam and Gidago, 2013). Ogbonna *et al.* (2012) observed that application of amended organic waste increased maize stem length, girth, number of leaves, leaf length and chlorophyll content. Abdou *et al.* (2016) reported that the combined application of compost and NPK fertilizers recorded highest millet yield of 1762 and 866 kg ha^{-1} and the highest cow pea yield of 360.5 and 389 kg ha^{-1}. An enhancement in plant height, number of branches, number of nodules and grain yield of cowpea was observed on addition of vermicompost enriched with the rock phosphate (Sailajakumari, 1999).

Leno *et al*. (2016) reported that the fortified fertilizer produced by rapid thermochemical conversion technology had superior effects on vine length, fruits per plant, fruit polar and equatorial diameter, fruit weight, fruit volume, flesh thickness, 100 seed weight and fruit yield of oriental pickling melon. Jayakrishna (2017) observed that the custom blended thermochemical digest had significant influence on chilli plant height at 30, 60 and 90 days after planting and total dry matter production. Fortification of thermochemical digest with NPK (100% POP) and weekly application @ 25 g per plant gave highest yield.

2.5.2 Plant Nutrient Concentration

Addition of organic fertilizer has been proved to enhance the soil health and crop growth (Kang *et al*., 2016). Agegnehu *et al.* (2016) reported that organic soil amendments significantly increased barley shoot contents of N, P and K. There was no significant interaction effect of organic amendment with N fertilizer rate. Adekiya and Agbede (2016) reported that poultry manure application at 3 weeks before transplanting gave highest values of foliar N, P, K, Ca and Mg while 6 weeks after transplanting gave the lowest values. An increased grain P concentration was observed by Andriamananjara *et al.* (2016) in irrigated rice grown on highly weathered soils consequent to FYM application.

Vanilarasu and Balakrishnamurthy (2014) found that combined application of organic manure, amendments and green manures recorded highest nutrient content of N, P and K at 5th and 7th months after planting ensuring adequate levels of NPK during the entire crop growth period in banana cv. Grand Nain. Application of rabbit manure, rock phosphate and feldspar with the bio-fertilizer (Bio-N-P-K) inoculation increased the foliar NPK concentration by 34, 35 and 50% compared to the same treatment without the biofertilizers (Youssef and Eissa, 2016)

Jayakrishna (2017) observed that custom blended thermochemical digest from degradable waste enhanced N, P, K, Ca, Mg, S concentration in the shoot of chilli. Increase in micronutrient concentration of Fe, Mn, Zn and B were also observed with thermochemical digest blended with NPK (100% POP) applied weekly @ 25 g per plant.

2.5.3 Pest and Disease Resistance

Attributes of a healthy soil such as high organic matter, good soil structure, high water holding and drainage capacities and an array of ecologically beneficial microbes result in resilience to adverse events and stress and low pathogen and pest populations (Larkin, 2015). Van Bruggen and Finckh (2016) observed a less incidence of *Fusarium graminearum* in organically managed soils associated with a richer soil biodiversity coupled with less nitrogen content. Shrestha *et al*. (2014) reported reduced damping off by *R. solani* in *Brassica* spp.

Enriched organic fertilizer treatments was reported to have lesser *Colletotrichum* fruit rot disease incidence in chilli (Lekshmi, 2011). Subash *et al.* (2014) found that damping off disease in chilli could be brought under control with *Trichoderma harizanum* enriched sugarcane bagasse. Populations of root knot nematodes were consistently lower in organically managed plots (Van Bruggen and Finckh, 2016).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A study entitled 'Evaluation of a customised organic fertilizer in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana' was conducted from October 2014 to August 2016 at the College of Agriculture, Vellayani with the objective of evaluating the customised organic fertilizer obtained from degradable solid waste by rapid thermochemical conversion technology, in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana in agro-ecological unit 8 of Kerala. The four parts of the study were characterisation of degradable solid waste (DSW) and the transformed organic fertilizer (OF), soil test based fortification of the manure with inorganic nutrients for customised application to Nendran banana in AEU 8, investigations on nutrient release characteristics of customised organic fertilizer (COF) and the effect of COF on labile carbon dynamics and yield of Nendran banana. The materials and methods used for the study are described in this chapter.

3.1. CHARACTERISATION OF DSW AND THE TRANSFORMED ORGANIC FERTILIZER

3.1.1. Production of OF from DSW

Organic fertilizer (OF) was produced from DSW by rapid thermochemical processing (Sudharmaidevi *et al*., 2017). Segregated DSW was collected from various sources like college hostel mess, residents' association and grocery. The DSW was then ground to a homogenous mass of uniform consistency in the grinder unit of the 'KAU Suchitha' waste to manure converter machine and was boiled at 100^{O}C in the reactor unit of the machine where 2 sets of (patent pending) chemical reagents were added at a time interval of 30 minutes. Processing is completed at the end of one hour and OF produced. Coir pith @ 40 g kg^{-1} waste was added and sun dried to reduce the moisture content (Plate 1).

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A. Grinding of DSW

B. Addition of reagents

C. Addition of coir pith to processed OF

D. Sun drying of processed OF

E. Processed and dried OF

Plate 1. Rapid processing technology of conversion of DSW to OF

3.1.2. Characterisation Studies

The DSW and the OF were characterised for physical, chemical and biochemical properties and compost maturity parameters assessed as per standard methodologies outlined in Table 1. The Fertilising Index and Clean Index of the OF were worked out using the following formula according to the criteria and ratings provided in Appendix1 (Saha *et al.*, 2010).

$$\text{Fertilising Index} = \frac{\sum_{n}^{i=1} S_i Wi}{\sum_{n}^{i=1} Wi}$$

where 'S_i' is the score value of analytical data and 'W_i' is weighing factor of the 'i'th fertility parameter

$$\text{Clean Index} = \frac{\sum_{n}^{j=1} Sj\, Wj}{\sum_{n}^{j=1} W_j}$$

where 'S_j' is the score value of analytical data and 'W_j' is weighing factor of the 'j'th heavy metal

Table 1. Standard analytical methods of DSW and OF

Parameter	Method	Reference
Physical		
Colour/Odour	Sensory perception	FAI (2007)
Particle size	Sieving	FAI (2007)
Moisture content	Gravimetry	FAI (2007)
Bulk density	Tap volume	Saha *et al.* (2010)
Chemical		
pH (1:2)	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	FAI (2007)
EC (1:5)	Conductometry EC-TDS Analyzer (CM 183, Elico, India)	FAI (2007)
Total organic carbon (TOC)	Weight loss on ignition CHNS Analyzer (Vario El cube, Elementar, Germany)	FAI (2007)
N		
P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdo yellow color method (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Greenberg *et al.* (1992)
K	Nitric-perchloric (9:4) acid digestion and flame photometry (Digital Flame Photometer 130, Systronics, India)	FAI (2007)
Ca, Mg Fe, Mn, Zn, Cu	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry (A Analyst 400, PerkinElmer Inc., USA)	FAI (2007)
S	Nitric-perchloric (9:4) acid digestion and turbidimetry (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Tabatabai (1974)
B	Dry ashing at 550^0C in silica crucibles followed by extraction of ash in 10 ml of 0.36 N H_2SO_4 for one hour at room temperature and filtration through Whatman No. 42 filter paper. Spectrophotometry (Azomethine-H method) (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Roig *et al.* (1996)
Pb, Cd, Ni, Cr, As, Zn, Cu	Nitric-perchloric (9:4) acid digestion and emission spectroscopy (ICP OES Optima 8000, PerkinElmer Inc., USA)	Wei and Yang (2010)
Biochemical		
Cellulose	Colorimetry	Updegraff (1969)
Hemicellulose	Gravimetry	Goering and Van Soest (1970)
Lignin	Gravimetry	
Crude fiber	ASTA Method 7.0	ASTA (1997)
Tannin	Spectrophotometry (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Price and Butler (1977)
Total protein	AOAC Method 40.1.06	AOAC (2016)

Compost maturity parameters		
CEC	$BaCl_2$-TEA, pH 8.1	Lax *et al.* (1986)
NH_4^+-N, NO_3^- N	Macrokjeldahl distillation and titrimetry	Hesse (1971)
Water soluble organic carbon (C_w)	Titrimetry	Monedero *et al.* (1996)
0.1 *M* NaOH extractable organic carbon (C_{EX})	Titrimetry	Monedero *et al.* (1996)
Fulvic acid carbon (C_{FA})	Gravimetry	Monedero *et al.* (1996)
Humic acid carbon (C_{HA})	C_{EX} - C_{FA}	
Polymerisation Index (PI)	C_{HA}/C_{FA}	Roletto *et al.* (1985)
Humification ratio (HR)	C_{EX} / TOC x 100	
Humification index (HI)	C_{HA} /C_{org} x 100	
Percent of humic acids (PHA)	C_{HA} /C_{EX} x 100	
Respirometric studies		
CO_2-C	Alkali trap and titrimetry	Jimenez and Garcia (1989)
Phytotoxicty tests		
Germination Index GI	(% seed germination x % root growth) /100	Gariglio *et al.* (2002)
Microbial population	Serial dilution and plate count	Timonin (1940)

3.2. SOIL TEST BASED FORTIFICATION OF ORGANIC FERTILIZER WITH INORGANIC NUTRIENTS FOR CUSTOMISED APPLICATION TO NENDRAN BANANA IN AEU 8

3.2.1 Generation of Soil Test Based Fertilizer Recommendation for Banana in AEU 8

Composite soil samples were drawn from Block B of the Instructional Farm, College of Agriculture, Vellayani, a representative site of agro ecological unit 8 where bulk crop of Nendran banana was raised in blocks. Soil testing of the samples were done to determine the pH, OC content, major (N, P, K), secondary (Ca, Mg, S) and micronutrients (Fe, Mn, Zn, Cu, B). Based on the analytical results, the blanket fertilizer recommendation for Nendran banana as per Package of Practices (POP) of Kerala Agricultural University was modified and soil test based recommendation worked out from the soil fertility rating classes for each nutrient. The data on soil test are given in the Results chapter (Table 15).

3.2.2 Fixation of Rate of OF to be Applied to Nendran banana

Since the POP recommendation of FYM for Nendran banana is 10 kg plant^{-1}, the rate of OF was fixed as 2 kg plant^{-1}on the basis of rates (1/5th of FYM) standardised for vegetables (Sudharmaidevi *et.al.*, 2017). Of the 2 kg of OF fixed for application to one banana plant, 1 kg of OF was apportioned for basal application and the remaining 1 kg apportioned for the split applications.

3.2.3 Customisation of OF for basal application and top dressing

The OF thus produced was then subjected to customisation for two levels of application *viz.*, COF for basal application as substitution for FYM and COF for split applications.

The OF produced by thermochemical conversion was customised with inorganic nutrients (chapter Results, Table 16) so as to constitute a complete and well balanced COF for basal application to Nendran banana. Customisation of OF for top dressing was done with the addition of soil test based inorganic nutrients for Nendran banana which was worked out. The rate of COF to be given for top dressing was @ 200 g plant^{-1} each for the first two top dressings and 150 g plant^{-1} each for the next four top dressings to synchronise with the manurial schedule for Nendran banana as per POP. The inorganic nutrients were added to the OF, machine mixed and pulverized to a fine homogenous powder of uniform consistency.

3.3 INVESTIGATIONS ON THE NUTRIENT RELEASE CHARACTERISTICS OF THE CUSTOMISED ORGANIC FERTILIZER (COF)

A 300 day (300 D) laboratory soil incubation experiment was conducted from May 2015 at the College of Agriculture, Vellayani, incubating the soil collected from the experimental field of the representative site of AEU 8 with FYM and COF based fertilizers as per treatment combinations in consonance with the field treatments (Table 2). The investigation was done to study the pattern of release of nutrients from these sources to the soil at periodic intervals to be taken as the indication of the availability of these nutrients to the crop at its different growth stages.

Design : CRD
Treatments : 7
Replications : 3

Table 2. Treatment combinations of soil incubation study

Treatment Code	Treatments	Dosage
F	POP (FYM + NPK)	Soil $_{\text{2 kg}}$ + FYM $_{\text{22.32 g}}$ + N $_{\text{0.424 g}}$ + P $_{\text{0.257g}}$ + K $_{\text{0.670 g}}$
FST	Modified POP (FYM + STB NPK)	Soil $_{\text{2 kg}}$ + FYM $_{\text{22.32 g}}$ + N $_{\text{0.301 g}}$ + P$_{\text{0.064 g}}$ + K $_{\text{0.167 g}}$ + Lime $_{\text{0.223 g}}$
FSTSM	FYM + STB (NPK + Secondary + Micro)	Soil $_{\text{2 kg}}$ + FYM $_{\text{22.32 g}}$ + N $_{\text{0.301 g}}$ + P$_{\text{0.064 g}}$ + K $_{\text{0.167 g}}$ + $MgSO_4$ $_{\text{0.112 g}}$ + Borax $_{\text{0.009 g}}$ + Lime $_{\text{0.223 g}}$
FFSTSM	FYM + COF (OF fortified with STB NPK + Secondary + Micro)	Soil $_{\text{2 kg}}$ + FYM $_{\text{22.32 g}}$ + COF $_{\text{2.23 g}}$ + N $_{\text{0.301 g}}$ + P$_{\text{0.064 g}}$ + K $_{\text{0.167 g}}$ + $MgSO_4$ $_{\text{0.112 g}}$ + Borax $_{\text{0.009 g}}$ + Lime $_{\text{0.223 g}}$
FFSTSMP	FYM + COF (OF fortified with STB NPK + Secondary + Micro) + PGPR Mix I	Soil $_{\text{2 kg}}$ + FYM $_{\text{22.32 g}}$ + COF $_{\text{2.23 g}}$ + N $_{\text{0.301 g}}$ + P $_{\text{0.064 g}}$ + K $_{\text{0.167 g}}$ + $MgSO_4$ $_{\text{0.112 g}}$ + Borax $_{\text{0.009 g}}$ + Lime $_{\text{0.223 g}}$ + PGPR Mix I $_{\text{0.446 g}}$
OFSTSM	COF (substitute for FYM) + COF (OF fortified with STB NPK + Secondary + Micro)	Soil $_{\text{2 kg}}$ + COF $_{\text{4.46 g}}$ + N $_{\text{0.301 g}}$ + P$_{\text{0.064 g}}$ + K $_{\text{0.167 g}}$ + $MgSO_4$ $_{\text{0.112 g}}$ + Borax $_{\text{0.009 g}}$ + Lime $_{\text{0.223g}}$
S	Control	Soil $_{\text{2 kg}}$

POP: Package of practices; FYM: Farm yard manure; STB: Soil test based; Micro: Micronutrients; COF: Customised organic fertilizer

The collected samples were thoroughly mixed, air dried under shade and sieved through 2 mm sieve. Two kilogram each of soil was incubated at field capacity for 300 D in plastic pots (Plate 2). FYM and COF based fertilizers as per the treatments were added and thoroughly mixed with the soil. Plant growth promoting rhizobacteria (PGPR) Mix I (a consortium of *Azospirillum licoserrum, Azotobacter chroococcum, Bacillus megatherium and Bacillus* sp.) was mixed with FYM @ 20 g kg^{-1} for application. The pots were maintained at field capacity throughout the period of incubation by replenishing the moisture lost by evaporation which was found out by calculating the weight difference. Soil samples were drawn at 10 days interval for the first month and at 30 days interval thereafter up to 300 D and analysed for soil fertility parameters to study the nutrient release characteristics, the methodologies of which are given in Table 3.

Table 3. Analytical methods of soil in laboratory incubation study

Parameter	Method	Reference
pH (1:2.5)(w/v)	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	Jackson (1973)
EC (1:2.5)	Conductometry EC-TDS Analyzer (CM 183, Elico, India)	Jackson (1973)
OC	Wet digestion method	Walkley and Black (1934)
Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
Available P	Bray No.1 extraction and spectrophotometry (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Jackson (1973)
Available K	Neutral 1*N* NH_4OAc extraction and flame photometry (Digital Flame Photometer 130, Systronics, India)	Jackson (1973)
Available Ca, Mg	Neutral 1*N* NH_4OAc extraction and Atomic Absorption Spectrophotometry (A Analyst 400, PerkinElmer Inc., USA)	Hesse (1971)
Available S	0.15% $CaCl_2$ extraction and turbidimetry (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Tabatabai (1982); Massoumi and Cornfield (1963)
Available Fe, Mn, Zn, Cu	0.1 *M* HCl extraction and Atomic Absorption Spectrophotometry (A Analyst 400, PerkinElmer Inc., USA)	Sims and Johnson (1991)
Available B	Hot water extraction and spectrophotometry (Azomethine-H method) (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Gupta (1967)

3.4. EFFECT OF COF ON LABILE CARBON DYNAMICS AND YIELD OF NENDRAN BANANA

3.4.1. Experimental Site and Season

A field experiment was laid out in the Block B of the Instructional Farm, College of Agriculture, Vellayani with Nendran banana. The experiment was conducted from October 2014 to August 2015.

3.4.2. Location

The experimental field is located at 8^0 25'46.94"N latitude and 76^0 59'1.12"E longitude with an altitude of 23.8 m above MSL (Plate 3).

Plate 2. Laboratory soil incubation study

Plate 3. Imagery of the location of the experimental site

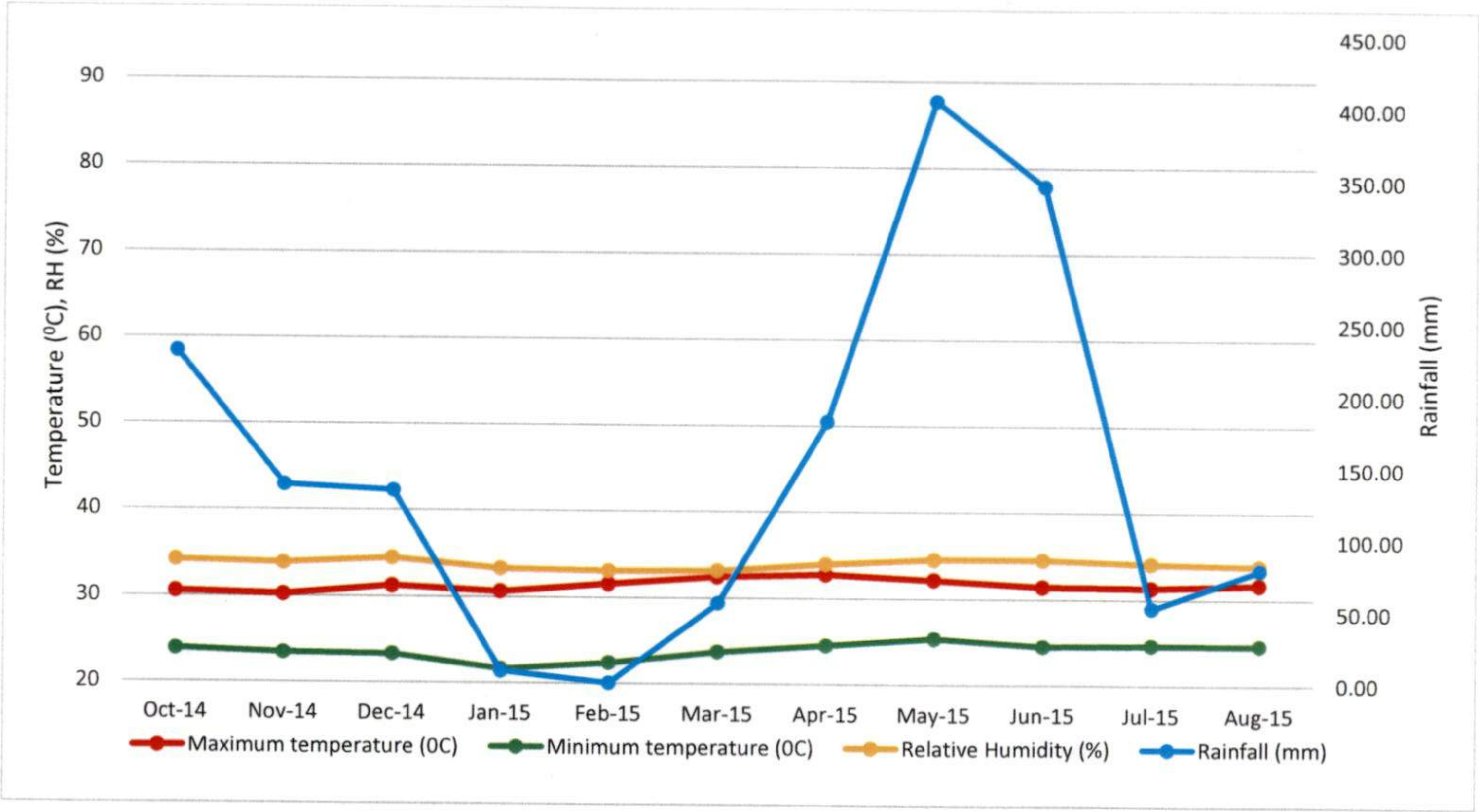

Fig.1. Weather parameters during the growth period of banana crop

Plate 4. A view of the experimental field

3.4.3. Weather parameters

The mean temperature of the location ranged from 21.56 ^{0}C to 32.74 ^{0}C and relative humidity from 78.25 - 87 per cent during the crop growth period. A total rainfall of 1634 mm was received which ranged from 0 to 406 mm in different months. The weather parameters during the cropping season were monitored and are presented in Fig. 1 and Appendix I.

3.4.4. Soil Parameters

The soil in the experimental site was classified as clayey, kaolinitic, isohyperthermic, Typic Kandiustults belonging to Vellayani series. The fertility status of the soil is outlined along with the results.

3.4.5. Design and Layout of the Experiment

Design : RBD
Treatments : 8
Replications : 3
Plot size : 6 m x 6 m
Spacing : 2 m x 2 m
No of plants per plot : 9

3.4.6. Treatments

The treatment combinations of the field experiment are given in Table 4 and the lay out of the experimental field is depicted in Fig.2. Observations were taken from the central plant in each plot.

Table 4. Treatment combinations of field experiment

Treatment Code	Treatments	Dosage
F	POP (FYM + NPK)	$FYM_{10\,kg} + N_{190g} + P_{115\,g} + K_{300\,g}$
FST	Modified POP (FYM + STB NPK)	$FYM_{10\,kg} + N_{135g} + P_{30\,g} + K_{75\,g} + Lime_{100\,g}$
FSTSM	FYM + STB (NPK + Secondary + Micro)	$FYM_{10\,kg} + N_{135g} + P_{30\,g} + K_{75\,g} + MgSO_{4\;50g} + B_{4\,g} + Lime_{100\,g}$
FSTSM(F)	FYM + STB [NPK + Secondary + Micro (F)]	$FYM_{10\,kg} + N_{135g} + P_{30\,g} + K_{75\,g} + MgSO_{4\;50g} + B_{0.2\%} + Lime_{100\,g}$
FFSTSM	FYM + COF (OF fortified with STB NPK + Secondary + Micro)	$FYM_{10\,kg} + COF_{1kg} + N_{135\,g} + P_{30\,g} + K_{75\,g} + MgSO_{4\;50\,g} + B_{4g} + Lime_{100\,g}$
FSTSM(F)	FYM + COF [OF fortified with STB NPK + Secondary + Micro(F)]	$FYM_{10\,kg} + COF_{1kg} + N_{135g} + P_{30\,g} + K_{75\,g} + MgSO_{4\;50\,g} + B_{0.2\%} + Lime_{100\,g}$
FFSTSMP	FYM + COF (OF fortified with STB NPK + Secondary + Micro) + PGPR Mix I	$FYM_{10\,kg} + COF_{1kg} + N_{135g} + P_{30\,g} + K_{75\,g} + MgSO_{4\;50\,g} + B_{4g}$ + PGPR Mix I $_{2\%}$ + $Lime_{100\,g}$
OFSTSM	COF (basal) + COF (OF fortified with STB NPK + Secondary + Micro)	$COF_{2\,kg} + N_{135\,g} + P_{30\,g} + K_{75\,g} + MgSO_{4\;50g} + B_{4\,g} + Lime_{100\,g}$

POP: Package of practices, FYM: Farm yard manure, STB: Soil test based, Micro: Micronutrients, COF: Customised organic fertilizer, (F): Foliar application; PGPR was mixed with FYM @ 2%

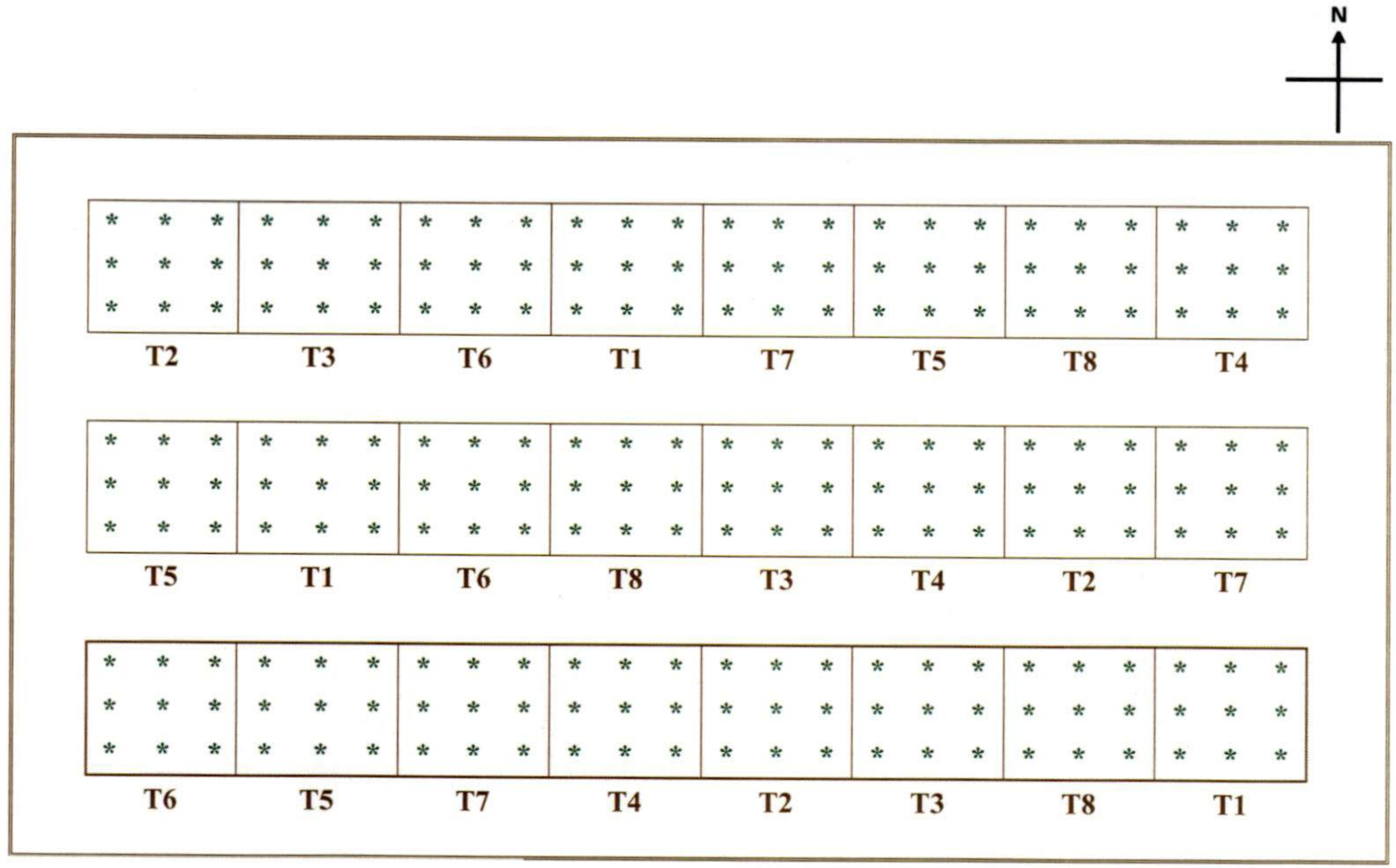

Fig.2. Lay out of the experimental field

3.4.7. Soil analysis

Soil samples were drawn at monthly intervals up to last top dressing and also at harvest and analysed as per standard procedures for various parameters outlined in Table 5.

3.4.8. Foliar Nutrient Concentration

Index leaf parts were analysed at monthly intervals before each top dressing to find out the foliar concentration. Analytical methods are outlined in Table 6.

3.4.9. Crop Growth Characters

Crop growth characters were recorded from the observational plants at 2 M, 4M and 6M of crop growth and at harvest stage.

3.4.9.1. Plant Height

The height of the plant from the base of the pseudostem at the soil level up to the axil of the youngest unopened leaf was measured and expressed in cm.

3.4.9.2. Girth of Pseudostem

Girth of the pseudostem was taken at 20 cm above the ground level by measuring the circumference of the pseudostem and expressed in cm.

3.4.9.3. Number of Leaves per Plant

The total number of fully opened functional leaves per plant were counted and recorded.

3.4.9.4. Total Dry Matter Production

The fresh weight of pseudostem, leaves, fruits and rhizome were recorded at harvest. Samples of these parts were separately oven dried at 65 °C till it attained constant dry weight and was expressed in kg ha^{-1}.

3.4.10 Yield Attributes and Yield

Bunches were harvested at full maturity as indicated by the disappearance of angles from fingers (Stover and Simmonds, 1987). The following observations were made on the bunch characters from the observational plants.

Table 5. Analytical methods of soil in the experimental field

Parameter	Method	Reference
pH (1:2.5)(w/v)	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	Jackson (1973)
EC (1:2.5)	Conductometry EC-TDS Analyzer (CM 183, Elico, India)	Jackson (1973)
SOC	Wet digestion method	Walkley and Black (1934)
Labile carbon (C_L)	0.02 *M* $KMnO_4$ oxidisable	Weil *et al.* (2003)
Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
Available P	Bray No.1 extraction and spectrophotometry (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Jackson (1973)
Available K	N *N* NH_4OAc extraction and flame photometry (Digital Flame Photometer 130, Systronics, India)	Jackson (1973)
Available Ca, Mg	N *N* NH_4OAc extraction and Atomic Absorption spectrophotometry (A Analyst 400, Perkin Elmer Inc., USA)	Hesse (1971)
Available S	0.15% $CaCl_2$ extraction and turbidimetry (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Tabatabai,1982;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)	Sims and Johnson (1991)
Available B	Hot water extraction and spectrophotometry(Azomethine-H method) (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Gupta (1967)
WHC	Core method	Gupta and Dakshinamoorthy (1980)
Dehydrogenase activity	Reduction of 3 % TTC to methanol soluble formazon and spectrophotometry (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Lenhard (1956)
Non labile carbon (C_{NL})	SOC – C_L	Blair *et al.* (1995)
Lability of carbon (L)	C_L / C_{NL}	Blair *et al.* (1995)
Lability Index (LI)	C_L (sample) / C_L (reference)	Blair *et al.* (1995)
Carbon pool index (CPI)	SOC (sample) / SOC(reference)	Blair *et al.* (1995)

Table 6. Analytical methods of foliar nutrient analysis

Nutrient	Method	Reference
N	Microkjeldahl distillation after digestion in H_2SO_4	Jackson (1973)
P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdo yellow color 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 atomic absorption spectrophotometry (A Analyst 400, Perkin Elmer Inc., USA)	Piper (1966)
S	Turbidimetry – $BaCl_2$ method (0.15 % $CaCl_2$ extraction) (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Chesnin and Yien (1951)
Fe, Mn, Zn, Cu	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry (A Analyst 400, Perkin Elmer Inc., USA)	Lindsay and Norvel (1978)
B	Dry ashing and extraction with 0.36 *N* H_2SO_4 and Azomethine-H spectrophotometry (Double Beam UV-VIS Spectrophotometer 2201, Systronics)	Bingham (1982)

3.4.10.1 Bunch Characters

3.4.10.1.1 Bunch Weight

Weight of the bunch including the portion of the peduncle up to the first scar (exposed outside the plant) was recorded in kg.

3.4.10.1.2 Length of Bunch

The length of the bunch was measured from the point of attachment of the first hand to that of the last hand and expressed in cm.

3.4.10.1.3 Hands Bunch^{-1}

Total number of hands in each bunch of the observational plant was counted and recorded.

3.4.10.1.4 Fingers Bunch^{-1}

The total number of fingers in each bunch of the observational plant was counted and recorded.

3.4.10.1.5 Fingers in the D-hand

The second hand from the top of the bunch is regarded as D-hand (Dadzie and Orchard, 1997). The number of fingers in the D- hand was recorded.

3.4.10.2 Finger Characters

3.4.10.2.1 Weight of Index Finger

The middle finger in the top row of the second hand is designated as the representative finger or index finger for studying the fruit characters (Gottriech *et al.*, 1964). The weight of the index finger was taken as the mean finger weight and expressed in g.

3.4.10.2.2 Length of Index Finger

Length was measured from the tip of the index finger to the point of attachment of the peduncle using a thread and scale and expressed in cm.

3.4.10.2.3 Girth of Index Finger

The girth measurement of the index finger at the mid portion was recorded using a thread and scale and expressed in cm.

3.4.11 Fruit Quality Parameters

The fully ripe index finger selected for recording the observations was used for quality analysis. Portions from the top, middle and bottom of the sample fruit were macerated in a mortar and pestle and samples drawn for analysis of quality parameters

3.4.11.1 Total Soluble Solids

The total soluble solids (TSS) was estimated using a hand refractometer and expressed in degree brix (^{0} B).

3.4.11.2 Ascorbic Acid

The ascorbic acid content of the fruits was estimated as per the method developed by Ranganna (1977) and expressed in mg 100 g^{-1} of fresh fruit sample.

3.4.12 Shelf Life at Ambient Conditions

The number of days taken from harvest to the development of black spots on the peel was recorded to determine the shelf life or keeping quality of fruits at room temperature (Stover and Simmonds, 1987).

3.4.13 Economic Analysis

3.4.13.1 Cost of Cultivation

Cost of cultivation under different treatments were calculated and expressed in ₹ ha^{-1} and is presented in Appendix III.

3.4.13.2 Gross income

Gross income was calculated on the basis of market price of the produce and expressed in ₹ ha^{-1}.

3.4.13.3 Net Income

Net income was calculated by subtracting cost of cultivation from gross income and is expressed in ₹ ha^{-1}.

3.4.13.4 Benefit Cost Ratio (BCR)

BCR was worked out as the ratio of gross income to cost of cultivation

$$\text{BCR} = \frac{\text{Gross income (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.4.14 Statistical Analysis

The data obtained from the lab incubation study and the field experiment were analysed statistically by applying the techniques of analysis of variance (Gomez and Gomez, 1984). The F values for treatments were compared with the table values. If the effects were significant, critical differences at the 5% significance level were calculated for effecting comparison among the means. Data analytical package Web Agri Stat Package (WASP) ver 2.0 was used for data analysis. For the data on characterisation studies, the means and standard deviations were calculated. The correlation of chemical characteristics with compost maturity parameters were also computed.

RESULTS

4. RESULTS

A study on the physical, chemical and biochemical characteristics, extent of heavy metal contamination, and an evaluation of the compost maturity parameters of DSW and the organic fertilizer produced by rapid thermochemical conversion technology was attempted under the title 'Evaluation of a customised organic fertilizer in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana' during October 2014 to August 2016 at the College of Agriculture, Vellayani. Soil test based customisation of the organic fertilizer for Nendran banana in AEU 8 was done. A laboratory incubation investigation on the nutrient release characteristics of COF was carried out. A field experiment was laid out to study the effect of COF on soil labile carbon dynamics and growth and yield of Nendran banana, the results of which are presented in this chapter.

4.1 CHARACTERISATION OF DSW AND THE TRANSFORMED OF

The collected DSW and the resultant organic fertilizer produced through rapid thermochemical technology were subjected to physical, chemical and biochemical analysis, the results of which are presented in Tables 7 - 13.

4.1.1 Composition of DSW

The average composition of DSW, segregated at source and collected for thermochemical conversion to OF is outlined in Fig.3. The values represent an average of 12 lots collected at different days. In general, cooked food waste comprised of 45% of DSW to be followed by spoiled vegetables and over ripe fruits.

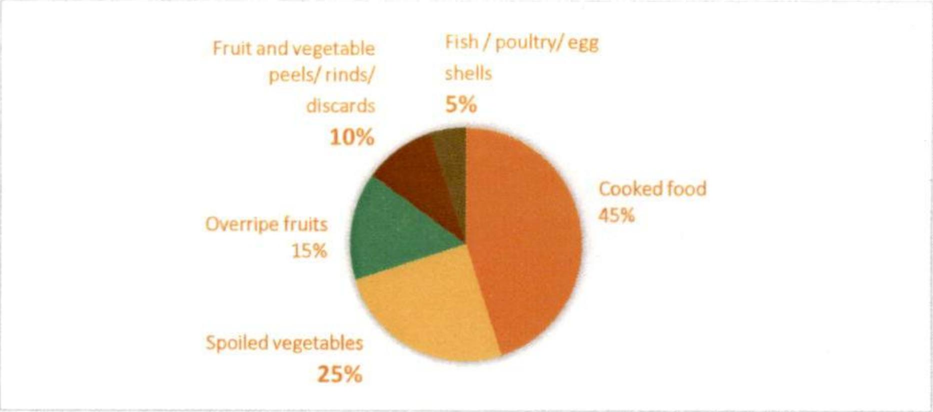

Fig. 3. Average composition of degradable solid waste segregated at source, %

4.1.2 Characteristics of DSW and OF Produced by Thermochemical Conversion

The outcome of the visual observations, mechanical tests and gravimetric measurements performed to describe the physical characteristics of both DSW and the OF are detailed in Table 7.

While a major fraction of DSW was constituted by particles of size > 4 mm, 95 ± 4.20% of OF was < 4 mm in size. The DSW was also marked by a higher moisture content (70.56 ± 5.43%) and bulk density (1490 ± 32 g cm $^{-3}$).

Table 8 revealed that the thermochemically processed OF recorded a near neutral pH of 7.02, lower EC (1.82 ± 0.15 dS m^{-1}) and TOC (23.9 ± 0.89 %) as compared to DSW which had an acidic pH of 4.47, high EC (6.32 ± 0.44 dS m^{-1}) and TOC (38.2 ± 4.00%). An increase in the content of all major nutrients was observed in the OF as compared to DSW. However, there was a slight decrease in the contents of the secondary and micronutrients with the exception of boron in OF.

The estimated concentration of heavy metals both in DSW and in the OF are furnished in Table 9. Of all the heavy metals determined, Zn recorded the highest concentration of 171.1 ± 28.04 mg kg $^{-1}$in DSW and 134.56 ± 17.27 mg kg^{-1} in the OF. Concentration of Pb, Ni, Cr, and Cu were lower in the OF than DSW. Cd and As contents were below detectable levels in both DSW and in the OF.

Table 7. Physical characteristics of DSW and OF

	DSW	OF	FAI (2007) specifications
Colour	Straw to light brown	Black to deep brownish	Dark brown to black
Odour	Foul odour on decomposing	Odourless	Absence of foul odour
Particles < 4mm (%)	25 ± 5.50	95 ± 4.20	> 90
Moisture content (%)	70.56 ± 5.43	16.40 ± 3.42	15 -25
Bulk density (Mg m $^{-3}$)	1.49 ± 0.32	0.76 ± 0.14	< 1

Table 8. Chemical characteristics of DSW and OF

	DSW	OF	FAI (2007) specifications
pH (1:2)	4.47 ± 0.53	7.02 ± 0.17	6.5 - 7.5
EC (1:5) (dS m^{-1} at 25°C)	6.32 ± 0.44	1.82 ± 0.15	< 4
TOC (%)	38.2 ± 4.0	23.9 ± 0.89	> 12.0
N (%)	1.30 ± 0.19	1.47 ± 0.13	> 0.8
P (%)	0.31 ± 0.14	0.53 ± 0.06	> 0.4
K (%)	0.83 ± 0.26	1.29 ± 0.66	> 0.4
Ca (%)	2.23 ± 1.81	1.48 ± 0.82	
Mg (%)	0.39 ± 0.17	0.35 ± 0.21	
S (mg kg $^{-1}$)	0.32 ± 0.16	0.15 ± 0.07	
Fe (mg kg $^{-1}$)	732.33 ± 75.24	592.67 ± 42.25	
Mn (mg kg $^{-1}$)	152.23 ± 45.4	92.33 ± 56.87	
Zn (mg kg $^{-1}$)	176.9 ± 27.63	136.95 ± 19.27	
Cu (mg kg $^{-1}$)	20.05 ± 2.10	19.35 ± 3.01	
B (mg kg $^{-1}$)	0.14 ± 0.04	0.21 ± 0.03	

Table 9. Extent of heavy metal contamination in DSW and OF, mg kg^{-1}

Heavy metal	DSW	OF	FAI (2007) specifications
Pb	2.67 ± 1.20	2.55 ± 0.97	< 100
Cd	BDL	BDL	< 5
Ni	6.02 ± 2.88	3.85 ± 1.42	< 50
Cr	12.10 ± 7.76	8.11 ± 2.50	< 50
As	BDL	BDL	< 10
Zn	171.1 ± 28.04	134.56 ± 17.27	< 1000
Cu	19.28 ± 2.58	19.24 ± 2.58	< 300

(BDL: Below detectable level)

Table 10. Biochemical constituents of DSW and OF, %

	DSW	OF
Cellulose	22.10 ± 0.29	13.67 ± 1.82
Hemicellulose	4.80 ± 1.54	10.01 ± 1.62
Lignin	16.23 ± 1.92	20.43 ± 1.96
Crude fiber	5.70 ± 1.61	8.30 ± 1.73
Tannin	0.80 ± 0.10	0.40 ± 0.10
Total protein (crude)	9.87 ± 1.14	10.30 ± 1.80

The analytically estimated major biochemical constituents of DSW and the OF are presented in Table 10. Cellulose content of OF (13.67 ± 1.82 %) was lower than that of DSW (22.10 ± 0.29 %). On the contrary, a perceptible increase in the hemicellulose and lignin contents of the OF was evidenced in the estimation. The crude fibre and protein content too increased whereas tannin concentration declined in OF produced by thermochemical conversion.

4.1.3 Maturity Parameters of DSW and OF by Thermochemical Conversion

In the absence of specific standards for assessing the maturity of OF produced by thermochemical conversion, standards prescribed for conventional composts were adopted. Analytical results pertaining to various maturity parameters and indices with regard to DSW and OF are put up in Table 11. DSW recorded a wider C: N ratio (29.38 ± 3.74) and C: P ratio (121.91 ± 54.22) as compared to that of the OF.

The content of NH_4^+ -N was comparatively higher in DSW (1.00 ± 0.12 %) while NO_3^- N was higher in OF (0.24 ±0.16 %). Ratio of $NH4^+$/ NO_3^- was relatively lower in OF than in DSW. CEC value of 85.70 ± 4.31cmol kg^{-1} and CEC/TOC ratio of 3.59 ± 0.20 were higher for OF. Of the various C fractions, it was revealed that OF had higher C_w, C_{EX}, and C_{HA} than DSW whereas DSW predominated in C_w/TOC ratio and C_{FA} content. With regard to the indices used for valuation of humification level, OF produced from thermochemical conversion recorded higher values for all the indices – Polymerisation Index, Humification ratio, Humification Index and Percent of Humic Acids.

Respirometric studies revealed the evolution of only 6.11 ± 2.65 mg CO_2 $kg^{-1}h^{-1}$ in the OF which is lower in comparison with DSW.

4.1.4 Quality Indices of OF by Thermochemical Conversion

As evident from Table 12, the laboratory petri plate test revealed a germination index of 84 ± 3.06 % for OF. Colony formation by microorganisms could not be found in the serial dilution and plate count method. The values obtained for Fertilising Index and Clean Index were 4.7 and 5.0 respectively.

Table 11. Maturity parameters of DSW and OF

Parameter	DSW	OF	Index value*	Reference
C:N ratio	29.38 ±3.74	16.26 ±1.85	< 20	FAI (2007)
C : P ratio	121.91 ± 54.22	44.81 ± 6.17		
NH_4^+ -N (%)	1.00 ± 0.12	0.74 ±0.05	< 0.04	Zucconi and Bertoldi (1987)
NO_3^- N (%)	0.19 ± 0.06	0.24 ± 0.16		
NH_4^+/NO_3^-	5.35 ± 0.96	3.09 ± 1.98	< 0.16	Bernal *et al.* (1998)
CEC (cmol kg^{-1})	42.83 ± 8.53	85.70 ± 4.31	> 60	Harada and Inoko (1980)
CEC / TOC	1.12 ± 0.23	3.59 ± 0.20	> 1.7	Roig *et al.* (1988)
C_W (g kg^{-1})	8.8 ± 1.28	11.90 ± 2.82	≤ 17	Bernal *et al.* (2009)
C_w/TOC	0.23 ± 0.04	0.50 ± 0.11	≤ 0.70	
C_{EX} (g kg^{-1})	14.70 ± 1.73	33.6 ± 3.70	≤ 60	
C_{FA} (g kg^{-1})	10.45 ± 0.85	8.90 ± 0.44	≤ 12.5	
C_{HA} (g kg^{-1})	4.25 ± 1.33	24.70 ± 4.12		
PI [C_{HA}/C_{FA}]	0.41 ± 0.13	2.78 ± 0.62	> 1.9	Jimenez and Garcia (1992)
HR [C_{EX}/TOC]	3.85 ± 0.51	14.06 ± 1.37	≥ 7.0	Roletto *et al.* (1985)
HI [C_{HA}/TOC x 100]	1.11 ± 0.34	10.33 ± 1.57	≥ 3.5	
PHA [C_{HA}/C_{EX} x 100]	28.91 ± 6.26	73.51 ± 3.98	≥ 50	
CO_2-C (mg CO_2 $kg^{-1}h^{-1}$)	58.06 ± 10.59	6.11 ± 2.65	< 120	Hue and Liu (1995)

* Values prescribed for conventional composts

Table 12. Values of quality indices of OF produced by thermochemical conversion

Index	Value
GI (%)	84 ± 3.06
Serial dilution and plate count (cfu)	Nil (no colony of fungi, bacteria and actinomycetes)
Fertilising Index	4.7
Clean Index	5.0

4.1.5 Correlation Studies between Various Maturity Parameters

Correlation analysis between the various chemical characteristics and maturity parameters were performed and the resultant correlation matrix obtained is presented in Table 13. C_{HA} had a very high positive correlation with CEC, CEC/TOC, C_w/TOC ratios and all humification indices of PI, HI, HR and PHA and had significant negative correlation with C_{FA} and C/N ratio. On the contrary, C_{FA} was significantly and negatively correlated with the humification indices but had positive correlation with C_w/N_{org} and C/N ratios. CEC and CEC/TOC were strongly intercorrelated and both parameters exhibited very high significant positive correlation with Cw/TOC, C_{HA}/C_{FA}, HI, HR and PHA but had a significant inverse relationship with C_w/N_{org} ratio and C/N ratio. There was a high intercorrelation among C_w/TOC and C_{HA}/C_{FA} ratios which had positive correlation with the humification indices. C/N ratio displayed a strong negative correlation with almost all the ratios and humification indices but for with C_{FA} and C_w/N_{org} ratio. Though with a lower probability, lignin content was positively correlated with CEC/TOC, C_{HA}/C_{FA}, HI, HR and PHA. The inverse correlation with CEC/TOC was the only significant correlation observed with GI. Correlations of NH_4^+/NO_3^- ratio with none of the other parameters were statistically significant.

Table 13. Correlation matrix between chemical characteristics and maturity indices

	C_w	C_{FA}	C_{HA}	Lignin	GI	CEC	CEC/TOC	C_w/TOC	C_{HA}/C_{FA}	HI	HR	PHA	C_w/N_{org}	NH_4^+/NO_3^-	C/N
C_w	1	n.s.	0.778^*	n.s.	n.s.	0.683^*	0.675^*	0.932^{***}	0.738^*	0.777^*	0.765^*	0.701^*	n.s.	n.s.	-0.672^*
C_{FA}		1	-0.759^*	n.s.	n.s.	n.s.	n.s.	n.s.	-0.890^{**}	-0.749^*	-0.693^*	-0.769^*	0.719^*	n.s.	0.782^*
C_{HA}			1	0.718^*	n.s.	0.913^{***}	0.935^{***}	0.939^{***}	0.960^{***}	0.998^{***}	0.991^{***}	0.991^{***}	n.s.	n.s.	-0.930^{***}
Lignin				1	n.s.	n.s.	0.666^*	n.s.	0.775^*	0.726^*	0.715^*	0.718^*	n.s.	n.s.	n.s.
GI					1	n.s.	-0.694^*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
CEC						1	0.993^{***}	0.866^{**}	0.829^{**}	0.928^{***}	0.941^{***}	0.904^{***}	-0.699^*	n.s.	-0.924^{***}
CEC/TOC							1	0.879^{**}	0.849^{**}	0.950^{***}	0.964^{***}	0.934^{***}	-0.673^*	n.s.	-0.938^{***}
C_w/TOC								1	0.877^{**}	0.943^{***}	0.942^{***}	0.899^{***}	n.s.	n.s.	-0.859^{**}
C_{HA}/C_{FA}									1	0.953^{***}	0.925^{***}	0.956^{***}	n.s.	n.s.	-0.899^{***}
HI										1	0.996^{***}	0.990^{***}	n.s.	n.s.	-0.940^{***}
HR											1	0.983^{***}	n.s.	n.s.	-0.932^{***}
PHA												1	n.s.	n.s.	-0.933^{***}
Cw/N_{org}													1	n.s.	0.768^*
NH_4^+/NO_3^-														1	n.s.
C/N															1

***, **, * significant at $p < 0.001$, 0.01 and 0.05; n.s. not significant

4.2 SOIL TEST BASED FORTIFICATION OF ORGANIC FERTILIZER WITH INORGANIC NUTRIENTS FOR CUSTOMISED APPLICATION TO NENDRAN BANANA IN AEU 8

4.2.1 Assessment of Soil Fertility Status of Experimental Area Representative of Agro Ecological Unit 8

The soil test results of the representative sample of AEU 8 from the experimental area of Nendran banana is furnished in Table 14. The soil was acidic, high in organic carbon content (1.69 ± 0.3%), available P and available K contents and was in the medium in N content. Among the secondary nutrients, Mg alone was deficient (78.6 ± 4.4 mg kg^{-1}). With a content of 0.08 ± 0.01 mg kg^{-1}, B was the sole micronutrient element that exhibited deficiency.

4.2.2 Soil Test Based Fertilizer Recommendation and Customised Organic Fertilizer for Nendran Banana in AEU8

The POP blanket recommendation and the computed soil test based nutrient recommendation for Nendran banana in AEU 8 are presented in Table 15. Constitution of the COF had also been worked out. One kg of the OF produced by thermochemical conversion formed the organic base for the six split doses in COF treatments @ 200 g plant^{-1} each for the first two top dressings and 150 g plant^{-1} each for the next four top dressings.The nutrients supplied by 1 kg of OF was computed and the supplementary quantity of inorganic nutrients to be added to form the COF was also calculated.

Composition of the COF for basal application (to be applied @ 1 kg plant^{-1}) to banana was done with the addition of nutrients as detailed in Table 16 so as to have a balanced and complete fertilizer which would supply all the essential major, secondary and micro nutrient elements. The chemical characteristics of COF used for basal application is shown in Table 17. As in the case of OF, the

Table 14. Soil fertility parameters of experimental site representative of AEU 8

Fertility parameters	**Content**	**Status**
pH	5.45 ± 0.05	Moderately acidic
OC %	1.69 ± 0.3	High
N (kg ha^{-1})	539 ± 13	Medium
P (kg ha^{-1})	180 ± 23	High
K (kg ha^{-1})	358 ± 26	High
Ca (mg kg^{-1})	448 ± 40.1	Sufficient
Mg (mg kg^{-1})	78.6 ± 4.4	Deficient
S (mg kg^{-1})	13.5 ± 5.4	Sufficient
Fe (mg kg^{-1})	193.9 ± 55.6	Sufficient
Mn (mg kg^{-1})	3.0 ± 1.1	Sufficient
Zn (mg kg^{-1})	12.60 ± 0.85	Sufficient
Cu (mg kg^{-1})	1.07 ± 0.21	Sufficient
B (mg kg^{-1})	0.08 ± 0.01	Deficient

Table 15. COF customised for top dressing in Nendran banana

	POP	STB	COF		
			Nutrient content in 1 kg OF (g)	Inorganic nutrient	
				g $plant^{-1}$	Source
N	190	135	14.55	120.45	Urea
P	115	30	5.25	24.75	Rock phosphate
K	300	75	12.80	62.20	Muriate of potash
Mg	---	50	3.50	46.50	Magnesium sulphate
B	---	4	2.08	1.92	Boric acid

Table 16. Composition of COF customised for basal application to Nendran banana

Nutrient	Source	Quantity (g)
	OF	700
N	Urea	50
P	Rock phosphate	100
Ca	Calcium carbonate	50
Mg	Magnesium chloride	50
S & Zn	Zinc sulphate	50
B	Boric acid	0.1
	Total	1000

Table 17. Chemical characteristics of COF for basal application to Nendran banana

Parameter	COF (basal)	FAI (2007) specifications
pH (1:2)	6.91 ± 0.66	6.5 - 7.5
EC (1:5) (dSm^{-1} @ 25°C)	2.14± 0.14	< 4
TOC (%)	23.6 ± 0.5	> 12.0
N (%)	2.31 ± 0.14	> 0.8
P (%)	1.01 ± 0.09	> 0.4
K (%)	1.37 ± 0.36	> 0.4
Ca (%)	2.47 ± 1.81	
Mg (%)	1.09 ± 0.04	
S (%)	0.72 ± 0.33	
Fe (mg kg $^{-1}$)	655 ± 67.67	
Mn (mg kg $^{-1}$)	154.6 ± 52.68	
Cu (mg kg $^{-1}$)	19.13 ± 4.11	
B (mg kg $^{-1}$)	0.55 ± 0.15	
Pb (mg kg $^{-1}$)	1.08 ± 0.76	< 100
Cd (mg kg $^{-1}$)	BDL	< 5
Ni (mg kg $^{-1}$)	5.65 ± 2.59	< 50
Cr (mg kg $^{-1}$)	11.68 ± 5.59	< 50
As (mg kg $^{-1}$)	BDL	< 10
Zn (mg kg $^{-1}$)	474.75 ± 182.20	< 1000
Cu (mg kg $^{-1}$)	19.13 ± 4.11	< 300

(BDL: Below detectable level)

nutrient contents of the COF for basal application were in conformity with the prescribed minimum standards specified by FAI, 2007. The heavy metal contents were also within the prescribed safe limits.

4.3 INVESTIGATIONS ON NUTRIENT RELEASE CHARACTERISTICS OF COF

A laboratory soil incubation experiment was carried out to study the nutrient release characteristics of the customised organic fertilizer as compared with FYM and inorganic fertilizers for a period of 300 D, the results of which are presented.

4.3.1 Soil pH

Statistical analyses revealed that there was a significant difference in soil reaction among the various treatments during the entire period of study as evidenced in Table 18. The pH of the incubated soil samples ranged from 3.84 to 5.72. The highest pH (5.72) was recorded in the S treatment at 10 D and lowest by FST (3.84) at 120 D. On a given day of sampling, OFSTSM recorded the highest pH at 30, 60, 180 and 210 D, FSTSM at 90 and 120 D and FFSTSMP at 240, 270 and 300 D. The soil reaction decreased up to 60 D in all the treatments except F. The pH of F increased up to 20 D and thereafter decreased till 60 D. A sharp decline in the soil reaction was observed up to 20 D in S which then gradually increased up to 150 D and then decreased up to 240 D following which it progressively increased to a higher value (4.44) at 300 D, though falling short of attaining the initial highest value. The soil reaction of OFSTSM treatment exhibited three distinct depressions at 20 D, 90 D and at 240 D. Similarly distinct peaks indicative of the magnitude of rise in pH were observed at 60, 210 and 300 D. However unlike the S treatment, OFSTSM attained a pH value (4.57) higher than its initial value (4.27), at 300 D.

4.3.2 Electrical Conductivity

The electrical conductivity observed at 25^0C exhibited significant difference among various treatments (Table 19). The highest EC value of 1.345 dS m^{-1} was recorded by FFSTSMP treatment at 60 D. While considering the individual sampling days also, FFSTSMP recorded the highest EC in samples

Table 18. Effect of treatments on soil pH at different periods of incubation

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	4.47^{b}	4.565^{a}	4.03^{c}	4.01^{b}	4.18^{c}	4.04^{e}	3.98^{e}	4.14^{d}	3.99^{f}	3.93^{d}	3.96^{e}	4.51^{cde}
FST	4.24^{d}	4.30^{b}	4.34^{ab}	4.09^{b}	3.95^{d}	3.84^{f}	4.19^{d}	4.38^{bc}	4.49^{b}	4.08^{bc}	3.98^{e}	4.43^{e}
FSTSM	4.40^{b}	4.33^{b}	4.09^{c}	3.98^{b}	5.67^{a}	4.93^{a}	4.64^{b}	4.35^{c}	4.28^{d}	4.14^{b}	4.15^{cd}	4.55^{bcd}
FFSTSM	4.36$^{b\,c}$	4.20^{c}	4.06^{c}	4.00^{b}	4.04^{cd}	4.16^{d}	4.28^{cd}	4.34^{c}	4.15^{e}	4.03^{cd}	4.09^{d}	4.66^{b}
FFSTSMP	4.38$^{b\,c}$	4.09^{d}	4.06^{c}	4.00^{b}	4.74^{b}	4.67^{b}	4.39^{c}	4.16^{d}	4.24^{d}	4.35^{a}	5.06^{a}	5.19^{a}
OFSTSM	4.27$^{c\,d}$	4.04^{d}	4.38^{a}	4.46^{a}	4.11^{cd}	4.36^{c}	4.52^{b}	4.63^{a}	4.84^{a}	4.01^{cd}	4.26^{b}	4.57^{bc}
S	5.72^{a}	4.045^{d}	4.26^{b}	4.32^{a}	4.59^{b}	4.68^{b}	4.85^{a}	4.46^{b}	4.39^{c}	4.18^{b}	4.22^{bc}	4.44^{de}
SEm (±)	0.054	0.043	0.045	0.092	0.098	0.040	0.058	0.041	0.040	0.051	0.048	0.054
CD (0.05)	0.115	0.092	0.098	0.197	0.211	0.086	0.125	0.089	0.085	0.109	0.104	0.115

$^{a,\,b,\,c,\,d,\,e,\,f}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 19. Effect of treatments on soil EC at different periods of incubation, dS m^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	0.532^{c}	0.701^{d}	0.938^{b}	1.210^{ab}	1.123^{a}	1.094^{a}	1.043^{a}	1.030^{a}	1.047^{a}	1.078^{abc}	1.043^{ab}	0.376^{b}
FST	0.617^{b}	0.931^{ab}	0.952^{b}	0.996^{c}	0.866^{bc}	0.819^{bc}	0.746^{c}	0.641^{c}	0.749^{bc}	0.916^{bc}	0.934^{ab}	1.022^{a}
FSTSM	0.438^{d}	0.696^{d}	0.872^{b}	1.098^{bc}	0.641^{de}	0.693^{c}	0.725^{c}	0.885^{b}	0.912^{ab}	0.994^{bc}	0.899^{b}	1.051^{a}
FFSTSM	0.542^{c}	0.818^{bc}	0.971^{b}	1.238^{ab}	0.892^{b}	0.913^{b}	0.861^{b}	0.852^{b}	0.963^{a}	1.156^{ab}	1.155^{a}	1.072^{a}
FFSTSMP	0.734^{a}	1.005^{a}	1.246^{a}	1.345^{a}	0.740^{cd}	0.683^{c}	0.584^{d}	0.435^{d}	0.543^{cd}	0.904^{c}	0.956^{ab}	0.931^{a}
OFSTSM	0.592^{bc}	0.753^{cd}	0.891^{b}	1.113^{bc}	0.815^{bc}	0.802^{bc}	0.794^{bc}	0.766^{b}	0.934^{ab}	1.314^{a}	1.053^{ab}	0.968^{a}
S	0.213^{e}	0.316^{e}	0.497^{c}	0.642^{d}	0.549^{e}	0.492^{d}	0.428^{e}	0.314^{d}	0.397^{d}	0.459^{d}	0.529^{c}	0.368^{b}
SEm (±)	0.034	0.054	0.061	0.073	0.060	0.080	0.052	0.057	0.098	0.112	0.118	0.067
CD (0.05)	0.074	0.116	0.131	0.156	0.128	0.172	0.112	0.122	0.211	0.240	0.253	0.144

$^{a,\,b,\,c,\,d,\,e}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

drawn on 10, 20 and 30 D. Treatment F registered the highest EC values from 90 D to 210 D, and OFSTSM at 240 D. However it was the FFSTSM treatment that recorded highest values at 270 and 300 D. Invariably the S treatment was observed to have the lowest EC value during all sampling days ranging from 0.213 dS $m^{-1}$to 0.642 dS m^{-1}, with the lowest EC value of 0.213 dS m^{-1} recorded at 10 D. Generally change in EC was found to follow a reverse trend of that observed in the case of pH. In all the treatments, EC increased gradually up to 60 D and then decreased at 90 D. From 90 D to 180 D, though there was a gentle decrease, they remained fairly stable. From 180 D it again showed an increase up to 240 D with the exception of F treatment. Thereafter a slight decrease was observed in all the treatments. As far as treatment F is concerned, an almost stable pattern was observed from 60 D to 270 D with a subsequent decrease. This temporal stability pattern is in absolute contradiction with the temporal pattern of pH for the same treatment F during the same incubation period.

4.3.3 Organic Carbon

The organic carbon content of the samples exhibited significant variation among the treatments during incubation (Table 20). The OC content of the incubated samples ranged from 1.28 % to 2.09 % during the entire period of study. The highest OC content was observed in FFSTSMP at 30 D (2.09 %), 60, 90 and 270 D and in OFSTSM at 10, 20 and 120 D. The lowest OC content (1.28 %) was for the treatments F at 90 D and S at 270 D. On 240 D, OFSTSM was on par with FFSTSM which recorded the highest OC content. Invariably treatment S recorded the lowest values at 10, 20, 30, 150, 180, 210, 240, 270 and 300 D. It was revealed that there occurred a general slow decline in the OC for all treatments up to 20 D following which different treatments exhibited varying patterns of decrease in OC content. The treatments F and FST were seen to follow an identical pattern of OC kinetics. A similar pattern of slow decrease in OC content was observed up to 60 D which was followed by a sharp decline during 90 D. The treatments FSTSM and FFSTSM also had an identical mineralization pattern. Although there was not much variation up to 20 D, there was a slow but steady decline in OC content up to 60 D. Thereafter the increasing trend resumed. In the case of OFSTSM treatment, the initial declining phase though gradual, progressed in a steady manner up to 90 D. The OC content at 90 D was higher than all other treatments with the exception of FFSTSMP. An appreciable increase in OC content of S was observed only on 20 D. Thereafter both the S and FFSTSMP treatments showed a similar pattern of OC kinetics.

4.3.4 Nitrogen

Available nitrogen content in the incubated soil samples exhibited significant difference among treatments as is presented in Table 21. The available N content of the samples ranged from 125.33 kg ha^{-1} to 633.47 kg ha^{-1}, the highest and lowest values being recorded by the same treatment F at 10 and 20 D. However the treatment FFSTSMP recorded the highest available N status on 20 D, 60 D and consecutively from 180 D to 300 D. OFSTSM recorded the lowest N availability at 60, 120 and 150 D. FFSTSM recorded the lowest availability at 90 D and 210 D while FSTSM at 240 D and 270 D. Available N status of control treatment S was the lowest on 10 D and 300 D, and highest on 90 D and 150 D. Treatment F recorded lowest values on 30 D and 180 D.

A critical consideration of the rate of mineralisation of N (N_{min}) revealed that there was a net mineralization on 10 D which was followed by a sharp decline up to 20 D in all the treatments (Table 22). Treatment F which recorded highest N_{min} of 50.50 % at 10 D registered the lowest (10 %) at 20 D, which was also the lowest rate recorded in the entire incubation study. Treatment F also recorded lowest N_{min} rates at 30 D and 180 D. Control treatment S recorded highest N_{min} values consecutively from 20 D up to 270 D. On a given day of sampling, FFSTSMP was the lone soil test based treatment to register the highest N_{min} value at 300 D. FFSTSMP on 60 D and FFSTSM on 90, 210 and 240 D exhibited the lowest values. Treatment FSTSM recorded the lowest N_{min} values on 10 D and on 270 D.

Table 20. Effect of treatments on soil OC content at different periods of incubation, %

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	1.90^{d}	1.88^{b}	1.86^{b}	1.84^{c}	1.28^{f}	1.43^{f}	1.64^{d}	1.80^{cd}	1.80^{bc}	1.80^{b}	1.76^{b}	1.94^{a}
FST	1.98^{bc}	1.96^{a}	1.94^{a}	1.92^{b}	1.44^{e}	1.58^{e}	1.78^{c}	1.98^{a}	1.97^{a}	1.96^{a}	1.58^{d}	1.86^{b}
FSTSM	2.01^{b}	2.00^{a}	1.84^{b}	1.62^{e}	1.72^{c}	1.74^{d}	1.79^{c}	1.82^{c}	1.84^{b}	1.96^{a}	1.64^{c}	1.90^{ab}
FFSTSM	1.95^{cd}	1.90^{b}	1.73^{c}	1.58^{e}	1.78^{b}	1.81^{c}	1.89^{b}	1.92^{b}	1.97^{a}	2.00^{a}	1.78^{b}	1.80^{c}
FFSTSMP	1.99^{bc}	1.88^{b}	1.97^{a}	2.09^{a}	2.02^{a}	1.86^{b}	1.78^{c}	1.76^{d}	1.78^{cd}	1.80^{b}	2.08^{a}	1.90^{ab}
OFSTSM	2.08^{a}	1.96^{a}	1.83^{b}	1.74^{d}	1.70^{c}	2.09^{a}	1.98^{a}	1.68^{e}	1.75^{d}	1.98^{a}	1.58^{d}	1.90^{ab}
S	1.60^{e}	1.60^{c}	1.69^{c}	1.78^{d}	1.65^{d}	1.59^{e}	1.42^{e}	1.36^{f}	1.31^{e}	1.29^{c}	1.28^{e}	1.48^{d}
SEm	0.027	0.017	0.024	0.025	0.017	0.022	0.025	0.026	0.020	0.039	0.022	0.026
CD (0.05)	0.058	0.041	0.052	0.054	0.037	0.047	0.054	0.055	0.043	0.083	0.052	0.055

$^{a, b, c, d, e, f}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 21. Effect of treatments on soil available N content at different periods of incubation, kg ha^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	633.47^{a}	125.33^{d}	184.12^{c}	288.51^{bc}	301.11^{b}	388.86^{c}	344.98^{c}	188.16^{e}	273.08^{ab}	250.88^{b}	249.91^{b}	313.60^{b}
FST	439.04^{c}	250.88^{b}	293.23^{a}	326.14^{a}	351.23^{ab}	335.23^{e}	298.00^{d}	250.88^{cd}	243.19^{c}	238.34^{bc}	238.34^{b}	312.84^{b}
FSTSM	382.66^{d}	238.33^{b}	247.18^{b}	250.88^{e}	376.32^{a}	363.78^{d}	370.05^{b}	275.97^{b}	258.09^{bc}	213.25^{d}	207.00^{c}	301.06^{b}
FFSTSM	442.33^{c}	200.66^{c}	229.22^{b}	301.06^{b}	163.07^{c}	501.76^{a}	332.42^{c}	238.34^{d}	234.31^{c}	225.79^{cd}	238.34^{b}	275.97^{c}
FFSTSMP	482.94^{b}	301.06^{a}	298.27^{a}	263.41^{de}	376.32^{a}	439.04^{b}	351.00^{bc}	326.14^{a}	294.14^{a}	275.97^{a}	376.32^{a}	401.41^{a}
OFSTSM	388.86^{d}	225.66^{bc}	232.28^{b}	250.88^{e}	288.52^{b}	275.96^{f}	282.23^{d}	250.88^{cd}	246.48^{bc}	225.79^{cd}	250.88^{b}	225.79^{d}
S	228.93^{e}	288.67^{a}	281.14^{a}	275.97^{cd}	401.41^{a}	439.04^{b}	420.23^{a}	263.42^{bc}	251.19^{bc}	238.34^{bc}	238.34^{b}	163.07^{e}
SEm (±)	11.038	12.943	12.086	10.713	30.437	8.503	9.533	11.245	13.373	10.323	12.187	10.480
CD (0.05)	23.677	27.763	25.925	22.980	65.287	18.240	20.449	24.120	28.686	22.142	26.141	22.479

$^{a, b, c, d, e, f}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 22. Effect of FYM and COF based treatments on N_{min} at different periods of incubation, %

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	50.50^{a}	10.00^{e}	14.67^{e}	23.00^{cd}	24.00^{c}	31.00^{de}	27.50^{cd}	15.00^{e}	21.76^{bc}	20.00^{cd}	20.00^{d}	25.00^{de}
FST	39.33^{cd}	22.47^{bc}	26.25^{b}	29.22^{b}	31.46^{b}	30.03^{ef}	26.69^{d}	22.47^{cd}	21.77^{bc}	21.35^{bc}	21.35^{d}	28.09^{c}
FSTSM	34.27^{e}	21.35^{c}	22.13^{cd}	22.47^{d}	33.71^{b}	32.59^{d}	33.15^{b}	24.72^{bc}	23.11^{b}	19.10^{d}	18.54^{d}	26.97^{cd}
FFSTSM	37.11^{d}	16.84^{d}	19.22^{d}	25.27^{c}	13.69^{d}	42.11^{b}	27.90^{cd}	20.00^{d}	19.64^{c}	18.95^{d}	20.00^{d}	23.16^{ef}
FFSTSMP	40.53^{c}	25.27^{b}	25.01^{bc}	22.11^{d}	31.58^{b}	36.85^{c}	29.46^{c}	27.37^{b}	24.67^{b}	23.16^{b}	31.58^{b}	33.69^{a}
OFSTSM	39.24^{cd}	22.79^{bc}	23.41^{bc}	25.32^{c}	29.11^{bc}	27.85^{f}	28.48^{cd}	25.32^{bc}	24.82^{b}	22.79^{b}	25.32^{c}	22.79^{f}
S	43.44^{b}	54.74^{a}	53.32^{a}	52.37^{a}	76.17^{a}	83.31^{a}	79.74^{a}	49.98^{a}	47.63^{a}	45.23^{a}	45.23^{a}	30.94^{b}
SEm (±)	1.167	1.591	1.688	1.249	3.157	1.037	1.125	1.482	3.482	1.022	1.460	0.994
CD (0.05)	2.503	3.412	3.620	2.680	6.772	2.224	2.414	3.178	7.469	2.192	3.132	2.132

$^{a, b, c, d, e, f}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 23. Effect of FYM and COF based treatments on soil available P, kg ha^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	90.22^{de}	97.78^{c}	94.67^{c}	93.02^{bc}	84.04^{a}	115.40^{a}	88.36^{d}	20.33^{ab}	21.11^{ab}	22.78^{a}	70.27^{b}	37.27^{e}
FST	109.33^{a}	92.67^{d}	91.89^{c}	90.33^{c}	60.23^{d}	71.34^{bc}	90.18^{d}	24.56^{a}	23.67^{a}	21.83^{a}	58.57^{cd}	66.79^{b}
FSTSM	101.56^{bc}	100.89^{bc}	99.22^{b}	97.27^{b}	59.24^{d}	66.87^{cd}	127.93^{b}	11.78^{d}	15.22^{c}	20.44^{ab}	73.42^{ab}	64.21^{b}
FFSTSM	99.22^{c}	101.56^{b}	102.19^{ab}	110.19^{a}	58.65^{d}	65.46^{d}	135.40^{ab}	14.78^{cd}	17.03^{c}	19.78^{abc}	76.91^{a}	53.01^{c}
FFSTSMP	103.11^{b}	109.00^{a}	105.33^{a}	93.29^{bc}	56.98^{d}	56.33^{e}	105.86^{c}	17.11^{bc}	17.67^{c}	17.02^{bc}	74.21^{a}	44.55^{d}
OFSTSM	93.56^{d}	92.11^{d}	92.33^{c}	93.67^{bc}	68.44^{c}	69.41^{bcd}	138.38^{a}	19.56^{b}	18.22^{bc}	16.32^{c}	61.97^{c}	74.42^{a}
S	87.22^{e}	103.44^{b}	102.89^{ab}	98.11^{b}	73.02^{b}	72.34^{b}	110.51^{c}	21.33^{ab}	15.31^{c}	11.46^{d}	57.58^{d}	64.21^{b}
SEm (±)	1.425	1.306	1.774	2.148	1.453	1.930	3.799	1.795	1.382	1.514	1.545	2.383
CD (0.05)	3.056	2.801	3.806	4.608	3.117	4.141	8.149	3.851	2.965	3.248	3.314	5.111

$^{a, b, c, d, e}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

4.3.5 Phosphorus

Release of P among different treatments over various stages of incubation exhibited significant difference and is presented in Table 23. Availability of P ranged between 11.46 and 138.38 kg ha^{-1} over the period of study. The highest release observed on any sampling day ranged between 23.67 kg ha^{-1} and 138.38 kg ha^{-1} with the treatment OFSTSM recording the highest P availability over all other samples in the study at 150 D. At 300 D also, it was OFSTSM that scored highest P release while treatment FFSTSMP recorded highest values at 20 D and 60 D. FST registered highest availability at 10 D and at 180 D and 210 D. At 90, 120 and 240 D, treatment F recorded highest values. Minimum P release observed on any sampling day ranged from 11.46 to 92.11 kg ha^{-1} with the treatment S registering the lowest P availability during the entire incubation study at 240 D. Treatment S registered the lowest release at 10 D and 270 D also. OFSTSM recorded lowest release at 20 D whereas FFSTSMP registered the lowest rates at 90 D and 120 D. The treatment FSTSM registered lowest rates of P release on 180 D and 210 D. The FST treatment registered lowest availability at 30 D and 60 D while F treatment registered the lowest content at 150 D and 300 D. Available P status was invariably lower in all the treatments as compared with initial level at 10 D.

4.3.6 Potassium

In general a highest release of K was observed in treatment F whereas the control treatment S registered lowest levels of K release at different periods of incubation (Table 24). The release of available K spanned between 179.17 and 1346.24 kg ha^{-1} throughout the study period. The highest content of available K within particular sampling days varied from 574.67 kg ha^{-1} to 1346.24 kg ha^{-1}. Highest content of available K was detected at 240 D in all the treatments except control treatment where highest release was observed at 20 D. Treatment F yielded highest K release on 10 D, 30 D and consecutively from 90 D up to 240 D, the highest K availability over the entire incubation period (1346 kg ha^{-1}) being recorded at 240 D. Treatments OFSTSM, FFSTSM, FSTSM and FST recorded highest availability at 20, 60, 270 and 300 D respectively.

Lowest K availability on a given sampling day varied from 179.17 kg ha^{-1} to 543.54 kg ha^{-1}. The control treatment S registered the lowest availability at 10 D, 30 D and consecutively from 90 D to 240 D, the lowest availability of 179 kg ha^{-1} being registered at 30 D. The treatments FSTSM, FFSTSMP and F recorded the lowest release at 20, 60 and 270 D respectively.

4.3.7 Calcium

Though with a decreasing trend, highest release of Ca was observed in the treatment OFSTSM up to 30 D whereas FSTSM recorded the lowest release over the same period with a similar decreasing trend (Table 25). OFSTSM also recorded the highest release of 542.07 mg kg^{-1} at 10 D. However the lowest Ca availability in the entire study (119.13 mg kg^{-1}) was observed in FST both at 150 and 210 D. Highest Ca availability at 60, 150, 210, 270 and 300 D was observed in treatment F while that at 90 D and 180 D was in FSTSM and at 120 D and 240 D was in FFSTSM. The treatment FSTSM also recorded the lowest availability at 270 D and 300 D. Treatment FFSTSMP recorded lowest Ca release values at 90 D and 120 D. Ca availability was lowest in the control treatment S at 60, 180 and 240 D. The highest availability of Ca in all the treatments with the exception of FSTSM and control treatment S was recorded at 10 D while the lowest availability of Ca in all the treatments except FSTSM was observed at 210 D.

4.3.8 Magnesium

Release of available Mg varied between 36.43 mg kg^{-1} (FFSTSM at 90 D) and 127.07 mg kg^{-1} (FFSTSMP at 240 D) over the incubation period (Table 26). There was no significant variation among the treatments at 60, 90 and 120 D. At 10 D and 20 D, treatment F recorded highest Mg availability while OFSTSM recorded lowest Mg release. At 30 D, FST was found to have the highest availability whereas control treatment had the lowest availability. F treatment also yielded highest Mg release at 60, 120 and 150 D. OFSTSM recorded highest availability at 180 D, FFSTSMP at 210 D and FFSTSM at 270 D. Control

Table 24. Effect of FYM and COF based treatments on soil available K, kg ha^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	728.02 ^{a}	592.26 ^{c}	716.81 ^{a}	445.42 ^{d}	995.68 ^{a}	1037.12 ^{a}	1055.04 ^{a}	1232.04 ^{a}	1310.41 ^{a}	1346.24 ^{a}	543.54 ^{b}	596.06 ^{b}
FST	582.41 ^{c}	450.35 ^{d}	380.79 ^{d}	460.99 ^{d}	535.36 ^{e}	504.05 ^{e}	521.92 ^{e}	792.96 ^{d}	712.32 ^{d}	879.20 ^{e}	650.83 ^{a}	673.23 ^{a}
FSTSM	615.93 ^{b}	360.53 ^{e}	526.41 ^{c}	459.09 ^{d}	665.28 ^{c}	677.64 ^{d}	692.16 ^{d}	915.04 ^{c}	1001.28 ^{b}	1154.72 ^{b}	675.14 ^{a}	603.21 ^{b}
FFSTSM	537.62 ^{d}	444.19 ^{d}	582.38 ^{b}	574.67 ^{a}	607.04 ^{d}	733.59 ^{c}	798.56 ^{c}	890.41 ^{c}	914.06 ^{c}	1088.64 ^{c}	669.87 ^{a}	502.76 ^{c}
FFSTSMP	515.24 ^{d}	456.62 ^{d}	582.47 ^{b}	435.01 ^{d}	706.72 ^{bc}	786.24 ^{b}	871.36 ^{b}	1023.68 ^{b}	987.84 ^{b}	1139.04 ^{bc}	558.88 ^{b}	453.25 ^{d}
OFSTSM	627.21 ^{b}	747.15 ^{a}	515.19 ^{c}	494.93 ^{c}	734.69 ^{b}	777.28 ^{b}	687.86 ^{d}	919.52 ^{c}	919.52 ^{c}	983.36 ^{d}	673.68 ^{a}	534.46 ^{c}
S	202 ^{e}	662.93 ^{b}	179.17 ^{e}	547.23 ^{b}	224.02 ^{f}	207.20 ^{f}	218.42 ^{f}	402.08 ^{e}	259.84 ^{e}	430.08 ^{f}	646.46 ^{a}	510.61 ^{c}
SEm (±)	11.910	14.612	14.634	12.596	23.015	16.735	16.461	30.971	15.326	30.167	18.300	20.518
CD (0.05)	25.546	31.343	31.389	27.019	49.368	35.896	35.309	66.433	32.874	64.709	39.254	44.012

$^{a, b, c, d, e, f}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 25. Temporal variation in soil available Ca as affected by treatments, mg kg^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	395.08 ^{cd}	378.63 ^{cd}	382.08 ^{c}	389.63 ^{a}	317.11 ^{bc}	308.11	227.89 ^{a}	304.08 ^{a}	227.88 ^{a}	283.09 ^{bc}	31563 ^{a}	385.43 ^{a}
FST	412.15 ^{c}	389.62 ^{c}	384.15 ^{c}	370.25 ^{abc}	342.16 ^{b}	321.84	119.13 ^{e}	296.29 ^{ab}	119.13 ^{e}	263.21 ^{c}	285.48 ^{bc}	315.81 ^{b}
FSTSM	381.27^{d}	363.95 ^{d}	360.03 ^{d}	351.54 ^{c}	394.50 ^{a}	306.15	198.63 ^{b}	308.09 ^{a}	198.63 ^{b}	295.14 ^{b}	251.97 ^{d}	196.88 ^{e}
FFSTSM	528.09 ^{a}	501.75 ^{b}	429.67 ^{ab}	379.52 ^{ab}	333.19 ^{bc}	334.10	138.25 ^{de}	265 .03^{c}	138.25 ^{de}	352.23 ^{a}	303.77 ^{ab}	237.19 ^{d}
FFSTSMP	537.29 ^{a}	514.63 ^{ab}	409.15 ^{b}	364.63 ^{bc}	309.25 ^{c}	304.32	160.38 ^{cd}	284.28 ^{b}	160.38 ^{cd}	309.16 ^{b}	293.46 ^{ab}	300.88 ^{b}
OFSTSM	542.07 ^{a}	526.04 ^{a}	437.83 ^{a}	353.25 ^{c}	328.87 ^{bc}	322.16	170.50 ^{c}	290.14 ^{ab}	170.50 ^{c}	255.31 ^{c}	315.88 ^{a}	295.47 ^{b}
S	448.14 ^{b}	513.17 ^{ab}	416.89 ^{ab}	316.13 ^{d}	324.47 ^{bc}	332.27	148.94 ^{cd}	193.09 ^{d}	148.94 ^{cd}	206.19 ^{d}	264.66 ^{cd}	266.71 ^{c}
SEm (±)	10.731	11.197	9.952	9.771	12.138	11.139	10.434	8.475	10.772	12.921	11.564	10.781
CD (0.05)	23.018	24.017	21.346	20.959	26.036	NS	22.380	18.178	23.105	27.715	24.805	23.126

$^{a, b, c, d, e}$ Significant difference between treatments; NS: not significant; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 26. Temporal variation in soil available Mg content as affected by treatments, mg kg^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	73.07^{a}	70.25^{a}	63.01^{a}	52.63	39.35	50.11	72.63^{ab}	68.12^{cde}	74.11^{e}	77.08^{e}	86.22^{c}	109.82^{a}
FST	65.17^{c}	62.25^{b}	66.08^{a}	49.63	40.55	48.87	66.00^{bc}	59.32^{e}	49.12^{f}	104.02^{c}	79.97^{cd}	97.78^{b}
FSTSM	69.23^{b}	58.38^{bc}	51.19^{b}	40.75	48.39	45.57	47.38^{d}	74.11^{c}	106.22^{b}	86.15^{d}	106.53^{b}	88.36^{c}
FFSTSM	71.03^{ab}	56.50^{bcd}	53.14^{b}	47.63	36.43	43.19	77.38^{a}	70.22^{cd}	81.32^{d}	93.17^{d}	114.77^{a}	73.72^{d}
FFSTSMP	64.16^{c}	51.50^{cd}	50.54^{b}	49.01	44.61	42.23	60.02^{c}	87.17^{b}	113.00^{a}	127.07^{a}	104.76^{b}	113.41^{a}
OFSTSM	63.31^{c}	50.75^{d}	49.21^{b}	47.51	45.50	43.38	66.38^{bc}	99.21^{a}	94.19^{c}	108.11^{bc}	74.28^{de}	58.43^{e}
S	64.16^{c}	52.13^{cd}	48.21^{b}	47.02	39.91	44.13	41.88^{d}	63.12^{de}	84.27^{d}	115.21^{b}	69.32^{e}	72.44^{d}
SEm (±)	1.285	3.266	3.150	4.160	3.804	3.048	3.768	4.931	2.993	3.622	3.150	3.680
CD (0.05)	2.756	7.005	6.757	NS	NS	NS	8.083	10.576	6.419	7.770	6.757	7.894

$^{a, b, c, d, e}$ Significant difference between treatments; NS: not significant; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

treatment S gave the lowest release of Mg at 30, 150 and 270 D. At 180 and 210 D, FST registered the lowest available Mg content while F, at 240 D. Invariably the Mg release at 300 D was higher than the initial level in all the treatments. Control treatment, OFSTSM, FFSTSMP and FST recorded highest release at 240 D, FSTSM and FFSTSM at 270 D and F at the end of the incubation period. The lowest Mg availability in all treatments were registered during 60, 90 and 120 D, which did not have statistical significance.

4.3.9 Sulphur

A near identical pattern of nutrient release was observed in S with a progressive increase in availability upon incubation. Highest availability of S was noticed at 150 D invariably in all the seven treatments with the highest value of 31.6 mg kg^{-1} recorded by FFSTSMP (Table 27). Available S was highest for OFSTSM at 10, 90, 180 and 270 D. FSTSM registered highest availability at 20 D, treatment F at 60, 120 and 240 D. S release did not show significant treatment difference at 30 D. The lowest release of S in the various treatments ranged from 2.3 mg kg^{-1} to 6.9 mg kg^{-1} with the lowest availability recorded at 240 D in FST. The same treatment recorded lowest values at 150, 210 and 270 D. Treatment F recorded lowest availability at 10, 20 and at 300 D. At 90 D and 180 D, lowest values were registered for FFSTSM. Lowest release of S was observed for OFSTSM at 30, 60 and 120 D.

4.3.10 Iron

The kinetics of available Fe displayed significant variation during the 300 D study period with higher release towards the fag end of incubation than the initial values at 10 D for all treatments (Table 28). Treatment FFSTSMP recorded highest availability at 10, 180 and 300 D, with the highest Fe release of 788.94 mg kg^{-1} being recorded at 300 D. Highest available Fe content at various stages of incubation varied from 288.67 mg kg^{-1} to 788.94 mg kg^{-1}. Among the various treatments the highest Fe availability ranged from 496.41 mg kg^{-1} to 788.94 mg kg^{-1}. Treatment FFSTSM recorded the highest availability at 20, 30, 60, 120 and

240 D. Treatment OFSTSM recorded highest availability at 90 D, F at 150 D, FSTSM at 210 D and FST at 270 D. Control treatment registered the lowest Fe availability of 178 mg kg^{-1} at 10 D and the lowest availability at 300 D also. OFSTSM recorded lowest values at 20, 30, 150 and 270 D. FFSTSMP registered lowest values at 120 D and 210 D. Among the other periods of sampling, the lowest availability of Fe was recorded by FFSTSM at 90 D, FSTSM at 240 D and FST at 60 D and 180 D. At none of the periods, the F treatment was seen to record lowest Fe availability. Among the seven treatments, lowest Fe availability ranged from 178 mg kg^{-1} for control treatment to 246 mg kg^{-1} for treatment F.

4.3.11 Manganese

The dynamics of the release pattern of Mn revealed that the highest availability of this micronutrient element (14.19 - 21.17 mg kg^{-1}) occurred at 20 D invariably for all the treatments as laid out in Table 29. FST recorded the highest availability of 21.17 mg kg^{-1} besides attaining the top status at 240 D and 270 D. Treatment F scored the highest availability at 10, 30 and 210 D. Treatment FFSTSMP surpassed all other treatments in terms of Mn availability at 60 D and 90 D. Available Mn status of FSTSM was highest at 180 D while the control treatment was the dominant treatment with regard to Mn availability at 120, 150 and 300 D. The lowest Mn availability of the seven treatments varied from 1.86 mg kg^{-1} to 5.04 mg kg^{-1} over the incubation study period, the lowest value being recorded by FFSTSMP at 120 D. The same treatment registered lowest Mn release at 180, 210, 240 and 300 D. Release of available Mn was the lowest in FST at 60 D. At 150 D, available Mn was lowest in the treatment FSTSM as compared with the other treatments. The control treatment was observed to have the lowest availability of Mn at 20, 30 and 90 D. The Mn availability status of the treatment FFSTSM attained neither the highest level nor the lowest level at any stage of incubation. A consideration of the release pattern of Mn among the seven treatments revealed that the lowest availability occurred at 90 D for FST, FSTSM, OFSTSM and S, and at 120 D for F, FFSTSM and FFSTSMP.

4.3.12 Zinc

It was observed that the release pattern of the micronutrient Zn followed a similar pattern as that of Mn on incubation. The highest availability of Zn over the study period was 9.42 mg kg^{-1}at 20 D in FST treatment and the lowest availability was 1.38 mg kg^{-1} at 270 D in FSTSM treatment (Table 30). The highest availability of Zn at different periods of incubation varied from 3.45 mg kg^{-1} at 90 D for control treatment S to 9.42 mg kg^{-1} at 20 D in FST treatment. At 10 D, the treatment FST recorded highest availability of Zn whereas FFSTSM had the lowest availability. But FFSTSM registered highest availability at 30, 210 and 270 D. Treatment F was superior to all other treatments in terms of Zn availability at 60, 120, 150, 240 and 300 D. At 90 D when there occurred a decline in Zn availability in all fertilizer added treatments, control treatment S exhibited highest availability of Zn. At 180 D, availability of Zn was the highest in OFSTSM which was the lower limit of highest Zn availability when the seven individual treatments are considered.

The lowest level of available Zn at different stages of incubation ranged from 1.38 mg kg^{-1} at 270 D in FSTSM treatment to 5.61 mg kg^{-1} at 20 D in the control treatment. The control treatment also registered lowest levels of Zn availability at 30, 120 and 150 D. Lowest Zn release at 60, 180, 240 and 300 D was observed in the treatment FFSTSMP. At 90 D the treatment FST displayed the lowest Zn availability whereas FSTSM registered lowest available Zn status at 210 D.

4.3.13 Copper

Statistical analysis revealed significant difference in the available Cu in the various treatments at different periods of incubation. Among treatments, the highest availability of Cu at different stages of incubation varied between 4.08 mg kg^{-1} and 6.69 mg kg^{-1}, the former being recorded at 20 D in OFSTSM and the latter at 10 D in the F treatment (Table 31). At 20 D, FST recorded highest availability. FFSTSM yielded highest Cu release at 30, 60, 90 and 270 D. Cu release was highest in the control treatment at 120 D and 210 D. FFSTSMP

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Table 27. Temporal variation in soil available S content as affected by treatments, mg kg^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	4.1 ^{d}	4.3 ^{e}	7.1	9.4 ^{a}	11.9 ^{a}	17.1 ^{a}	25.8 ^{b}	9.2 ^{b}	5.7 ^{b}	8.5 ^{a}	7.5 ^{b}	5.06 ^{d}
FST	6.3 ^{c}	7.0 ^{cd}	7.5	7.0 ^{c}	9.1 ^{c}	10.4 ^{bc}	12.5 ^{g}	7.2 ^{c}	4.9 ^{c}	2.3 ^{e}	5.4 ^{c}	8.94 ^{b}
FSTSM	7.9 ^{ab}	10.2 ^{a}	8	8.2 ^{b}	7.6 ^{d}	9.3 ^{d}	16.0 ^{e}	5.6 ^{de}	6.8 ^{a}	4.6 ^{c}	6.3 ^{c}	7.36 ^{c}
FFSTSM	5.9 ^{c}	6.6 ^{d}	7.8	8.6 ^{b}	5.9 ^{e}	11.1 ^{b}	14.8 ^{f}	4.6 ^{e}	5.3 ^{bc}	7.6 ^{b}	8.2 ^{b}	10.11 ^{a}
FFSTSMP	7.3 ^{b}	7.4 ^{c}	6.9	6.3 ^{c}	10.3 ^{b}	10 ^{cd}	31.6 ^{a}	6.3 ^{cd}	5.5 ^{bc}	3.6 ^{d}	6.1 ^{c}	6.53 ^{c}
OFSTSM	8.7 ^{a}	8.2 ^{b}	6.7	4.3 ^{d}	12.6 ^{a}	6.8 ^{e}	17.2 ^{d}	10.4 ^{a}	5.3 ^{bc}	7.5 ^{b}	9.4 ^{a}	9.07 ^{b}
S	7.2 ^{b}	8.9 ^{b}	7.3	6.6 ^{c}	8.2 ^{cd}	10.8 ^{bc}	23.0 ^{c}	5.3 ^{de}	6.9 ^{a}	4.7 ^{c}	5.8 ^{c}	10.74 ^{a}
SEm (±)	0.400	0.356	0.404	0.355	0.446	0.469	0.536	0.520	0.355	0.330	0.477	0.421
CD (0.05)	0.858	0.764	NS	0.762	0.956	1.007	1.150	1.115	0.761	0.707	1.023	0.903

$^{a, b, c, d, e}$ Significant difference between treatments; NS: not significant; D: days;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB$_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 28. Temporal variation in soil available Fe content as affected by treatments, mg kg^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	265.32 ^{d}	245.87 ^{c}	347.17 ^{b}	414.75 ^{a}	318.54 ^{cd}	277.15 ^{d}	463.60 ^{a}	258.87 ^{e}	338.38 ^{c}	396.51 ^{abc}	543.12 ^{c}	507.77 ^{c}
FST	306.31 ^{c}	265.62 ^{b}	294.28 ^{d}	328.03 ^{d}	330.11 ^{c}	338.13 ^{b}	390.48 ^{b}	236.41 ^{f}	387.00 ^{b}	407.20 ^{ab}	668.91 ^{a}	642.19 ^{b}
FSTSM	188.65 ^{f}	276.54 ^{ab}	327.25 ^{c}	378.04 ^{bc}	405.87 ^{b}	288.58 ^{cd}	361.25 ^{c}	321.39 ^{c}	421.48 ^{a}	377.92 ^{c}	582.91 ^{b}	385.47 ^{e}
FFSTSM	211.42 ^{e}	288.67 ^{a}	369.16^{a}	427 .05^{a}	305.53 ^{d}	364.15 ^{a}	385.81 ^{b}	287.20 ^{d}	327.36 ^{c}	411.59 ^{a}	496.41 ^{d}	414.17 ^{d}
FFSTSMP	421.42 ^{a}	208.54 ^{d}	316.14 ^{c}	392.02 ^{b}	306.24 ^{d}	255.59 ^{e}	246.75 ^{d}	463.51 ^{a}	286.51 ^{d}	379.41 ^{c}	571.32 ^{b}	788.94 ^{a}
OFSTSM	354.32 ^{b}	198.32 ^{d}	258 .06^{e}	364.29 ^{c}	452.43 ^{a}	300.86 ^{c}	195.25 ^{e}	376.18 ^{b}	287.52 ^{d}	388.40 ^{bc}	487.15 ^{d}	648.64 ^{b}
S	178.39 ^{f}	207.32 ^{d}	283 .16^{d}	332.94 ^{d}	443.02 ^{a}	299.13 ^{c}	260.74 ^{d}	369.10 ^{b}	338.10 ^{c}	408.31 ^{a}	501.09 ^{d}	346.77 ^{f}
SEm (±)	8.024	8.143	8.610	6.997	8.563	9.195	8.563	9.071	8.002	8.871	8.867	9.199
CD (0.05)	17.212	17.467	18.468	15.008	18.367	19.723	18.367	19.458	17.165	19.029	19.020	19.731

$^{a, b, c, d, e, f}$ Significant difference between treatments; D: days;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB$_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 29. Effect of treatments on temporal variation of soil available Mn, mg kg^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	16.24 ^{a}	18.12 ^{c}	14.71 ^{a}	6.52 ^{b}	4.38 ^{ab}	2.81 ^{c}	8.4 ^{b}	10.12 ^{a}	7.7 ^{a}	10.33 ^{ab}	8.63 ^{ab}	8.99 ^{c}
FST	14.10 ^{b}	21.17 ^{a}	12.49 ^{b}	3.05 ^{d}	2.71 ^{cd}	4.42 ^{b}	4.3 ^{d}	8.96 ^{b}	3.62 ^{d}	11.37 ^{a}	9.19 ^{a}	10.73 ^{b}
FSTSM	6.02 ^{e}	17.12 ^{d}	8.41 ^{d}	4.63 ^{c}	3.39 ^{c}	3.99 ^{b}	4.1 ^{d}	10.44 ^{a}	6.05 ^{bc}	11.1 ^{a}	8.34 ^{ab}	9.65 ^{bc}
FFSTSM	11.13 ^{c}	18.21 ^{c}	9.60 ^{c}	5.04 ^{c}	4.19 ^{b}	2.95 ^{c}	5.3 ^{c}	8.29 ^{b}	5.42 ^{c}	10.9 ^{a}	7.77 ^{b}	12.46 ^{a}
FFSTSMP	5.76 ^{ef}	20.05 ^{b}	7.88 ^{de}	7.64 ^{a}	5.04 ^{a}	1.86 ^{d}	7.9 ^{b}	5.42 ^{c}	2.91 ^{d}	5.9 ^{d}	6.35 ^{c}	8.52 ^{c}
OFSTSM	4.97 ^{f}	15.20 ^{e}	8.71 ^{d}	4.98 ^{c}	2.84 ^{cd}	3.32 ^{c}	12.6 ^{a}	8.94 ^{b}	6.69 ^{b}	9.73 ^{b}	5.82 ^{c}	9.58 ^{bc}
S	8.12 ^{d}	14.19 ^{f}	7.20 ^{e}	4.93 ^{c}	2.59 ^{d}	5.23 ^{a}	12.9 ^{a}	5.68 ^{c}	3.65 ^{d}	7.89 ^{c}	8.41 ^{ab}	13.13 ^{a}
SEm (±)	0.434	0.419	0.375	0.459	0.349	0.279	0.336	0.328	0.410	0.530	0.446	0.614
CD (0.05)	0.931	0.898	0.805	0.984	0.749	0.598	0.721	0.704	0.880	1.136	0.957	1.316

$^{a, b, c, d, e, f}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB) $_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 30. Effect of treatments on temporal variation of soil available Zn, mg kg^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	4.49 ^{d}	7.94 ^{c}	8.13 ^{ab}	4.11 ^{a}	3.36 ^{a}	6.55 ^{a}	6.31 ^{a}	4.67 ^{b}	2.93 ^{c}	5.04 ^{a}	1.47 ^{f}	5.76 ^{a}
FST	5.98 ^{a}	9.42 ^{a}	6.47 ^{d}	2.80 ^{de}	1.84 ^{d}	4.14 ^{b}	3.71 ^{d}	4.64 ^{b}	3.4 ^{b}	4.82 ^{b}	3.34 ^{b}	4.04 ^{b}
FSTSM	3.73 ^{f}	8.67 ^{b}	7.48 ^{c}	3.91 ^{b}	2.57 ^{c}	2.66 ^{e}	4.52 ^{c}	4.63 ^{b}	2.74 ^{c}	4.75 ^{bc}	1.38 ^{f}	3.31 ^{c}
FFSTSM	2.52 ^{g}	7.57 ^{d}	8.28 ^{a}	3.37 ^{c}	2.82 ^{b}	3.13 ^{cd}	3.81 ^{d}	4.18 ^{c}	3.92 ^{a}	4.66 ^{c}	7.43 ^{a}	2.99 ^{d}
FFSTSMP	3.98 ^{e}	7.03 ^{e}	7.61 ^{c}	2.77 ^{e}	2.74 ^{bc}	3.06 ^{d}	5.91 ^{b}	2.98 ^{d}	3.56 ^{b}	3.45 ^{f}	1.96 ^{e}	1.68 ^{e}
OFSTSM	5.49 ^{b}	7.43 ^{d}	7.94 ^{b}	2.99 ^{d}	2.59 ^{c}	3.29 ^{c}	3.80 ^{d}	5.61 ^{a}	3.39 ^{b}	4.22 ^{d}	2.51 ^{d}	3.26 ^{c}
S	5.16 ^{c}	5.61 ^{f}	5.49 ^{e}	4.05 ^{ab}	3.45 ^{a}	2.65 ^{e}	2.95 ^{e}	4.80 ^{b}	2.93 ^{c}	3.84 ^{e}	2.69 ^{c}	2.93 ^{d}
SEm (±)	0.075	0.092	0.095	0.089	0.080	0.076	0.089	0.080	0.099	0.069	0.061	0.101
CD (0.05)	0.160	0.197	0.204	0.190	0.172	0.164	0.190	0.172	0.213	0.149	0.130	0.216

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB) $_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 31. Effect of treatments on temporal variation of soil available Cu, mg kg^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	6.69^{a}	4.87^{b}	3.72^{b}	1.17^{e}	2.47^{a}	2.04^{cd}	1.76^{d}	1.80^{b}	1.60^{cd}	3.02^{a}	1.16^{f}	2.51^{a}
FST	5.39^{c}	5.09^{a}	3.69^{b}	2.67^{b}	2.24^{b}	1.22^{e}	2.08^{c}	1.63^{c}	1.91^{a}	1.29^{f}	2.85^{b}	1.86^{c}
FSTSM	5.62^{b}	3.67^{d}	2.96^{d}	2.34^{c}	2.10^{bc}	2.17^{c}	3.14^{b}	2.40^{a}	1.47^{d}	1.69^{e}	1.06^{f}	2.27^{b}
FFSTSM	4.70^{e}	2.40^{e}	4.05^{a}	5.60^{a}	2.52^{a}	2.36^{b}	1.60^{e}	1.54^{c}	1.73^{bc}	2.06^{cd}	3.72^{a}	1.53^{d}
FFSTSMP	5.00^{d}	4.12^{c}	3.52^{c}	2.34^{c}	2.04^{cd}	2.15^{cd}	4.21^{a}	1.01^{e}	1.86^{ab}	2.23^{c}	2.05^{d}	1.29^{e}
OFSTSM	2.32^{g}	4.08^{c}	2.86^{d}	1.95^{d}	1.92^{de}	1.99^{d}	3.15^{b}	1.20^{d}	1.53^{d}	1.99^{d}	1.86^{e}	2.19^{b}
S	4.17^{f}	3.82^{d}	2.63^{e}	2.27^{c}	1.84^{e}	2.53^{a}	2.06^{c}	2.33^{a}	1.97^{a}	2.63^{b}	2.21^{c}	1.84^{c}
SEm (±)	0.068	0.081	0.067	0.063	0.077	0.075	0.057	0.071	0.061	0.083	0.071	0.074
CD (0.05)	0.145	0.173	0.143	0.135	0.166	0.161	0.123	0.153	0.131	0.179	0.153	0.158

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB$_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone

Table 32. Effect of treatments on temporal variation of soil available B, mg kg^{-1}

Treatments	10 D	20 D	30 D	60 D	90 D	120 D	150 D	180 D	210 D	240 D	270 D	300 D
F	0.10^{c}	0.10^{c}	0.10^{d}	0.10^{d}	0.65	0.90	0.92^{bc}	1.20^{abc}	1.0^{ab}	0.60^{c}	1.17^{d}	2.39^{bc}
FST	0.50^{bc}	1.10^{a}	0.90^{bc}	0.10^{d}	0.75	0.80	0.71^{c}	0.80^{c}	0.80^{b}	1.30^{ab}	1.60^{cd}	1.89^{c}
FSTSM	0.40^{bc}	0.10^{c}	0.50^{cd}	0.80^{c}	0.70	0.90	1.58^{a}	1.60^{ab}	0.80^{b}	1.40^{a}	1.01^{d}	2.66^{b}
FFSTSM	0.70^{abc}	0.20^{c}	0.80^{bc}	0.50^{cd}	0.90	1.10	1.43^{ab}	1.70^{a}	0.70^{b}	1.20^{ab}	2.39^{bc}	4.07^{a}
FFSTSMP	1.20^{a}	0.80^{ab}	1.70^{a}	2.10^{a}	0.75	1.10	1.49^{a}	1.20^{abc}	0.50^{b}	1.50^{a}	2.63^{b}	2.29^{bc}
OFSTSM	1.03^{ab}	0.70^{b}	1.20^{ab}	1.40^{b}	0.90	1.10	1.30^{ab}	0.80^{c}	1.40^{a}	0.80^{bc}	3.99^{a}	1.03^{d}
S	0.40^{bc}	0.20^{c}	0.10^{d}	0.10^{d}	0.70	0.80	1.66^{a}	1.10^{bc}	0.70^{b}	0.60^{c}	2.59^{b}	0.93^{d}
SEm (±)	0.30	0.14	0.28	0.21	0.17	0.29	0.24	0.25	0.27	0.26	0.42	0.29
CD (0.05)	0.65	0.30	0.59	0.46	NS	NS	0.51	0.53	0.57	0.55	0.90	0.62

$^{a, b, c, d}$ Significant difference between treatments; NS: not significant; D: days;

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB$_{NPK+Sec+Micro}$; FFSTSM: FYM + COF; FFSTSMP: FYM + COF + PGPR I; OFSTSM: COF only; S: soil alone recorded highest Cu availability at 150 D whereas FSTSM scored highest availability a 180 D. Treatment F was dominant over the other treatments in Cu availability at 240 D and 300 D. The lowest levels of Cu at different stages of incubation varied from 1.01 mg kg^{-1} at 180 D in FFSTSMP to 2.63 mg kg^{-1} at 30 D in control treatment. However the control treatment scored the lowest available Cu level for the particular treatment (1.84 mg kg^{-1}) at 90 D, which was the upper limit of the lowest Cu availability on consideration of the seven individual treatments. Treatment OFSTSM scored the lowest release at 10 D and FFSTSM had the least availability of Cu at 20 D and 150 D while it was for treatment F at 60 D. FST had lowest Cu availability at 120 D and 240 D. At 210 D and 270 D, FSTSM had the lowest Cu availability.

4.3.14 Boron

Release of B seemed to follow a similar pattern for all treatments. Highest B availability of 4.07 mg kg^{-1}was observed in FFSTSM treatment at 300 D (Table 32). OFSTSM recorded highest B release at 210 D and 270 D. FFSTSMP recorded highest availability at 10, 30, 60 and 240 D. Treatment effects on B availability were not statistically significant at 90 D and 120 D. Control treatment displayed highest availability at 150 D. B level of FFSTSM dominated the other treatments at 180 D. FST had highest B availability at 20 D. Lowest availability of B (0.10 mg kg^{-1}) was observed in four treatments during incubation *viz.*, F at 10, 20, 30, 60 D; FST at 60 D; FSTSM at 20 D and control treatment S at 60 D. At 150 D treatment FST contained lowest available B whereas both FST and OFSTSM represented lowest B levels at 180 D. Treatments F and S recorded lowest values at 240 D whereas FSTSM had the lowest B availability at 270 D. Control treatment recorded lowest B availability at 300 D. Available B status at the end of the study was higher than the initial status for all the treatments except for OFSTSM treatment which attained a similar status as that of 10 D (1.03 mg kg^{-1}).

4.4 EFFECT OF CUSTOMISED ORGANIC FERTILIZER ON LABILE CARBON DYNAMICS AND YIELD OF NENDRAN BANANA

The results of the field experiment conducted to study the labile carbon dynamics, soil fertility parameters, dehydrogenase activity, foliar nutrient concentration and plant growth and yield characters are presented in this section.

4.4.1 Soil Organic Carbon and Labile Carbon Dynamics as Governed by FYM and COF Based Fertilizer Treatments

The pattern of changes in the soil organic carbon content and the impact on labile carbon dynamics consequent to FYM and COF based fertilizer treatments applied as split doses were studied and indices in relation to carbon pools and lability worked out, the salient results of which are illustrated in Tables 33 to 38.

4.4.1.1 Soil Organic Carbon

A significant effect in the soil organic carbon content was evident at the split application stages in various treatments as detailed in Table 33 except at 5 M. The highest soil organic carbon content of 2.47% was observed in OFSTSM treatment at the first instance of sampling. Although in a decreasing manner, OFSTSM maintained the highest status up to 4 M as compared to the other treatments. A drop in the soil organic carbon content was noticed at 4 M invariably in all the treatments. The decreasing trend in soil organic carbon content continued in the F and OFSTSM treatments at 5 M also. The soil organic carbon content of all treatments with the exception of OFSTSM showed an increasing trend at the sixth stage of sampling where FST scored the highest carbon content of 2.01 %. However there was no significant difference in the soil organic carbon content at harvest stage.

4.4.1.2 Labile Carbon

A perceptible dominance of labile carbon content was noticed in the COF based treatments as compared to the FYM treatments at 1, 2 and 3 M with the OFSTSM treatment registering the highest content at all these stages as is evident in Table 34. An increase in labile carbon content was seen in all the treatments at 4 M which was statistically not significant. The highest content of labile carbon at the fifth and sixth months was also in OFSTSM treatment. While there was a preponderance of the COF based treatments at 6 M, the FYM based treatments dominated at the harvest stage. The highest content of 1436.95 mg kg^{-1} labile carbon at this stage was registered in FSTSM (F) treatment.

4.4.1.3 Non Labile Carbon

The different treatments displayed a more or less decreasing trend in non labile carbon content in the first half of 6 M as revealed in Table 35. The OFSTSM treatment recorded the highest non labile carbon content from 1-4 M, with a highest of 2.327 % among these four stages. The FST treatment registered the lowest non labile carbon content of 1.223 % in the entire study at 4 M. There was no significant difference in the non labile carbon content at 5 M and H.

4.4.1.4 Lability of Soil Carbon

The highest lability of soil carbon in the study, 0.116 was recorded in the FST and FSTSM (F) treatment at 4 M (Table 36). It was observed that the highest lability of soil carbon was for FST treatment at the 1, 2, 3 and 4 M. The 6 M evidenced highest soil carbon lability for the OFSTSM treatment. The FST treatment recorded the highest lability at 3 M.

Table 33. Organic carbon dynamics as affected by FYM and COF based treatments, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	1.93 ^{bc}	1.86 ^{bc}	1.87 ^{b}	1.85 ^{ab}	1.57	1.64 ^{b}	1.85
FST	1.51 ^{d}	1.45 ^{e}	1.41^{d}	1.37 ^{d}	1.62	2.01 ^{a}	1.76
FSTSM	1.59 ^{d}	1.54 ^{de}	1.57 ^{cd}	1.56 ^{cd}	1.58	1.62 ^{b}	1.76
FSTSM(F)	1.58 ^{d}	1.60^{de}	1.57 ^{cd}	1.48 ^{cd}	1.56	1.65 ^{b}	1.80
FFSTSM	1.87 ^{bc}	1.73 ^{cd}	1.61^{cd}	1.50 ^{cd}	1.53	1.64^{b}	1.71
FFSTSM(F)	1.74 ^{cd}	1.63 ^{cde}	1.59 ^{cd}	1.52 ^{cd}	1.69	1.83 ^{ab}	1.76
FFSTSMP	2.08 ^{b}	2.04 ^{b}	1.81 ^{bc}	1.66 ^{bc}	1.73	1.85 ^{ab}	1.89
OFSTSM	2.47 ^{a}	2.32 ^{a}	2.17 ^{a}	1.95 ^{a}	1.84	1.66 ^{b}	1.95
SEm(±)	0.116	0.115	0.112	0.105	0.056	0.120	0.077
CD (0.05)	0.248	0.246	0.240	0.225	NS	0.258	NS

$^{a, b, c, d}$ Significant difference between treatments; NS: not significant; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 34. Labile carbon dynamics as affected by FYM and COF based treatments, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	1431.08^{c}	1431.44^{bcd}	1433.46^{c}	1434.17	1434.40^{ab}	1433.12^{c}	1435.12^{bc}
FST	1430.95^{c}	1431.04^{cd}	1433.83^{bc}	1435.21	1434.77^{ab}	1433.88^{bc}	1434.73^{b}
FSTSM	1430.92^{c}	1430.75^{cd}	1434.63^{ab}	1434.78	1432.63^{c}	1432.87^{c}	1433.96^{bc}
FSTSM(F)	1431.74^{bc}	1432.50^{ab}	1434.17^{bc}	1434.40	1434.43^{ab}	1434.03^{bc}	1436.95^{a}
FFSTSM	1431.39^{bc}	1431.76^{bc}	1434.08^{bc}	1434.11	1433.59^{bc}	1433.28^{bc}	1432.90^{c}
FFSTSM(F)	1432.67^{ab}	1433.14^{a}	1433.74^{bc}	1435.41	1434.63^{ab}	1434.40^{b}	1433.58^{bc}
FFSTSMP	1430.98^{c}	1430.29^{d}	1433.91^{bc}	1434.78	1434.46^{ab}	1434.37^{b}	1433.34^{c}
OFSTSM	1433.58^{a}	1433.64^{a}	1435.17^{a}	1435.06	1435.83^{a}	1435.67^{a}	1433.44^{c}
SEm(±)	0.708	0.566	0.449	0.808	0.746	0.577	0.591
CD (0.05)	1.518	1.214	0.964	NS	1.601	1.237	1.267

$^{a, b, c, d}$ Significant difference between treatments; NS: not significant M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 35. Non labile carbon as affected by FYM and COF based treatments, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	1.787 ^{bc}	1.713 ^{bc}	1.727 ^{b}	1.703 ^{ab}	1.427	1.495 ^{b}	1.703
FST	1.367 ^{d}	1.306 ^{e}	1.267 ^{d}	1.223 ^{d}	1.476	1.863 ^{a}	1.616
FSTSM	1.447 ^{d}	1.393 ^{de}	1.427 ^{cd}	1.416 ^{cd}	1.437	1.473 ^{b}	1.612
FSTSM(F)	1.437 ^{d}	1.457 ^{de}	1.427 ^{cd}	1.336 ^{cd}	1.417	1.507 ^{b}	1.656
FFSTSM	1.727 ^{bc}	1.586 ^{cd}	1.467 ^{cd}	1.357 ^{cd}	1.387	1.497 ^{b}	1.567
FFSTSM(F)	1.597 ^{cd}	1.491 ^{cde}	1.447 ^{cd}	1.377 ^{cd}	1.546	1.686 ^{ab}	1.612
FFSTSMP	1.937 ^{b}	1.906 ^{b}	1.667 ^{bc}	1.514 ^{bc}	1.587	1.709 ^{ab}	1.743
OFSTSM	2.327 ^{a}	2.173 ^{a}	2.023 ^{a}	1.806 ^{a}	1.693	1.514 ^{b}	1.807
SEm(±)	0.116	0.116	0.116	0.105	0.056	0.117	0.077
CD (0.05)	0.248	0.249	0.249	0.226	NS	0.252	NS

$^{a, b, c, d, e}$ Significant difference between treatments; NS: not significant M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB) $_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 36. Soil carbon lability as affected by FYM and COF based treatments

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	0.083 ^{cd}	0.086 ^{cd}	0.083 ^{bcd}	0.084 ^{d}	0.101	0.093	0.084
FST	0.105 ^{a}	0.107 ^{a}	0.113 ^{a}	0.116 ^{ab}	0.093	0.076	0.089
FSTSM	0.099 ^{ab}	0.106 ^{ab}	0.106 ^{ab}	0.103 ^{bc}	0.096	0.093	0.083
FSTSM(F)	0.103 ^{ab}	0.106 ^{ab}	0.106 ^{ab}	0.116 ^{ab}	0.106	0.093	0.096
FFSTSM	0.083 ^{cd}	0.096 ^{bc}	0.098 ^{abc}	0.106 ^{abc}	0.104	0.099	0.093
FFSTSM(F)	0.090 ^{bc}	0.096 ^{abc}	0.099 ^{abc}	0.103 ^{abc}	0.096	0.083	0.089
FFSTSMP	0.073 ^{de}	0.073 ^{de}	0.083 ^{bcd}	0.095 ^{cd}	0.096	0.084	0.086
OFSTSM	0.066 ^{e}	0.066 ^{e}	0.071 ^{d}	0.073 ^{d}	0.086	0.096	0.073
SEm(±)	0.007	0.007	0.008	0.007	0.004	0.004	0.004
CD (0.05)	0.014	0.015	0.017	0.016	NS	NS	NS

$^{a, b, c, d, e}$ Significant difference between treatments; NS: not significant; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB) $_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 37. Soil carbon lability index as affected by treatments

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	0.82^{d}	0.85^{e}	0.85^{c}	0.86^{d}	1.03^{b}	0.98^{b}	0.86^{bc}
FST	1.07^{a}	1.12^{a}	1.16^{a}	1.20^{a}	0.99^{bc}	0.79^{d}	0.91^{b}
FSTSM	1.01^{b}	1.05^{b}	1.03^{b}	1.04^{b}	1.02^{b}	0.99^{b}	0.91^{b}
FSTSM(F)	0.74^{e}	0.76^{f}	0.79^{d}	0.81^{d}	0.82^{e}	0.83^{cd}	0.67^{d}
FFSTSM	0.85^{d}	0.92^{d}	1.00^{b}	1.16^{a}	1.14^{a}	1.11^{a}	1.03^{a}
FFSTSM(F)	0.92^{c}	0.98^{c}	1.01^{b}	1.07^{b}	0.95^{cd}	0.87^{c}	0.91^{b}
FFSTSMP	0.75^{e}	0.77^{f}	0.88^{c}	0.97^{c}	0.92^{d}	0.86^{c}	0.84^{c}
OFSTSM	0.63^{f}	0.67^{g}	0.72^{e}	0.81^{d}	0.87^{e}	0.97^{b}	0.81^{c}
SEm(±)	0.022	0.017	0.022	0.025	0.026	0.027	0.026
CD (0.05)	0.047	0.037	0.047	0.054	0.055	0.057	0.056

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 38. Soil carbon pool index as affected by FYM and COF based treatments

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	1.206^{bc}	1.160^{bc}	1.170^{c}	1.156^{b}	0.980	1.023^{b}	1.16^{c}
FST	0.943^{d}	0.903^{g}	0.883^{e}	0.853^{e}	1.013	1.253^{a}	1.10^{d}
FSTSM	0.993^{d}	0.963^{f}	0.980^{d}	0.973^{d}	0.990	1.013^{b}	1.10^{d}
FSTSM(F)	0.990^{d}	1.003^{b}	0.983^{b}	0.923^{a}	0.976	1.030^{b}	1.46^{a}
FFSTSM	1.170^{bc}	1.080^{cd}	1.006^{d}	0.940^{e}	0.956	1.023^{b}	0.98^{e}
FFSTSM(F)	1.086^{cd}	1.020^{cde}	0.993^{d}	0.953^{d}	1.056	1.146^{ab}	1.10^{d}
FFSTSMP	1.303^{b}	1.280^{b}	1.130^{c}	1.040^{c}	1.083	1.156^{ab}	1.18^{bc}
OFSTSM	1.546^{a}	1.450^{a}	1.360^{a}	1.220^{a}	1.150	1.036^{b}	1.22^{b}
SEm(±)	0.070	0.074	0.073	0.068	0.035	0.070	0.048
CD (0.05)	0.151	0.158	0.156	0.145	NS	0.150	NS

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; NS: not significant; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

4.4.1.5 Lability Index of Soil Carbon

The lability index of carbon in the soils treated with FYM and COF based fertilizers at each crop growth stage is presented in Table 37. The FYM based FST treatment registered the highest lability index at the first four crop growth stages with a highest of 1.20 at 4 M, which thereafter declined sharply to register the lowest value of 0.79 at 6 M. However it was observed that the COF based FFSTSM treatment which recorded a steady progressive increase in lability index of carbon at the first four stages registered the highest values at 5, 6 M and H.

4.4.1.6 Carbon Pool Index

Table 38 revealed a progressive drop in carbon pool index from 1 M to 4 M invariably in all the treatments. The treatment OFSTSM recorded the highest carbon pool index at the first four crop growth stages, with the highest value of 1.546 at 1 M. Treatment effects were not significant at 5 M and H. The FST treatment had the highest carbon pool index at 6 M. The FST treatment recorded the lowest carbon pool index of 0.853 at 4 M even as it maintained the lowest status all through the first four stages.

4.4.2 Effect of Customised Organic Fertilizer on Soil Fertility Parameters

4.4.2.1 pH

The soil reaction registered considerable variation at each crop growth stage between the eight treatments. The highest soil pH value before top dressing was recorded for treatment F (Table 39).

All the treatments with basal application of FYM and inorganic fertilizers registered higher pH values than the treatments which received COF as basal and customised with inorganic fertilizers. A decrease in pH was observed at each growth stage in the FYM based treatments whereas an increase was observed in the COF based treatments.

Soil analysis at 3 M revealed the highest pH for FFSTSM (F) treatment and the lowest for F treatment. At 5 M, highest pH value was noticed in OFSTSM and the lowest in F. At harvest stage the FYM with recommended NPK treatment, the COF based basal treatment and the customised split dose treatment with PGPR registered higher pH values than all the other treatments. The soil reaction was rendered more acidic than the initial level invariably in all the treatments.

4.4.2.2 Electrical Conductivity

The determination of EC of the soil samples revealed variation among the different treatments as is detailed in Table 40. The highest EC value of the entire field experiment was 0.317 dS m^{-1} which was recorded in FSTSM treatment at 4 M. It was observed that the highest EC values in all the treatments was recorded at 4 M with the exception of FFSTSM (F). Treatment FFSTSM (F) registered highest value at 2 M while FST, FSTSM and FSTSM (F) registered an identical highest EC value (0.193 dS m^{-1}) at 3 M.

The lowest soil EC value recorded during the entire field experiment was 0.049 dS m^{-1} in FSTSM at 1 M. The same treatment continued to exhibit lowest value at 2 M also. OFSTSM recorded the lowest EC at 3 M whereas FFSTSM (F) registered the lowest EC at 4 and 5 M.

4.4.2.3 Water Holding Capacity

As far as the WHC of the soils of different treatments at various crop growth stages are concerned, two glaringly distinct patterns have been revealed in the results obtained (Table 41). The highest WHC at 1 M was 31.93 % by OFSTSM and the lowest (20.37 %) for FFSTSM. WHC followed the order OFSTSM > FFSTSMP > FST > FFSTSM (F) > FSTSM > F > FSTSM (F) > FFSTSM at 1 M. OFSTSM registered the highest WHC at 4, 6 M and H attaining the highest WHC of the field trial (38.85 %) at H. It was the COF based FFSTSMP treatment that recorded highest water holding capacity at the 2, 3 and 5 M stages of banana crop growth. FSTSM recorded the lowest WHC of the trial (20.15 %) at the third stage apart from being the minimum scorer at the fourth stage of sampling. WHC was the minimum in FST at 5 and 6 M.

Table 39. Effect of treatments on soil pH at different growth stages of banana

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	6.52 ^{a}	5.42 ^{bc}	5.17 ^{e}	5.26 ^{cd}	5.18 ^{e}	5 ^{ef}	4.95 ^{a}
FST	6.15 ^{b}	5.92 ^{a}	5.79 ^{abc}	5.76 ^{a}	5.72 ^{bcd}	5.69 ^{a}	4.7 ^{abc}
FSTSM	5.6 ^{d}	5.58 ^{b}	5.32 ^{de}	5.27 ^{cd}	5.21 ^{e}	5.17 ^{de}	4.4 ^{d}
FSTSM(F)	5.88 ^{c}	5.58 ^{b}	5.54 ^{cd}	5.02 ^{d}	5.43 ^{de}	5.54 ^{ab}	4.82 ^{ab}
FFSTSM	5.31 ^{e}	5.22 ^{c}	5.88 ^{ab}	5.92 ^{a}	5.99 ^{ab}	5.04 ^{de}	4.6 ^{bcd}
FFSTSM (F)	5.52 ^{d}	5.47 ^{bc}	6.04 ^{a}	5.41 ^{bc}	5.57 ^{cd}	4.85 ^{f}	4.51 ^{cd}
FFSTSMP	5.47 ^{de}	5.28 ^{bc}	5.58 ^{cd}	5.69 ^{ab}	5.82 ^{bc}	5.2 ^{cd}	4.94 ^{a}
OFSTSM	5.48 ^{de}	5.54 ^{bc}	5.7 ^{bc}	5.82 ^{a}	6.15 ^{a}	5.38 ^{bc}	4.91 ^{a}
SEm(±)	0.097	0.154	0.136	0.143	0.147	0.086	0.136
CD (0.05)	0.207	0.331	0.292	0.307	0.316	0.185	0.291

$^{a, b, c, d, e, f}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 40. Effect of treatments on soil EC, dS m^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	0.09 ^{a}	0.100 ^{b}	0.154 ^{abc}	0.206 ^{c}	0.184 ^{bc}	0.169 ^{a}	0.101 ^{abc}
FST	0.107 ^{a}	0.128 ^{ab}	0.193 ^{a}	0.274 ^{ab}	0.238 ^{a}	0.102 ^{bc}	0.073 ^{c}
FSTSM	0.049 ^{b}	0.051 ^{c}	0.193 ^{a}	0.317 ^{a}	0.169 ^{cd}	0.08 ^{c}	0.122 ^{ab}
FSTSM(F)	0.111 ^{a}	0.132 ^{ab}	0.193 ^{a}	0.271 ^{ab}	0.204 ^{b}	0.109 ^{b}	0.135 ^{a}
FFSTSM	0.088 ^{a}	0.111 ^{b}	0.174 ^{ab}	0.221 ^{bc}	0.168 ^{cd}	0.0942 ^{bc}	0.086 ^{bc}
FFSTSM (F)	0.085 ^{a}	0.165 ^{a}	0.147 ^{bc}	0.134 ^{d}	0.117 ^{e}	0.0891 ^{bc}	0.105 ^{abc}
FFSTSMP	0.114 ^{a}	0.117 ^{b}	0.149 ^{abc}	0.184 ^{cd}	0.139 ^{de}	0.08 ^{c}	0.115 ^{ab}
OFSTSM	0.086 ^{a}	0.101 ^{b}	0.115 ^{c}	0.221 ^{bc}	0.203 ^{b}	0.185 ^{a}	0.107 ^{abc}
SEm(±)	0.015	0.018	0.021	0.028	0.015	0.012	0.018
CD (0.05)	0.033	0.038	0.045	0.059	0.032	0.026	0.038

$^{a, b, c, d, e}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 41. Effect of FYM and COF based treatments on soil WHC, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	24.01^{d}	26.53^{c}	28.07^{b}	30.42^{a}	32.97^{b}	34.86^{b}	21.21^{e}
FST	29.43^{b}	28.47^{b}	27.59^{b}	26.48^{cd}	25.60^{d}	24.72^{d}	27.52^{bc}
FSTSM	24.95^{c}	22.51^{e}	20.15^{e}	25.61^{d}	26.58^{d}	25.43^{d}	28.00^{b}
FSTSM(F)	23.83^{d}	24.64^{d}	25.69^{c}	27.83^{bc}	33.60^{ab}	34.19^{b}	25.85^{cd}
FFSTSM	20.37^{e}	22.41^{e}	23.51^{d}	28.37^{b}	34.70^{ab}	35.26^{ab}	21.81^{e}
FFSTSM (F)	29.42^{b}	27.84^{b}	25.27^{c}	27.29^{bcd}	29.80^{c}	31.46^{c}	24.76^{d}
FFSTSMP	31.47^{a}	30.26^{a}	29.60^{a}	27.82^{bc}	35.10^{a}	35.24^{ab}	24.12^{d}
OFSTSM	31.93^{a}	30.19^{a}	28.06^{b}	30.91^{a}	31.00^{c}	36.82^{a}	38.85^{a}
SEm(±)	0.405	0.348	0.704	0.855	0.851	0.763	0.916
CD (0.05)	0.869	0.746	1.511	1.835	1.826	1.636	1.964

$^{a, b, c, d, e}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 42. Soil available N as affected by treatments, kg ha^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	273.62 ^{c}	250.88 ^{c}	246.30 ^{bc}	238.34 ^{cd}	264.73 ^{c}	301.06 ^{b}	275.97 ^{e}
FST	364.95 ^{a}	439.04 ^{a}	294.50 ^{a}	225.79 ^{d}	283.61 ^{b}	351.23 ^{a}	326.14 ^{ab}
FSTSM	206.73 ^{f}	225.79 ^{d}	253.41 ^{bc}	288.51 ^{b}	281.46 ^{bc}	275.97 ^{c}	288.51 ^{de}
FSTSM(F)	219.27 ^{ef}	225.79 ^{d}	247.62 ^{bc}	275.97 ^{b}	287.39 ^{b}	301.06 ^{b}	338.69 ^{a}
FFSTSM	239.58 ^{d}	263.42 ^{c}	258.42 ^{b}	250.88 ^{c}	263.29 ^{c}	250.88 ^{d}	301.06 ^{cd}
FFSTSM (F)	337.86 ^{b}	351.23 ^{b}	310.43 ^{a}	288.51 ^{b}	280.48 ^{bc}	275.97 ^{c}	288.51 ^{de}
FFSTSMP	244.81 ^{d}	250.88 ^{c}	238.75 ^{c}	225.79 ^{d}	263.47 ^{c}	301.06 ^{b}	313.60 ^{bc}
OFSTSM	237.53 ^{de}	263.42 ^{c}	297.61 ^{a}	326.14 ^{a}	342.96 ^{a}	351.23 ^{a}	288.51 ^{de}
SEm (±)	9.106	10.510	7.910	8.558	8.591	9.972	9.988
CD (0.05)	19.533	22.543	16.967	18.357	18.427	21.389	21.425

$^{a, b, c, d, e, f}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

4.4.2.4 Available Nitrogen

Soil analysis at each crop growth stage revealed significant variation in the available N content which is outlined in the Table 42. With the exception of FST and FFSTSM (F), all the treatments registered an increase in available N content at the end of the experiment. Highest N availability at different crop growth stages varied from 310.43 kg ha^{-1} for FFSTSM (F) at 3 M to 439.04 kg ha^{-1} at 2 M in treatment FST. Treatments FST and OFSTSM recorded highest N release at 1 and 6 M respectively. However at the harvest stage, treatment FSTSM (F) recorded the highest value. The lowest N availability at different stages of crop growth varied from 206.73 kg ha^{-1} at 1 M in treatment FSTSM to 275.97 kg ha^{-1} in F at H. Both FSTSM and FST treatments exhibited identical lowest available N content (225.79 kg ha^{-1}) at 2 and 4 M.

4.4.2.5 Available Phosphorus

Analytical results indicate that the P availability (Table 43) was enhanced at 1 and 5 M and H invariably in all the treatments as compared with the initial available levels. The highest P release analysed ranged from 69.22 kg ha^{-1} for treatment F at 1 M to 117.48 kg ha^{-1} for treatment FSTSM (F) at H. The lowest availability of P varied from 36.33 kg ha^{-1} observed at 1 M for OFSTSM to 69.19 kg ha^{-1} recorded for F treatment at 6 M. Treatment OFSTSM had the lowest P release at 1 and 2 M. Treatment FFSTSMP recorded the lowest P release at harvest stage which was however higher than the initial level.

4.4.2.6 Available Potassium

Available K release (Table 44) initially followed a similar pattern as P with an increasing availability for all treatments up to 2 M. The release of available K continued to increase at 3 and 4 M in all treatments except FFSTSM, FFSTSM (F) and FFSTSMP. The OFSTSM treatment maintained a definite increase in availability throughout the experiment registering highest K release at 5 and 6 M.

Table 43. Effect of treatments on soil available P, kg ha^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	69.22^{a}	71.76^{ab}	74.89	80.97	81.78^{bc}	69.19^{e}	81.80^{d}
FST	46.78^{c}	49.53^{de}	63.22	71.43	83.56^{a}	98.81^{a}	108.52^{b}
FSTSM	58.44^{b}	60.25^{bcd}	62.19	62.49	64.33^{e}	91.51^{b}	92.09^{c}
FSTSM (F)	67.56^{a}	69.03^{abc}	68.11	67.78	82.44^{abc}	99.89^{a}	117.48^{a}
FFSTSM	56.38^{b}	58.29^{cd}	59.87	61.46	63.44^{e}	87.86^{c}	81.80^{d}
FFSTSM (F)	68.67^{a}	72.84^{a}	74.67	80.64	81.11^{c}	81.97^{d}	91.43^{c}
FFSTSMP	47.00^{c}	49.53^{de}	57.78	65.62	74.89^{d}	85.45^{c}	57.49^{e}
OFSTSM	36.33^{d}	43.80^{e}	58.67	72.26	82.89^{ab}	91.92^{b}	91.92^{c}
SEm (±)	4.057	5.681	3.109	8.475	0.774	1.274	0.558
CD (0.05)	8.702	12.185	NS	NS	1.660	2.732	1.197

$^{a, b, c, d, e}$ Significant difference between treatments; NS: Not significant; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 44. Effect of treatments on soil available K, kg ha^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	407.11^{c}	439.04^{f}	523.12^{b}	589.12^{a}	462.08^{bc}	323.56^{e}	416.64^{b}
FST	314.08^{e}	356.16^{g}	394.12^{d}	420.03^{c}	438.12^{c}	461.44^{b}	340.48^{c}
FSTSM	421.08^{c}	478.24^{e}	518.12^{b}	563.36^{a}	472.28^{b}	398.72^{c}	448.00^{a}
FSTSM(F)	498.29^{b}	549.92^{c}	559.13^{a}	573.55^{a}	458.26^{bc}	332.64^{e}	342.72^{c}
FFSTSM	506.19^{b}	592.48^{b}	579.31^{a}	570.08^{a}	$476\ .30^{b}$	368.48^{d}	238.56^{e}
FFSTSM (F)	542.25^{a}	624.96^{a}	564.14^{a}	515.20^{b}	438.28^{c}	331.52^{e}	334.88^{c}
FFSTSMP	482.12^{b}	516.32^{d}	423.21^{c}	273.28^{d}	283.11^{d}	288.96^{f}	295.68^{d}
OFSTSM	352.10^{d}	455.84^{f}	509.21^{b}	567.84^{a}	563.31^{a}	561.12^{a}	318.08^{cd}
SEm (±)	15.061	10.000	11.181	13.007	11.651	12.944	12.109
CD (0.05)	32.306	21.451	23.984	27.900	24.992	27.765	25.973

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

and thereafter declining at H. The extent of highest K availability was from 448.00 kg ha^{-1}observed in FSTSM treatment at harvest to 624.96 kg ha^{-1}in FFSTSM (F) at 2 M. The latter treatment also registered highest K availability at 1 M. The lowest availability of K varied from 238.56 kg ha^{-1} in FFSTSM at H to 394.12 kg ha^{-1} in FST at 3 M.

4.4.2.7 Available Calcium

A similarity was observed in the Ca release pattern (Table 45) of almost all the treatments in the first four crop growth stages. An appreciation of available Ca was evident till 2 M invariably in all the treatments following which the Ca status depreciated gradually till 4 M in all but for FFSTSMP and OFSTSM treatments. From 5 to 6 M also there was a higher availability of Ca for all the treatments. At H, this increasing pattern was observed only in the treatments applied with FYM alone as organic component. The highest availability of Ca at different stages spanned from 211.88 mg kg^{-1} at 4 M in F treatment to 802.38 mg kg^{-1} in OFSTSM at 6 M. Highest Ca release from 1 to 4 M was observed in the treatment F whereas OFSTSM registered highest availability at 5 M. Highest availability of Ca at the harvest stage was for FSTSM (F). The lowest availability was in the range of 119.18 mg kg^{-1} scored by FFSTSMP at 1 M to 274.63 mg kg^{-1} scored by FSTSM at harvest stage.

4.4.2.8 Available Magnesium

A steady increase in the available Mg status was observed in all the treatments except F till 4 M which thereafter declined steeply to the lowest values at 6 M (Table 46). The decline continued steadily up to harvest stage in treatments OFSTSM and FSTSM whereas in all other treatments the values recorded a slight increase. Highest release of Mg in each treatment was recorded either at 2 or 4 M and varied from 91.05 mg kg^{-1} at 6 M in OFSTSM to 124.25 mg kg^{-1} at 4 M in OFSTSM. Treatment FFSTSM maintained the lowest available Mg status consistently up to 4 M with the lowest value of 49.26 mg kg^{-1} recorded at 1 M.

Table 45. Effect of treatments on temporal variation of soil available Ca, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	234.08 ^{a}	289.98 ^{a}	243.27 ^{a}	211.88 ^{a}	220.24 ^{fg}	235.75 ^{e}	461.50 ^{b}
FST	217.12 ^{b}	264.25 ^{b}	218.39 ^{b}	188.5 ^{b}	199.61 ^{g}	224.13 ^{e}	415.00 ^{c}
FSTSM	224.25 ^{ab}	241.38 ^{c}	196.00 ^{d}	180.38 ^{bc}	228.26 ^{ef}	299.63 ^{d}	274.63 ^{g}
FSTSM(F)	208.15 ^{b}	217.38 ^{d}	182.11 ^{e}	165.88 ^{cd}	249.30 ^{de}	307.63 ^{d}	501.08 ^{a}
FFSTSM	211.31 ^{b}	227.01 ^{d}	207.25 ^{c}	158.88 ^{de}	283.12 ^{bc}	364.88 ^{c}	284.75 ^{fg}
FFSTSM (F)	152.27 ^{c}	177.75 ^{e}	159.25 ^{f}	146.13 ^{e}	306.60 ^{b}	387.75^{b}	387.75 ^{d}
FFSTSMP	119.18 ^{d}	130.38 ^{f}	154.16 ^{f}	191.02 ^{b}	274.22 ^{cd}	389.63 ^{b}	296.38 ^{f}
OFSTSM	149.12 ^{c}	172.75 ^{e}	178.23 ^{e}	186.25 ^{b}	471.13 ^{a}	802.38 ^{a}	371.88 ^{e}
SEm (±)	7.890	6.392	3.861	9.130	13.208	6.344	5.715
CD (0.05)	16.924	13.710	8.282	19.584	28.332	13.608	12.259

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 46. Effect of treatments on temporal variation of soil available Mg, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	78.12 ^{bc}	90.13 ^{abc}	72.11 ^{bc}	63.00 ^{b}	59.19 ^{e}	48.50 ^{c}	71.75 ^{bc}
FST	53.08 ^{ef}	66.38 ^{cd}	81.09 ^{abc}	106.75 ^{a}	79.22 ^{cd}	62.88 ^{bc}	68.63. ^{c}
FSTSM	69.19 ^{cd}	86.50 ^{abc}	109.11 ^{a}	119.13^{a}	104.12 ^{ab}	55.63 ^{c}	51.5 ^{d}
FSTSM(F)	61.11 ^{de}	74.63 ^{bcd}	89.22 ^{ab}	113.00 ^{a}	73.09 ^{de}	61.00 ^{bc}	74.38 ^{bc}
FFSTSM	49.26^{f}	55.25 ^{d}	51.08 ^{c}	62.13 ^{b}	60.23 ^{e}	62.25 ^{bc}	51.63 ^{d}
FFSTSM (F)	85.31 ^{ab}	108.88 ^{a}	101.31 ^{ab}	110.13 ^{a}	89.07 ^{bc}	79.38 ^{ab}	82.63 ^{ab}
FFSTSMP	81.14 ^{ab}	97.50 ^{ab}	90.14 ^{ab}	87.25 ^{ab}	62.08 ^{e}	51.03 ^{c}	94.13 ^{a}
OFSTSM	92.08 ^{a}	101.63 ^{ab}	111.08^{a}	124.25^{a}	112.31 ^{a}	91.05 ^{a}	66.75 ^{c}
SEm (±)	5.141	14.440	16.559	18.838	7.085	9.048	6.499
CD (0.05)	11.028	30.974	35.519	40.408	15.245	19.407	13.940

$^{a, b, c, d, e, f}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

4.4.2.9 Available Sulphur

The initial release pattern of S (Table 47) closely followed Mg with an inflation in available S content till 2 M except in FSTSM (F). A waning of available S was evident up to 3 M in all treatments but for FSTSM (F) and FFSTSM (F). Increment in the available S content in the three treatments FST, FSTSM (F) and FFSTSM (F) and a decrease in the other four treatments were observed up to 4 M. As observed in Mg, highest release of S in each treatment was realized either at 2 M or 4 M. Available S status at harvest stage was below the initial level in all the treatments but was statistically not significant. The extent of highest availability of S was from 16.0 mg kg^{-1} at harvest stage in FSTSM (F) to 37.9 mg kg^{-1} in OFSTSM at 2 M. The latter treatment also recorded highest S release at 1 and 3 M. FFSTSM (F) maintained highest availability from 4 to 5 M followed by FST till 6 M. The lowest S availability stretched from 6.6 mg kg^{-1} in FFSTSM at 4 M to 17.8 mg kg^{-1} at 1 M.

4.4.2.10 Available Iron

Contrary to the almost uniform nutrient release pattern observed in secondary nutrients, there was a drop in the availability of Fe in all the treatments at 2 M of the field experiment with the exception of F which incidentally registered the highest availability of 494.02 mg kg^{-1} (Table 48). With the exclusion of F, a consistent increase in the availability of Fe in the entire treatments was then observed throughout 3 and 4 M till the attainment of highest release of Fe in all but FSTSM treatment. Then followed a phase of substantial slackening of Fe availability till 6 M invariably in the entire set of treatments. A slight gain in Fe status at harvest stage was noticed in all but FST treatment.

The F treatment recorded highest Fe availability from the initial stages up to 3 M. FFSTSM (F) registered highest availability at 4 M while FFSTSMP realized highest release at 5 M and H. OFSTSM had an available Fe content of 118.09 mg kg^{-1} at 6 M which was the lower limit of the highest Fe availability recorded in the experiment. The extent of lowest availability of Fe was from

Table 47. Effect of treatments on temporal variation of soil available S, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	18.2^{c}	23.8^{bc}	22.7^{cd}	15.6^{c}	13.2^{c}	12.5^{bc}	11.3
FST	21.6^{bc}	30.9^{ab}	26.3^{de}	12.9^{bc}	14.4^{bc}	17.2^{a}	8.6
FSTSM	17.8^{c}	22.7^{bc}	19.7^{bc}	23.0^{abc}	17.5^{abc}	15.2^{ab}	12.5
FSTSM(F)	18.5^{c}	17.2^{c}	25.2^{ab}	30.1^{ab}	22.4^{ab}	9.5^{c}	16.0
FFSTSM	20.6^{c}	23.0^{bc}	16.4^{e}	6.6^{c}	10.2^{c}	15.6^{ab}	10.9
FFSTSM (F)	21.6^{bc}	30.1^{ab}	31.5^{a}	34.0^{a}	24.7^{a}	12.9^{bc}	11.7
FFSTSMP	25.7^{ab}	32.4^{ab}	25.4^{de}	14.1^{c}	13.8^{c}	14.1^{ab}	14.1
OFSTSM	28.9^{a}	37.9^{a}	31.9^{cd}	19.1^{abc}	18.2^{abc}	16.0^{ab}	12.9
SEm (±)	1.979	4.978	3.581	4.073	3.813	1.751	1.727
CD (0.05)	4.246	10.678	7.681	8.736	8.179	3.756	NS

$^{a, b, c, d, e}$ Significant difference between treatments; NS: not significant; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 48. Effect of treatments on temporal variation of soil available Fe, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	357.41^{a}	494.02^{a}	427.51^{a}	332.25^{d}	226.41^{bc}	88.58^{b}	121.50^{c}
FST	273.20^{c}	260.47^{b}	278.47^{c}	321.25^{e}	201.39^{d}	62.76^{d}	54.53^{f}
FSTSM	342.84^{b}	291.25^{b}	317.29^{b}	331.75^{d}	186.90^{e}	59.03^{d}	66.85^{e}
FSTSM(F)	261.72^{d}	224.25^{b}	302.40^{bc}	360.50^{c}	235.21^{ab}	98.68^{b}	116.91^{c}
FFSTSM	236.53^{d}	203.00^{b}	291.72^{c}	388.75^{b}	221.29^{c}	61.16^{d}	74.90^{d}
FFSTSM (F)	223.40^{f}	180.25^{b}	286.29^{c}	407.25^{a}	238.78^{a}	75.46^{c}	82.87^{d}
FFSTSMP	262.88^{d}	155.25^{b}	289.10^{c}	401.75^{a}	243.40^{a}	110.40^{a}	169.48^{a}
OFSTSM	257.59^{d}	245.25^{b}	286.39^{c}	306.25^{f}	227.61^{bc}	118.09^{a}	136.93^{b}
SEm (±)	2.869	73.653	11.266	4.165	4.875	5.308	3.731
CD (0.05)	6.153	157.985	24.165	8.934	10.456	11.386	8.002

$^{a, b, c, d, e, f}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

54.53 mg kg^{-1} noted for FST at harvest to 306.25 mg kg^{-1} for OFSTSM at 4 M. FSTSM maintained the lowest availability from 5 to 6 M.

4.4.2.11 Available Manganese

The data on available Mn is presented in Table 49. An increase in available Mn status was observed evenly in all treatments at 2 M and variably in FST, FSTSM and FFSTSMP treatments at 3 M. Treatment effects at 4, 5 and 6 M were statistically not significant. A decline in available Mn as compared with initial levels was evident at the harvest stage identically in all treatments. The expanse of highest Mn availability was from 14.60 mg kg^{-1} (at 5 M in FFSTSM) to 38.01mg kg^{-1} (at 2 M in OFSTSM). The OFSTSM treatment also realized highest availability at 1 M while FSTSM (F) and FFSTSM recorded the highest value at 3 M and at H. The lowest content of available Mn (7.13 mg kg^{-1}) was seen in FST at harvest stage. FFSTSMP steadily maintained the minimum level all through 1 and 2 M.

4.4.2.12 Available Zinc

A scrutiny of the Zn availability (Table 50) at various crop growth stages revealed two seemingly distinct patterns of nutrient release. The steady appreciation in Zn availability displayed by the treatments FSTSM, FFSTSM (F), FFSTSMP and OFSTSM at 1 M continued consistently throughout 2 and 3 M. A further progress in Zn release of these treatments was observed at 4 M also barring the treatment FFSTSMP where a slight drop was visible. Treatments FSTSM and OFSTSM exhibited an identical decrease in Zn release during 5 and 6 M. The treatments F, FST, FSTSM (F) and FFSTSM on the contrary exposed a steady depreciation in Zn availability at 1 M and continued incessantly throughout 2, 3 and 4 M. Thereafter availability of Zn in these four treatments along with FFSSM (F) and FFSTSMP increased constantly up to 6 M. At harvest stage a gain in Zn availability was found which was higher than the initial value in all but FFSTSM treatment.

Table 49. Soil available Mn as affected by the treatments, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	16.60^{ab}	19.03^{b}	18.90^{ab}	19.20	13.60	9.89	14.70^{a}
FST	13.40^{bc}	15.09^{bc}	15.30^{bc}	15.91	12.40	11.78	7.13^{c}
FSTSM	11.20^{bc}	12.32^{bc}	12.60^{c}	12.91	12.20	11.99	9.15^{bc}
FSTSM(F)	21.17^{a}	31.63^{a}	23.28^{a}	18.97	14.60	11.78	11.53^{ab}
FFSTSM	21.20^{a}	31.58^{a}	23.20^{a}	19.20	14.10	9.53	14.70^{a}
FFSTSM (F)	14.30^{bc}	17.19^{bc}	16.40^{bc}	15.42	11.20	8.04	7.44^{bc}
FFSTSMP	8.10^{c}	10.35^{c}	12.80^{c}	15.01	9.30	7.28	10.81^{abc}
OFSTSM	21.40^{a}	38.01^{a}	22.20^{c}	13.76	14.60	15.77	7.92^{bc}
SEm (±)	3.196	3.735	2.536	1.562	1.179	1.104	1.919
CD (0.05)	6.855	8.011	5.440	NS	NS	NS	4.116

$^{a, b, c}$ Significant difference between treatments; NS: not significant; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 50. Soil available Zn as affected by the treatments, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	4.86^{c}	3.72^{d}	3.26^{e}	2.71^{g}	4.29^{de}	5.91^{a}	7.04^{b}
FST	5.83^{b}	4.99^{c}	4.04^{cd}	3.43^{e}	3.87^{e}	4.61^{cd}	6.20^{e}
FSTSM	4.36^{d}	4.77^{c}	4.89^{b}	5.18^{a}	4.86^{bc}	4.29^{d}	4.51^{g}
FSTSM(F)	7.13^{a}	6.89^{a}	5.47^{a}	4.80^{b}	5.14^{ab}	5.87^{a}	7.46^{a}
FFSTSM	5.96^{b}	5.89^{b}	4.28^{c}	3.81^{d}	4.05^{de}	4.56^{cd}	3.75^{h}
FFSTSM (F)	2.97^{e}	3.11^{e}	3.86^{d}	4.27^{c}	4.72^{c}	5.01^{b}	5.89^{f}
FFSTSMP	2.41^{f}	2.89^{e}	2.96^{f}	2.89^{f}	4.16^{de}	6.10^{a}	6.81^{c}
OFSTSM	4.52^{cd}	4.87^{c}	5.02^{b}	5.29^{a}	5.17^{a}	4.72^{bc}	6.43^{d}
SEm (±)	0.186	0.198	0.132	0.069	0.139	0.157	0.054
CD (0.05)	0.399	0.424	0.284	0.148	0.299	0.336	0.115

$^{a, b, c, d, e, f, g, h}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

While the lowest Zn availability (2.41 mg kg^{-1}) over the entire crop growth period was seen in FFSTSMP treatment at 1 M, the upper limit of lowest availability (4.29 mg kg^{-1}) was observed in F at 5 M and in FSTSM at 6 M.

4.4.2.13 Available Copper

In close similarity to the initial release pattern of Mn and Zn, Cu availability too registered an increase up to 2 M before taking a downward path (Table 51). However the treatment effects at 3 M and H were statistically not significant. While there was an appreciation in Cu availability in F, FFSTSM, FFSTSM (F) and OFSTSM treatments at 4 M , treatments FST, FSTSM and FSTSM (F) exhibited depreciation of Cu availability at 4 M stage. A substantial drop in Cu availability followed in all but FSTSM (F) up to 6 M. Highest Cu availability observed was 5.0 mg kg^{-1} in FSTSM at 2 M. The same treatment recorded highest Cu availability at 1 and 4 M. FSTSM (F) registered highest availability at 5 and 6 M. At 1 M, OFSTSM had the lowest available content whereas F recorded the lowest content at the 2 M.

4.4.2.14 Available Boron

The pattern of B availability was almost identical to that of Fe (Table 52). A steady reduction in B availability was evidenced in all the treatments up to 2 M. Treatments FSTSM, FSTSM (F), FFSTSM (F), FFSTSMP and OFSTSM exhibited a steady increase in availability of B at 3 M which continued up to the 4 M barring OFSTSM, while treatments F, FST and FFSTSM displayed a constant recession in available B content throughout 3 and 4 M. The 5 and 6 M witnessed a decline in B availability in the entire treatments. However at harvest stage, an increase in the available B content was conspicuous in F, FST, FSTSM, FSTSM (F) and FFSTSM treatments whereas FFSTSM (F), FFSTSMP and OFSTSM treatments manifested a decline in B availability. The extent of highest B availability during various sampling stages was observed to be from 0.11mg kg^{-1} in FST at harvest sage to 0.23 mg kg^{-1} in FSTSM at 1 M. The stretch of lowest soil B availability was found to be from 0.05 mg kg^{-1} in the F treatment at 6 M

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Table 51. Temporal variation in soil Cu as affected by the treatments, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	1.6^{ef}	2.1^{c}	2.2	2.5^{bc}	1.5^{b}	0.8^{b}	0.7
FST	2.3^{c}	3.1^{bc}	2.6	1.9^{c}	0.8^{b}	0.3^{b}	0.3
FSTSM	3.7^{a}	5.0^{a}	4.1	3.9^{a}	1.9^{b}	0.5^{b}	0.6
FSTSM(F)	2.9^{b}	4.2^{ab}	4.0	3.8^{a}	4.1^{a}	4.8^{a}	1.1
FFSTSM	1.8^{de}	3.3^{bc}	3.4	3.5^{ab}	1.7^{b}	0.4^{b}	0.7
FFSTSM (F)	2.1^{cd}	2.7^{c}	3.3	3.8^{a}	2.1^{b}	0.7^{b}	0.9
FFSTSMP	1.6^{ef}	3.1^{bc}	3.0	3.0^{abc}	1.5^{b}	0.3^{b}	0.6
OFSTSM	1.2^{f}	2.7^{c}	2.8	3.1^{abc}	1.7^{b}	0.8^{b}	0.5
SEm (±)	0.200	0.570	0.268	0.541	0.683	0.475	0.135
CD (0.05)	0.430	1.223	NS	1.161	1.466	1.019	NS

$^{a, b, c, d, e, f}$ Significant difference between treatments; NS: not significant; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB$_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 52. Effect of treatments on temporal variation of soil available B, mg kg^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	0.19^{bc}	0.15^{abc}	0.10^{d}	0.07^{c}	0.06^{d}	0.05^{c}	0.09^{b}
FST	0.17^{d}	0.13^{abcd}	0.12^{cd}	0.09^{c}	0.08^{cd}	0.06^{bc}	0.11^{a}
FSTSM	0.23^{a}	0.16^{ab}	0.17^{a}	0.19^{a}	0.11^{abc}	0.07^{bc}	0.08^{bc}
FSTSM(F)	0.16^{e}	0.11^{d}	0.12^{cd}	0.14^{b}	0.09^{bcd}	0.05^{bc}	0.07^{bc}
FFSTSM	0.21^{ab}	0.17^{a}	0.16^{a}	0.15^{b}	0.12^{abc}	0.06^{bc}	0.07^{bc}
FFSTSM (F)	0.15^{e}	0.12^{cd}	0.13^{bc}	0.16^{b}	0.14^{a}	0.09^{abc}	0.06^{bc}
FFSTSMP	0.16^{e}	0.13^{bcd}	0.16^{a}	0.17^{ab}	0.12^{abc}	0.10^{ab}	0.05^{c}
OFSTSM	0.18^{cd}	0.14^{abcd}	0.15^{ab}	0.14^{b}	0.13^{ab}	0.13^{a}	0.08^{b}
SEm (±)	0.009	0.016	0.011	0.014	0.021	0.025	0.012
CD (0.05)	0.020	0.035	0.023	0.029	0.044	0.053	0.025

$^{a, b, c, d, e}$ Significant difference between treatments; M: months; H: harvest;
F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB$_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 53. Effect of treatments on soil dehydrogenase activity, μg TPF g^{-1} soil 24 h^{-1}

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	10.62 ^{a}	19.41^{a}	123.40 ^{a}	300.94 ^{a}	255.63 ^{b}	241.37 ^{b}	11.49 ^{e}
FST	5.48 ^{b}	8.17 ^{d}	39.49 ^{b}	73.05 ^{b}	87.73 ^{c}	113.66 ^{d}	78.67 ^{b}
FSTSM	5.74 ^{b}	8.68 ^{cd}	16.48 ^{d}	27.59 ^{c}	68.51 ^{d}	103.70 ^{de}	50.32^{c}
FSTSM(F)	11.65 ^{a}	17.88 ^{ab}	19.80 ^{cd}	18.39 ^{d}	32.97 ^{e}	55.17 ^{f}	26.56 ^{d}
FFSTSM	10.53 ^{a}	13.28 ^{bc}	20.47 ^{cd}	27.07 ^{c}	90.92 ^{c}	192.84 ^{c}	23.50 ^{d}
FFSTSM(F)	9.42 ^{a}	12.77 ^{cd}	19.92 ^{cd}	155.68 ^{cd}	284.86 ^{a}	417.10 ^{a}	278.92 ^{a}
FFSTSMP	8.91 ^{ab}	10.73 ^{cd}	14.89 ^{d}	22.48 ^{cd}	87.32 ^{c}	194.12 ^{c}	54.66 ^{c}
OFSTSM	12.46 ^{a}	19.92 ^{a}	23.65 ^{c}	27.07 ^{c}	58.69 ^{d}	97.31 ^{e}	25.29 ^{d}
SEm (±)	1.675	2.268	3.133	10.523	8.711	4.675	4.813
CD (0.05)	3.593	4.864	6.720	22.571	18.685	10.027	10.324

$^{a, b, c, d, e, f}$ Significant difference between treatments; M: months; H: harvest;
F:FYM+NPK; FST:FYM+Soil Test Based (STB)$_{NPK}$;FSTSM:FYM+STB $_{NPK+Sec+Micro}$; (F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

and FFSTSMP at harvest stage simultaneously to 0.15 mg kg^{-1} at 1 M in FFSTSM (F) treatment. While FSTSM (F) scored the lowest B content at 2 M, treatment F constantly proved to have the lowest content from 3 to 6 M.

4.4.3 Soil Dehydrogenase Activity as Affected by FYM and COF Based Fertilizer Treatments

Table 53 defines the effect of FYM and COF based treatments on the dehydrogenase activity in the soil at various crop growth stages. The OFSTSM treatment registered the highest dehydrogenase activity of 12.46 μg TPF g^{-1} soil 24 h^{-1} at 1 M which was on par with all the COF treatments and FYM based F and FSTSM (F) treatment. A predominance of the F treatment with regard to the dehydrogenase activity in soil was evident at 3 and 4 M. At 2 M it was on par with OFSTSM. The FFSTSM (F) treatment proved to be the highest at 5 and 6 M with the highest dehydrogenase activity value of 417.10 μg TPF g^{-1} soil 24 h^{-1} recorded in the study. The highest dehydrogenase activity of all treatments except F was recorded at 6 M. Even though a decline in the dehydrogenase activity followed up to harvest invariably in all the treatments, the final dehydrogenase activity status was above the initial level.

4.4.4 Foliar Nutrient Concentration of Nendran Banana as Influenced by FYM and COF Application

The data of the results obtained on analysis of the foliar nutrient concentration of all the eleven major, secondary and micronutrient essential elements are presented in Tables 54 to 64.

4.4.4.1 Foliar Nitrogen

The index leaf tissue analysis revealed significant difference in the foliar N concentration among the treatments at various growth stages of Nendran banana (Table 54). Foliar N concentration at 1 and 2 M decreased in the same manner as FFSTSM > F > FST > FSTSM (F) > FFSTSM (F) > OFSTSM > FFSTSMP > FSTSM. The treatment FFSTSM recorded progressively higher concentration of 4.37 %, 4.62 %, 4.05 % and 3.64 % at 1, 2, 3 and 4 M whereas FSTSM scored the lowest N concentration of 3.37 % , 3.64 %, 3.42 % and 3.27 % at 1, 2, 3 and 5 M. It was found that treatment F donned the highest foliar N concentration from 5 M up to H, with 5.88% at 6 M, which was the highest N concentration recorded in the experiment. FST recorded the lowest concentration at 4 M and H, the latter (1.54%) being the lowest N concentration recorded in the entire field trial. OFSTSM registered the lowest value at 6 M. The highest N concentration in all treatments except OFSTSM was recorded at 6 M. The OFSTSM registered the highest concentration at 2 M. All treatments except F had their lowest N concentration at the harvest stage. Treatment F registered the lowest concentration at 4 M.

Table 54. Temporal variation in foliar N concentration of banana as affected by the treatments, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	4.17^{b}	4.34^{b}	4.03^{a}	3.64^{ab}	4.68^{a}	5.88^{a}	3.71^{a}
FST	3.86^{c}	4.13^{c}	3.82^{b}	2.94^{c}	3.84^{d}	5.25^{b}	1.54^{g}
FSTSM	3.37^{f}	3.64^{e}	3.42^{d}	3.01^{bc}	3.27^{f}	4.27^{f}	2.66^{d}
FSTSM(F)	3.68^{d}	3.92^{d}	3.58^{c}	3.22^{bc}	3.94^{c}	4.34^{f}	2.52^{e}
FFSTSM	4.37^{a}	4.62^{a}	4.05^{a}	3.64^{a}	4.15^{b}	4.83^{c}	2.94^{c}
FFSTSM(F)	3.68^{d}	3.92^{d}	3.83^{b}	3.64^{a}	3.97^{c}	4.41^{e}	2.52^{e}
FFSTSMP	3.42^{f}	3.64^{e}	3.48^{cd}	3.36^{ab}	4.17^{b}	4.62^{d}	2.38^{f}
OFSTSM	3.54^{e}	3.85^{d}	3.43^{d}	3.22^{bc}	3.49^{e}	3.78^{g}	3.22^{b}
SEm (±)	0.042	0.041	0.058	0.185	0.043	0.049	0.051
CD (0.05)	0.091	0.089	0.125	0.397	0.093	0.106	0.110

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB)$_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 55. Effect of treatments on temporal variation of foliar P concentration of banana, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	0.29^{c}	0.25^{bc}	0.19^{b}	0.15^{ab}	0.09^{bc}	0.03^{c}	0.23^{ab}
FST	0.16^{g}	0.10^{f}	0.13^{cd}	0.15^{ab}	0.10^{bc}	0.03^{c}	0.30^{a}
FSTSM	0.17^{f}	0.13^{ef}	0.09^{d}	0.05^{d}	0.12^{b}	0.23^{a}	0.20^{bc}
FSTSM(F)	0.24^{d}	0.20^{cd}	0.15^{bc}	0.13^{bc}	0.21^{a}	0.28^{a}	0.18^{bc}
FFSTSM	0.35^{a}	0.33^{a}	0.26^{a}	0.10^{c}	0.11^{b}	0.10^{b}	0.13^{c}
FFSTSM(F)	0.31^{b}	0.28^{ab}	0.12^{cd}	0.05^{d}	0.06^{c}	0.08^{bc}	0.25^{ab}
FFSTSMP	0.22^{e}	0.18^{de}	0.19^{b}	0.18^{a}	0.20^{a}	0.25^{a}	0.25^{ab}
OFSTSM	0.16^{g}	0.13^{ef}	0.08^{d}	0.03^{d}	0.09^{bc}	0.13^{b}	0.28^{a}
SEm (±)	0.003	0.028	0.026	0.019	0.023	0.028	0.036
CD (0.05)	0.006	0.061	0.055	0.041	0.049	0.059	0.077

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB)$_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

4.4.2 Foliar Phosphorus

Highest concentration of foliar P ranged from 0.35% in FFSTSM at 1 M to 0.18 % in FFSTSMP in 4 M (Table 55). FFSTSM also scored the highest concentration at 2 and 3 M also. While FSTSM (F) dominated the foliar P concentration in 5 and 6 M, FST scored the highest at harvest stage. The lowest foliar P concentration varied from 0.03 % in F and FST at 6 M and OFSTSM at 4 M to 0.16 % registered for FST and OFSTSM at 1 M. FST and OFSTSM also contained the lowest foliar P concentration at 3 and 4 M. It was found that FFSTSM (F) contributed to lowest P concentration at 5 M and FFSTSM at H.

A definite pattern of foliar P concentration was clearly evident in the results obtained. In the first phase of gradual decline, there was a reduction in P concentration up to 4 M with the exception of F and FST. The decreasing succession of foliar P concentration at 1 and 2 M was FFSTSM > FFSTSM (F) > F > FSTSM (F) > FFSTSMP > FSTSM followed by OFSTSM = FST at 1 M and OFSTSM > FST at 2 M. The same pattern was observed in the third and fourth stages also, though there was an alteration in the order of decrement. However an increasing trend was noticed with FST and FFSTSMP treatments at the third and fourth stages.

F and FST displayed a decreasing trend at the fifth and sixth stages with both treatments attaining the identical lowest P concentration of 0.03% in the entire experiment. Treatments FSTSM (F), FFSTSMP, FSTSM, OFSTSM and FFSTSM (F) exhibited an enhancement in foliar P concentration at the fifth and sixth stages. It was detected that the P concentration status of FFSTSM treatment remained almost static (0.10 – 0.11%) at these two stages.

There was an overall increase in foliar P concentration at the harvest stage in all treatments but for FSTSM and FSTSM (F) which showed a depreciation. The FFSTSMP treatment remained static. The P concentration level followed the order FST > OFSTSM > FFSTSMP > FFSTSM (F) > F > FSTSM > FSTSM (F) > FFSTSM at the harvest stage.

Table 56. Effect of FYM and COF based treatments on foliar K concentration, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	3.58 ^{a}	3.45 ^{a}	2.84 ^{a}	2.08 ^{e}	2.11 ^{c}	2.13 ^{b}	2.72 ^{bcd}
FST	2.61 ^{e}	2.47 ^{e}	2.17 ^{e}	1.76 ^{f}	2.28 ^{b}	2.17 ^{b}	2.52 ^{cd}
FSTSM	2.92 ^{c}	2.87 ^{b}	2.28 ^{d}	1.83 ^{f}	1.89 ^{ef}	1.92 ^{c}	2.01 ^{e}
FSTSM(F)	2.89 ^{c}	2.62 ^{c}	2.43 ^{c}	2.36 ^{c}	2.04 ^{cd}	1.76 ^{d}	2.26 ^{d}
FFSTSM	2.73 ^{d}	2.55 ^{d}	1.87 ^{f}	1.39 ^{g}	1.76 ^{f}	2.03 ^{bc}	2.77 ^{bc}
FFSTSM(F)	2.39 ^{f}	2.13 ^{f}	2.18 ^{e}	2.24 ^{d}	1.94 ^{de}	1.66 ^{d}	3.16 ^{ab}
FFSTSMP	3.04 ^{b}	2.88 ^{b}	2.64 ^{b}	2.50 ^{b}	2.27 ^{b}	1.93 ^{c}	3.28 ^{a}
OFSTSM	2.71 ^{d}	2.55 ^{d}	2.69 ^{b}	2.89 ^{a}	2.68 ^{a}	2.52 ^{a}	2.52 ^{cd}
SEm (±)	0.046	0.026	0.045	0.040	0.065	0.068	0.233
CD (0.05)	0.098	0.055	0.096	0.085	0.139	0.146	0.500

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB)$_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 57. Effect of FYM and COF based treatments on foliar Ca concentration, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	4.27 ^{c}	4.50 ^{c}	4.81 ^{c}	5.06 ^{d}	5.49 ^{c}	6.06 ^{b}	4.47 ^{e}
FST	4.49 ^{b}	4.88 ^{b}	4.26 ^{e}	3.89 ^{f}	4.63^{e}	5.49 ^{c}	4.44 ^{e}
FSTSM	4.35 ^{bc}	4.76 ^{b}	5.18 ^{b}	5.46 ^{c}	5.97 ^{b}	6.59 ^{a}	4.82 ^{d}
FSTSM(F)	4.26 ^{c}	4.70 ^{bc}	4.82 ^{c}	3.00 ^{g}	4.04 ^{f}	4.98 ^{e}	5.01 ^{c}
FFSTSM	3.17 ^{d}	3.44 ^{d}	4.68 ^{cd}	5.50 ^{c}	5.18 ^{d}	4.69 ^{f}	5.44 ^{b}
FFSTSM(F)	2.64 ^{e}	3.00 e	5.74 ^{a}	8.84 ^{a}	6.27 ^{a}	5.16 ^{d}	6.06 ^{a}
FFSTSMP	4.99 ^{a}	4.92 ^{b}	4.53 ^{d}	4.03 ^{e}	3.94 ^{f}	4.01 ^{g}	3.24 ^{f}
OFSTSM	5.03 ^{a}	5.31^{a}	5.64 ^{a}	5.94 ^{b}	4.63 ^{e}	3.86 ^{h}	3.05 ^{g}
SEm (±)	0.081	0.113	0.072	0.058	0.059	0.061	0.067
CD (0.05)	0.174	0.243	0.155	0.125	0.126	0.131	0.144

$^{a, b, c, d, e, f, g, h}$ Significant difference between treatments; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB)$_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

4.4.3 Foliar Potassium

Table 56 revealed that the foliar K concentration of different treatments exhibited significant variation at various crop growth stages of Nendran banana. A recession in the foliar K concentration was conspicuous invariably in all the treatments throughout 1 and 2 M. The treatment sequence of decreasing foliar K concentration in these two stages was F > FFSTSMP > FSTSM > FSTSM (F) > FFSTSM > OFSTSM > FST > FFSTSM (F). The treatment F realized highest foliar concentration of K till 3 M, of which 3.58 % recorded at 1 M was the highest foliar K status in the whole field experiment. As compared with the second stage, foliar K gained higher levels only in OFSTSM and FFSTSM (F) at 3 M. FFSTSM was the lowest scorer at this stage.

The growth stage of 4 M was characterised by a decline in foliar K status of all treatments but for OFSTSM which registered the highest value at 4, 5 and 6 M. FFSTSM scored the lowest value at both the stages, of which 1.39% at the fourth stage was the lowest foliar K concentration recorded in the experiment. Increment in K concentration was seen only in the F and FST treatments at the fifth stage.

The treatments FFSTSMP, FSTSM (F) and FFSTSM (F) showed a sharp decline at this stage whereas the other treatments displayed an increasing trend. At the harvest stage, there was a perceptible increase in foliar K concentration for all the treatments. FFSTSMP scored the highest concentration whereas FSTSM registered the lowest concentration.

4.4.4 Foliar Calcium

Foliar Ca concentration too evinced pronounced variation within treatments among the different crop growth stages (Table 57). The foliar Ca concentration in the first two stages followed an almost similar pattern. OFSTSM was the superior treatment with highest Ca concentration. It was on par with FFSTSMP at 1 M. Foliar Ca concentration followed the order OFSTSM > FFSTSMP > FST > FSTSM > F >FSTSM (F) > FFSTSM >FFSTSM (F) in the first stage. 2 M also followed the same sequence but for the precedence of FSTSM (F) over F. Treatment FFSTSM (F) scored the lowest value for foliar Ca concentration in the entire study at the first stage. The FFSTSM (F) treatment recorded the highest Ca concentration at 3, 4 and 5 M with the highest value of 8.84 % being attained at 4 M. Treatment OFSTSM was on par with FFSTSM (F) at 3 M. While FST scored the lowest value at 3 M, FSTSM (F) and FFSTSMP were the lowest scorers at 4 and 5 M. Foliar Ca concentration of all the treatments were boosted at 6 M ranging from 3.86 % to 6.59 % with significant statistical differences between all of them. Among the eight treatments, the declination of foliar Ca concentration at 6 M was FSTSM >F >FST >FFSTSM (F)> FSTSM (F) > FFSTSM >FFSTSMP >OFSTSM. At harvest stage, the foliar concentration stretched from 3.05 % in OFSTSM to 6.06 % in FFSTSM (F). An increment in Ca concentration was sighted in FFSTSM (F), FFSTSM and FSTSM (F) treatments at the harvest stage.

4.4.5 Foliar Magnesium

Unlike the other essential nutrient elements, effect of various treatments at none of the crop growth stages was significant in the foliar Mg concentration (Table 58). However the foliar Mg concentration ranged between 0.09 % and 0.14% in the various treatments at different crop growth stages. The highest Mg concentration of 0.14 % was found in the FSTSM (F) and FFSTSM (F) treatments at 4 and 6 M. With the exception of FFSTSMP, the foliar Mg concentration at harvest stage of all other treatments was found to be similar or higher than at 1 M.

4.4.6 Foliar Sulphur

The pattern of foliar S concentration in the different treatments at various stages exhibited significant variation as is evident in Table 59. The highest concentration of 0.27 % foliar S was found in the FFSTSMP treatment at 2 M and the lowest concentration of 0.05 % foliar S in FST treatment at 1 M. FFSTSM (F) and FFSTSMP were the treatments that yielded highest foliar S concentration during different growth stages of Nendran banana. FST treatment in spite of recording lowest availability in the initial three stages, had the highest S concentration at harvest stage. A near reversal of the order of decrement in foliar S concentration was noted between the treatments at 1 M and H. While it was

FFSTSMP >OFSTSM> FSTSM (F) > FSTSM =FFSTSM =FFSTSM (F)> F >FST in the first stage, the sequence was FST > F >FFSTSM (F)>FSTSM >FFSTSM >OFSTSM >FFSTSMP >FSTSM (F) at harvest.

4.4.7 Foliar Iron

The values of foliar Fe concentration at various crop growth stages are presented in Table 60. The treatments F, FST, FSTSM, FFSTSM and OFSTSM registered the highest foliar Fe concentration at various crop growth stages. The extent of variation was found to be highest at 6 M ranging from 334.09 mg kg^{-1} in the F treatment to 2047.31 mg kg^{-1} in FFSTSM.

4.4.8 Foliar Manganese

The treatment F contributed the highest foliar concentration of Mn during the first four growth stages of Nendran banana (Table 61). FFSTSMP had the highest concentration at 5 and 6 M. However it was at the harvest stage that the highest foliar Mn concentration of 838.18 mg kg^{-1} in FSTSM treatment and the lowest Mn concentration of 56.29 mg kg^{-1} in the FFSTSMP treatment were registered over different stages of sampling. The pattern of foliar Mn concentration of the eight treatments at 1 and 2 M were almost similar and followed a decreasing order of F > FSTSM (F) > OFSTSM > FFSTSM >FFSTSM (F)> FST >FSTSM >FFSTSMP.

Table 58. Effect of treatments on foliar Mg concentration of banana, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	0.11	0.12	0.12	0.13	0.13	0.12	0.12
FST	0.10	0.11	0.12	0.13	0.11	0.10	0.13
FSTSM	0.11	0.12	0.12	0.13	0.12	0.10	0.13
FSTSM(F)	0.11	0.12	0.11	0.11	0.13	0.14	0.13
FFSTSM	0.10	0.11	0.11	0.11	0.11	0.12	0.10
FFSTSM(F)	0.11	0.12	0.13	0.14	0.12	0.11	0.12
FFSTSMP	0.11	0.12	0.12	0.13	0.13	0.13	0.10
OFSTSM	0.09	0.10	0.12	0.13	0.11	0.10	0.13
SEm (±)	0.008	0.011	0.009	0.012	0.009	0.015	0.013
CD (0.05)	NS	NS	NS	NS	NS	NS	NS

NS: not significant; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 59. Effect of FYM and COF based treatments on foliar S concentration, %

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	0.10 ^{b}	0.15 ^{b}	0.19	0.22 ^{ab}	0.18 ^{a}	0.13 ^{bc}	0.21 ^{ab}
FST	0.05 ^{c}	0.07 ^{c}	0.11	0.14 ^{cde}	0.13 ^{b}	0.11 ^{c}	0.24 ^{a}
FSTSM	0.11 ^{b}	0.14 ^{b}	0.17	0.21 ^{abc}	0.18 ^{a}	0.16 ^{ab}	0.14 ^{bcd}
FSTSM(F)	0.13 ^{b}	0.18 ^{b}	0.17	0.16 ^{bcde}	0.15 ^{ab}	0.15 ^{b}	0.11 ^{d}
FFSTSM	0.11 ^{b}	0.14 ^{b}	0.16	0.20 ^{abcd}	0.16 ^{ab}	0.11 ^{c}	0.13 ^{cd}
FFSTSM(F)	0.11 ^{b}	0.16 ^{b}	0.20	0.25 ^{a}	0.18 ^{a}	0.10 ^{c}	0.18 ^{abc}
FFSTSMP	0.19 ^{a}	0.27 ^{a}	0.19	0.13 ^{de}	0.15 ^{ab}	0.19 ^{a}	0.11 ^{d}
OFSTSM	0.14 ^{b}	0.18 ^{b}	0.15	0.11 ^{e}	0.12 ^{b}	0.13 ^{bc}	0.12 ^{cd}
SEm (±)	0.022	0.027	0.016	0.034	0.021	0.018	0.033
CD (0.05)	0.048	0.058	NS	0.072	0.044	0.039	0.070

$^{a, b, c, d, e}$ Significant difference between treatments; NS: not significant; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 60. Foliar Fe concentration at different growth stages of banana, mg kg $^{-1}$

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	1250.09 ^{a}	1287.10 ^{a}	356.18 ^{bc}	287.08 ^{cd}	302.11 ^{d}	334.09 ^{g}	485.19 ^{ab}
FST	1024.15 ^{b}	1059.35 ^{b}	635.14 ^{a}	548.12 ^{ab}	427.15 ^{c}	395.14 ^{g}	345.04 ^{d}
FSTSM	194.16 ^{e}	203.13 ^{d}	328.23 ^{bcd}	514.15 ^{b}	673.11^{a}	1043.23 ^{c}	276.21 ^{e}
FSTSM(F)	288.25 ^{d}	260.19 ^{cd}	249.14 ^{e}	237.21 ^{de}	493.19 ^{bc}	793.11 ^{d}	439.32 ^{bc}
FFSTSM	337.25 ^{c}	308.26 ^{c}	243.29 ^{e}	188.19 ^{e}	538.29 ^{b}	2047.31 ^{a}	550.19 ^{a}
FFSTSM(F)	226.29 ^{e}	241.21 ^{cd}	287.21 ^{cde}	331.24 ^{c}	683.19 ^{a}	1177.29 ^{b}	404.19 ^{cd}
FFSTSMP	184.24 ^{e}	205.30 ^{d}	279.07 ^{de}	335.33 ^{c}	486.26 ^{bc}	615.18 ^{e}	358.15 ^{d}
OFSTSM	219.28 ^{e}	248.18 ^{cd}	382.18 ^{b}	594.28 ^{a}	543.23^{b}	503.08 ^{f}	454.29 ^{bc}
SEm (±)	19.887	33.756	35.090	33.179	35.043	45.419	31.193
CD (0.05)	42.658	72.406	75.268	71.170	75.167	97.424	66.908

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 61. Effect of treatments on foliar Mn concentration of banana, mg kg $^{-1}$

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	492.11 ^{a}	488.19 ^{a}	439.08 ^{a}	401.28 ^{a}	410.32 ^{a}	404.18 ^{b}	340.19 ^{c}
FST	183.29 ^{e}	206.28 ^{d}	286.25 ^{b}	358.14 ^{ab}	285.26 ^{bc}	168.32 ^{de}	366.09 ^{c}
FSTSM	107.29 ^{f}	123.15 ^{e}	146.32 ^{e}	180.12 ^{ef}	152.32 ^{d}	104.47 ^{f}	838.18 ^{a}
FSTSM(F)	329.14 ^{b}	317.16 ^{b}	284.15 ^{b}	265.05 ^{d}	197.32 ^{d}	121.24 ^{ef}	558.13 ^{b}
FFSTSM	221.12 ^{d}	213.32 ^{d}	179.29 ^{d}	150.19 ^{f}	217 .04^{cd}	254.17 ^{c}	561.19 ^{b}
FFSTSM(F)	185.29 ^{e}	206.19 ^{d}	218 .29^{c}	225.12 ^{de}	328.25 ^{b}	405.16 ^{b}	196.23 ^{d}
FFSTSMP	83.12 ^{g}	97.26 ^{e}	182.04 ^{d}	337.21 ^{bc}	434.29 ^{a}	470.29 ^{a}	56.29 ^{e}
OFSTSM	241.15 ^{c}	264.08 ^{c}	276.12 ^{b}	285.12 ^{cd}	215.30 ^{d}	195.12 ^{cd}	377.32 ^{c}
SEm (±)	5.425	19.263	13.090	28.580	32.241	29.532	23.979
CD (0.05)	11.637	41.320	28.077	61.304	69.157	63.347	51.436

$^{a, b, c, d, e, f, g}$ Significant difference between treatments; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 62. Effect of FYM and COF based treatments on foliar Zn concentration of banana, mg kg $^{-1}$

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	21.0	35.0 ^{a}	30.5 ^{a}	21.5 ^{a}	20.0	17.0 ^{b}	15.5 ^{b}
FST	17.0	18.0 ^{b}	19.0 ^{b}	19.5 ^{ab}	18.0	15.5 ^{b}	14.5 ^{b}
FSTSM	16.0	20.5 ^{b}	21.0 ^{b}	21.0 ^{a}	19.5	17.0 ^{b}	14.5 ^{b}
FSTSM(F)	18.0	20.5 ^{b}	19.5 ^{b}	17.0 ^{bc}	16.0	13.5 ^{bc}	15.5 ^{b}
FFSTSM	13.0	15.0 ^{b}	14.5 ^{b}	14.0 ^{c}	17.0	22.5 ^{a}	20.5 ^{a}
FFSTSM(F)	12.0	14.0 ^{b}	17.5 ^{b}	19.0 ^{ab}	19.0	16.5 ^{b}	16.0 ^{b}
FFSTSMP	11.5	13.5 ^{b}	16.5 ^{b}	20.0 ^{ab}	16.5	10.0 ^{c}	21.5 ^{a}
OFSTSM	13.5	14.5 ^{b}	19.0 ^{b}	21.0 ^{a}	20.0	13.5 ^{bc}	15.5 ^{b}
SEm (±)	2.038	3.683	3.938	1.688	0.774	1.704	1.561
CD (0.05)	NS	7.901	8.448	3.620	NS	3.656	3.348

$^{a, b, c}$ Significant difference between treatments; NS: not significant; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 63. Effect of treatments on foliar Cu concentration of banana, mg kg $^{-1}$

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	10.0 ^{a}	14.5 ^{a}	9.5 ^{a}	6.0 ^{bcd}	5.5 ^{ab}	3.0 ^{bc}	1.0 ^{bc}
FST	4.0 ^{b}	5.0 ^{c}	7.0 ^{ab}	9.5 ^{ab}	7.0 ^{a}	5.0 ^{b}	2.0 ^{ab}
FSTSM	4.5 ^{b}	5.0 ^{c}	5.5 ^{bc}	6.5 ^{bc}	6.0 ^{ab}	5.0 ^{b}	0.5 ^{c}
FSTSM(F)	11.0 ^{a}	10.0 ^{b}	6.0 ^{ab}	3.5 ^{cde}	4.0 ^{bc}	3.5 ^{bc}	1.0 ^{bc}
FFSTSM	4.0 ^{b}	3.0 ^{c}	2.0 ^{c}	1.0 ^{e}	2.0 ^{c}	2.5 ^{bc}	0.5 ^{c}
FFSTSM(F)	1.0 ^{cd}	2.0 ^{c}	2.0 ^{c}	2.0 ^{de}	6.5 ^{a}	10.0 ^{a}	1.5 ^{bc}
FFSTSMP	0.5 ^{d}	2.0 ^{c}	6.0 ^{ab}	12.5 ^{a}	4.0 ^{bc}	0.5 ^{c}	1.0 ^{bc}
OFSTSM	2.0 ^{c}	3.0 ^{c}	7.5 ^{ab}	13.0 ^{a}	6.5 ^{a}	1.5 ^{bc}	3.0 ^{a}
SEm (±)	0.591	2.065	1.697	1.971	1.054	1.712	0.586
CD (0.05)	1.267	4.430	3.639	4.228	2.260	3.673	1.258

$^{a, b, c, d, e}$ Significant difference between treatments; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 64. Effect of treatments on foliar B concentration of banana, mg kg $^{-1}$

Treatments	1 M	2 M	3 M	4 M	5 M	6 M	H
F	35.26^{b}	33.70^{b}	31.25^{ab}	30.43^{a}	28.82^{a}	23.91^{bcd}	39.13^{a}
FST	23.82^{d}	22.39^{bc}	21.27^{cd}	18.91^{bc}	18.39^{c}	18.04^{d}	39.78^{a}
FSTSM	18.04^{f}	19.57^{c}	24.38^{cd}	27.83^{a}	26.41^{ab}	24.35^{abc}	34.13^{ab}
FSTSM(F)	17.43^{f}	19.78^{c}	20.25^{cd}	20.00^{bc}	23.72^{abc}	29.78^{ab}	23.91^{bc}
FFSTSM	22.17^{e}	20.43^{c}	18.91^{d}	17.39^{bc}	21.47^{bc}	23.04^{cd}	24.35^{bc}
FFSTSM(F)	25.41^{c}	23.48^{bc}	21.36^{cd}	16.74^{c}	20.81^{bc}	21.52^{cd}	19.13^{c}
FFSTSMP	22.61^{e}	24.78^{bc}	25.62^{bc}	23.70^{ab}	26.46^{ab}	26.30^{abc}	22.17^{bc}
OFSTSM	58.64^{a}	49.13^{a}	33.25^{a}	15.87^{c}	29.82^{a}	30.00^{a}	17.83^{c}
SEm (±)	0.540	5.297	2.872	3.224	3.164	2.838	6.351
CD (0.05)	1.159	11.362	6.160	6.915	6.787	6.087	13.623

$^{a, b, c, d, e, f}$ Significant difference between treatments; M: months; H: harvest;
F:FYM + NPK;FST:FYM + Soil Test Based (STB)$_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

4.4.9 *Foliar Zinc*

There was significant statistical difference between treatments in the foliar concentration of Zn at all stages of crop growth except for 1 and 2 M as presented in Table 62. The highest foliar Zn concentration of 35 mg kg^{-1} was found in the treatment F at the second stage of sampling and the lowest concentration in FFSTSMP at 6 M. The F treatment maintained the highest concentration from 1 to 5 M. The FFSTSMP treatment which registered lowest Zn concentrations initially recorded highest availability at the harvest stage. It was revealed that while the FYM based treatments had higher concentrations initially, the trend got reversed gradually and the COF based treatments were superior at the harvest stage, which followed the order FFSTSMP > FFSTSM > FFSTSM (F) > OFSTSM = F = FSTSM (F) > FSTSM = FST.

4.4.10 *Foliar Copper*

It was observed that the FYM based F and FST treatments registered highest levels of foliar Cu concentrations up to 3 M as seen in Table 63. At 2 M, treatment F registered the highest Cu concentration of 14.5 mg kg^{-1}. It was the COF based treatments that had the highest foliar Cu concentrations at 4, 6 M and

H. At 4 M, OFSTSM and FFSTSMP recorded foliar Cu concentration of 13.0 mg kg^{-1} and 12.5 mg kg^{-1}.

4.4.11 Foliar Boron

The COF based treatments were found to have the highest foliar B concentration at the first half of crop growth while the FYM based treatments registered the highest concentration at the second half of crop growth as is evident in Table 64. The OFSTSM treatment had the highest foliar B concentration at 1, 2 and 3 M with the highest status of 58.64 mg kg^{-1} being recorded at 1 M. FSTSM (F), the treatment which received foliar B application had the highest concentration at 5 and 6 M. Treatment FST recorded the highest concentration at harvest stage.

4.4.5 Growth Characters of Banana as Influenced by FYM and COF Based Treatments

The results of the bimonthly observations on the plant biometric characters plant height, girth of pseudostem and number of leaves per plant are presented in Tables 65 - 67.

4.4.5.1 Plant Height

Observations on the mean plant height of banana at 2, 4, 6 and 8 M are furnished in Table 65. The COF based treatments recorded the highest plant height at all stages. The OFSTSM treatment recorded the highest plant height of 333.83 cm at 8 M. The same treatment yielded highest plant height at 6 M also. At 4 M, FFSTSMP scored the highest plant height of 211 cm.

4.4.5.2 Girth of pseudostem

It is evident from Table 66 that the girth of pseudostem at the base is significantly influenced by the treatments at all stages of sampling. It was observed that all but F treatment attained highest pseudostem girths at the 6 M stage. The OFSTSM treatment recorded the highest pseudostem girth of 60 cm at 6 M which was on par with the FYM based treatments F, FST and FSTSM. At 2, 4 and 8 M stages also, OFSTSM registered the highest girths of 31.33 cm, 55.33 cm and 59.33 cm respectively.

4.4.5.3 Number of Leaves per Plant

Data on the total number of leaves per plant revealed the superiority of OFSTSM treatment at all stages of observation (Table 67). The highest number of leaves of 14.33 in the entire experiment was registered at 4 M by OFSTSM treatment which was on par with FST treatment. Treatments in the order of decreasing number of leaves at 4 M was OFSTSM > FST > F > FSTSM (F) > FFSTSM > FFSTSMP > FFSTSM (F) > FSTSM. At 2 MAP, OFSTSM recorded highest number of leaves (9.56) which was on par with FFSTSMP, FST and FSTSM treatments. At 6 and 8 M too, OFSTSM recorded the highest number of leaves, 12.67 and 10.83 respectively. The highest number of leaves in all the treatments were recorded at the 4 M stage.

4.4.5.4 Dry Matter Production in Banana as Influenced by FYM and COF Based Treatments

The various treatments exhibited significant statistical variation in the total dry matter produced as well as in its constituent plant parts of leaf, rhizome, pseudostem and fruit as is evident in Table 68. The highest dry matter production of 12868.21 kg ha^{-1} was recorded in the OFSTSM treatment which was on par with the FSTSM treatment. Total dry matter production in the eight treatments followed the order OFSTSM >FSTSM >FST > F > FFSTSM (F) > FFSTSMP > FFSTSM > FSTSM (F). Highest leaf production of 2995.83 kg ha^{-1} was by the OFSTSM treatment. The pseudostem weight of FYM based treatments were high compared to COF treatments. The F treatment produced the highest quantity of pseudostem, 4301.54 kg ha^{-1} which was on par with FST, FSTSM and also with the OFSTM treatment. In rhizome production OFSTSM was found to produce 2840.98 kg ha^{-1} which was on par with FSTSM treatments. Highest contribution of fruit weight to the total dry matter production, 3519.80 kg ha^{-1}, was observed in OFSTSM treatment.

Table 65. Effect of treatments on plant height of Nendran banana, cm

Treatments	2 M	4 M	6 M	8 M
F	73.08	194.33 ^{abc}	237.67 ^{ab}	246.67 ^{d}
FST	80.10	171.33 ^{bcd}	226.00 ^{bc}	309.33 ^{b}
FSTSM	104.58	158.33 ^{cd}	230.00 ^{bc}	274.00 ^{c}
FSTSM(F)	99.83	199.67 ^{ab}	181.33 ^{c}	318.67 ^{ab}
FFSTSM	84.75	149.33 ^{d}	234.33 ^{bc}	307.67 ^{b}
FFSTSM(F)	91.57	149.67 ^{d}	203.33 ^{bc}	304.67 ^{b}
FFSTSMP	98.80	211.00 ^{a}	197.00 ^{bc}	324.33 ^{ab}
OFSTSM	71.75	194.00 ^{abc}	289.67 ^{a}	333.83 ^{a}
SEm (±)	5.212	17.167	25.668	10.373
CD (0.05)	NS	36.824	55.058	22.25

$^{a, b, c, d}$ Significant difference between treatments; NS: not significant; M: months;
F:FYM + NPK;FST:FYM + Soil Test Based (STB)$_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 66. Effect of treatments on pseudostem girth of Nendran banana, cm

Treatments	2 M	4 M	6 M	8 M
F	29.00 ^{ab}	44.33 ^{b}	57.67 ^{a}	58.67 ^{a}
FST	30.89 ^{a}	55.17 ^{a}	59.67 ^{a}	59.00 ^{a}
FSTSM	30.58 ^{ab}	53.00 ^{a}	59.33 ^{a}	51.00 ^{b}
FSTSM(F)	30.97 ^{a}	52.00 ^{a}	53.67 ^{c}	53.00 ^{b}
FFSTSM	24.58 ^{a}	53.50 ^{a}	57.33 ^{ab}	48.33 ^{b}
FFSTSM(F)	28.20 ^{b}	44.67 ^{b}	52.00 ^{c}	50.67 ^{b}
FFSTSMP	29.33 ^{ab}	47.17 ^{b}	54.00 ^{bc}	50.33 ^{b}
OFSTSM	31.33 ^{a}	55.33 ^{a}	60.00 ^{a}	59.33 ^{a}
SEm (±)	1.231	1.676	1.704	2.330
CD (0.05)	2.641	3.594	3.656	4.998

$^{a, b, c}$ Significant difference between treatments; M: months;
F:FYM + NPK;FST:FYM + Soil Test Based (STB)$_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients;
FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 67. Effect of treatments on number of leaves of Nendran banana

Treatments	2 M	4 M	6 M	8 M
F	8.61^{b}	13.33^{bc}	11.83^{ab}	8.00^{d}
FST	9.22^{ab}	13.67^{ab}	10.83^{bc}	8.33^{cd}
FSTSM	9.03^{ab}	12.33^{d}	9.50^{c}	7.83^{d}
FSTSM(F)	8.70^{b}	13.17^{bcd}	10.67^{bc}	7.67^{d}
FFSTSM	7.71^{c}	13.00^{bcd}	11.83^{ab}	8.50^{cd}
FFSTSM(F)	8.67^{b}	12.50^{cd}	10.33^{c}	9.17^{bc}
FFSTSMP	9.43^{a}	12.83^{bcd}	12.00^{ab}	10.17^{ab}
OFSTSM	9.56^{a}	14.33^{a}	12.67^{a}	10.83^{a}
SEm (±)	0.310	0.437	0.622	0.490
CD (0.05)	0.665	0.937	1.335	1.051

$^{a, b, c, d}$ Significant difference between treatments; M: months;
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

Table 68. Effect of treatments on dry matter production in banana, kg ha^{-1}

Treatments	Leaf	Pseudostem	Rhizome	Fruit	Total
F	1574.93^{bc}	4301.54^{a}	1217.12^{d}	2535.11^{cd}	9628.77^{c}
FST	1924.22^{b}	3350.00^{a}	2376.48^{ab}	2535.71^{cd}	10186 .41^{bc}
FSTSM	2082.06^{b}	3975.41^{a}	2838.67^{a}	2966.43^{b}	11862.55^{ab}
FSTSM(F)	1620.00^{bc}	1682.00^{b}	1533.63^{cd}	2372.56^{d}	7208.20^{d}
FFSTSM	844.72^{c}	1953.33^{b}	1896.83^{bcd}	2546.50^{cd}	7241.39^{d}
FFSTSM(F)	1835.04^{b}	1443.74^{b}	2034.75^{bc}	2555.35^{cd}	7868.88^{d}
FFSTSMP	1604.35^{bc}	1610.49^{b}	1451.18^{cd}	2875.06^{bc}	7541.07^{d}
OFSTSM	2995.83^{a}	3511.61^{a}	2840.98^{a}	3519.80^{a}	12868.21^{a}
SEm (±)	391.14	632.28	327.18	163.49	1263.64
CD (0.05)	839.006	1356.242	701.81	350.685	2710.50

$^{a, b, c, d}$ Significant difference between treatments
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

4.4.6 Yield and Yield Attributes in Banana as Influenced by FYM and COF Based Treatments

The bunch yield and various yield attributes of banana with regard to the eight different FYM and COF based treatments have been outlined in Table 69. The yield and important yield characters subjected to study reflected the superiority of the FSTSM and OFSTSM treatments. The highest bunch yield of 10.74 kg was recorded by FSTSM treatment which was on par with the 10.67 kg bunch yield of OFSTSM (Plate 5). The bunch yield realised was in the order FSTSM > OFSTSM >FST > FFSTSM >F > FFSTSMP > FSTSM (F) >FFSTSM (F).

The number of hands bunch^{-1} was highest (5.51) in OFSTSM treatment which was on par with the FYM based treatments. FSTSM treatment registered highest number of fingers bunch^{-1} which was on par with F and OFSTSM treatments. Highest length of peduncle (44.14) was noted in FSTSM treatment which was on par with the OFSTSM treatment. Treatment effect with regard to the number of fingers in D hand was statistically not significant. The OFSTSM treatment proved to be superior to all other treatments in terms of the weight and length of the index finger. Highest girth of index finger was seen in FSTSM treatment which was on par with OFSTSM and other COF based treatments (Plate 6).

4.4.7 Correlation of Growth Characters with Yield and Yield Attributes

Correlation studies revealed that the bunch weight was significantly correlated with pseudostem girth, dry matter production, weight and length of index finger (Table 70). The girth of pseudostem was positively correlated with dry matter production, number of hands bunch^{-1}, number of fingers bunch^{-1} and weight of index finger.

Plate 5. Bunch yield of banana in different treatments

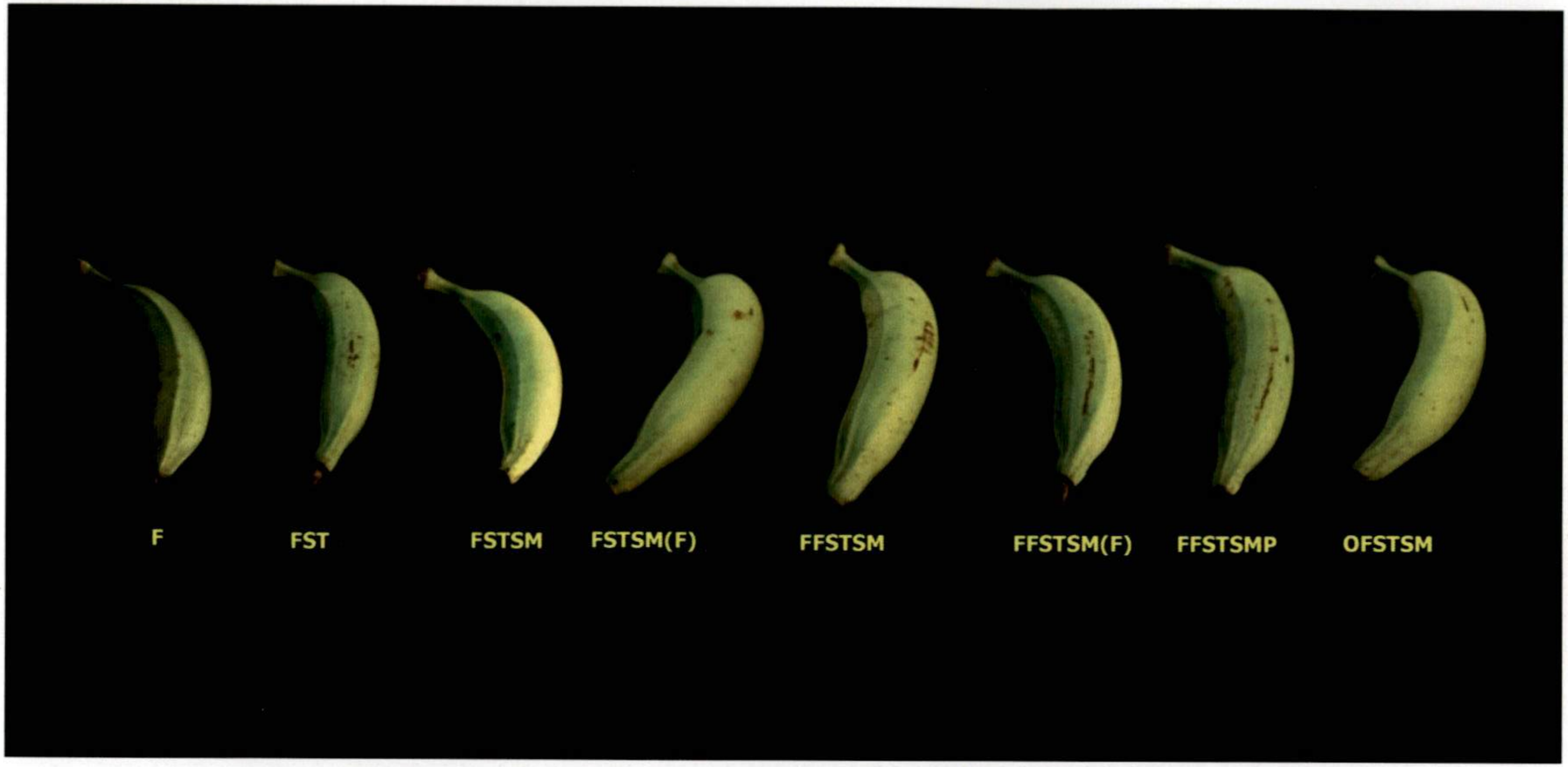


Plate 6. Index finger of banana in different treatments

Table 69. Bunch yield and bunch characters of banana as affected by treatments

Treatments	Weight of bunch (kg)	Number of hands bunch^{-1}	Number of fingers bunch^{-1}	Length of peduncle (cm)	Number of fingers in D hand	Index Finger		
						Weight (g)	Length (cm)	Girth (cm)
F	8.50 ^{b}	5.11 ^{ab}	46.33 ^{ab}	41.82 ^{bc}	10.49	172.43 ^{d}	22.17 ^{ef}	12.67 ^{bc}
FST	9.66 ^{ab}	4.98 ^{abc}	41.22 ^{cd}	41.14 ^{c}	9.11	186.94 ^{bc}	22.59 ^{de}	13.32 ^{ab}
FSTSM	10.74 ^{a}	5.38 ^{ab}	46.75 ^{a}	44.14 ^{a}	9.67	197.24 ^{b}	23.50 ^{b}	13.63 ^{a}
FSTSM(F)	8.19 ^{b}	5.22 ^{ab}	43.28 ^{bcd}	41.40 ^{c}	10.44	171.13 ^{d}	21.81 ^{f}	12.36 ^{c}
FFSTSM	9.29 ^{ab}	4.95 ^{abc}	43.20 ^{bcd}	40.72 ^{c}	9.50	174.08 ^{cd}	22.47 ^{de}	13.00 ^{abc}
FFSTSM(F)	7.80 ^{b}	4.52 ^{c}	40.06 ^{d}	38.44 ^{d}	9.11	182.99 ^{bcd}	23.14 ^{bc}	13.34 ^{ab}
FFSTSMP	8.38 ^{b}	4.87 ^{bc}	43.20 ^{bcd}	41.53 ^{bc}	9.71	188.29 ^{bc}	22.88 ^{cd}	13.43 ^{ab}
OFSTSM	10.67 ^{a}	5.51 ^{a}	44.32 ^{abc}	43.35 ^{ab}	9.95	217.87 ^{a}	24.04 ^{a}	13.49 ^{a}
SEm (±)	0.924	0.264	1.515	0.895	0.623	6.747	0.228	0.368
CD (0.05)	1.983	0.566	3.250	1.919	NS	14.472	0.488	0.789

$^{a, b, c, d, e, f}$ Significant difference between treatments; NS: not significant;

F:FYM + NPK; FST:FYM + Soil Test Based (STB)$_{NPK}$; FSTSM:FYM + STB $_{NPK+Sec+Micro}$; (F):Foliar application of micronutrients; FFSTSM:FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM:COF only

Table 70. Correlation of growth characters with yield and yield attributes

	Weight of bunch	Plant height	Pseudostem Girth	Number of leaves	Dry matter production	Number of hands bunch^{-1}	Number of fingers bunch^{-1}	Weight of index finger	Length of index finger	Girth of index finger
Weight of bunch	1	n.s.	0.474**	n.s.	0.622***	n.s.	n.s.	0.519***	0.477**	n.s.
Plant height		1	n.s.	0.492**	n.s.	n.s.	n.s.	0.377	0.455**	0.377*
Pseudostem Girth			1	n.s.	0.651***	0.548***	0.602***	0.438**	n.s.	n.s.
Number of leaves				1	n.s.	n.s.	n.s.	0.672***	0.658***	n.s.
Dry matter production					1	0.557***	0.409**	0.684***	0.670***	0.401*
Number of hands bunch^{-1}						1	0.503**	0.345	n.s.	n.s.
Number of fingers bunch^{-1}							1	n.s.	n.s.	n.s.
Weight of index finger								1	0.791***	0.484**
Length of index finger									1	0.614***
Girth of index finger										1

***, **, * significant at $p < 0.01$, 0.05 and 0.10; n.s. not significant

4.4.8 Quality Parameters of Fruit of Banana as Influenced by FYM and COF Based Treatments

The effect of the FYM and COF based treatments on the fruit quality parameters of banana like total soluble solids, ascorbic acid content and shelf life of the fruits were studied and were found to be statistically significant (Table 71).

Table 71. Effect of treatments on quality parameters of fruit of Nendran banana

Treatments	Total Soluble Solids (^{0} B)	Ascorbic acid (mg $100g^{-1}$)	Shelf life (days)
F	34^{ab}	1.01^{c}	4.94^{de}
FST	32^{b}	0.81^{c}	5.33^{cde}
FSTSM	32^{b}	1.01^{c}	6.17^{ab}
FSTSM(F)	32^{b}	1.21^{bc}	4.94^{de}
FFSTSM	36^{a}	1.41^{abc}	4.67^{e}
FFSTSM(F)	35^{a}	2.02^{ab}	5.61^{bcd}
FFSTSMP	32^{b}	1.61^{abc}	5.89^{bc}
OFSTSM	35^{a}	2.22^{a}	6.67^{a}
SEm (±)	1.189	0.406	0.349
CD (0.05)	2.550	0.870	0.749

$^{a, b, c, d, e}$ Significant difference between treatments;
F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

The highest total soluble solid content of 36 % was observed in FFSTSM treatment which was on par with FFSTSM (F), OFSTSM and F treatments. The highest ascorbic acid content recorded by OFSTSM treatment was 2.22 mg $100g^{-1}$ and it was on par with the other COF based treatments. The OFSTSM treatment registered the highest shelf life of 6.67 days which was on par with the FSTSM treatment.

4.4.9 Economic Analysis

Details regarding the economic analysis are presented in Table 72. Though the FSTSM treatment registered the highest gross income, it was the OFSTSM treatment that registered the highest net returns (₹ 764015) and B:C ratio (2.75) compared to all other treatments.

Table 72. Effect of treatments on gross income, net returns and B:C ratio of the treatments

Treatments	Gross income (₹)	Net returns (₹)	B:C ratio
F	956250	344610	1.56
FST	1086750	525140	1.94
FSTSM	1208250	637590	2.12
FSTSM(F)	921375	350090	1.61
FFSTSM	1045125	354465	1.51
FFSTSM(F)	877500	186840	1.27
FFSTSMP	942750	245090	1.35
OFSTSM	1200375	764015	2.75

F:FYM + NPK;FST:FYM + Soil Test Based (STB) $_{NPK}$;FSTSM:FYM + STB $_{NPK+Sec+Micro}$;(F):Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

4.4.10 Incidence of Pests and Diseases

Table 73 outlines the details regarding the incidence of pests and diseases noticed during the crop growth period. Pest infested and disease affected leaves were cut and burnt. A blanket spraying of Ekalux 2 mL L^{-1} was given for controlling *Spodoptera litura*. Sigatoka leaf spot was brought under control with a single foliar spray of Indofil M 45 @ 3 g L^{-1}.

Table 73. Incidence of pests and disease (%) in the field experiment

	Percentage incidence (%)
Pests	
Slug caterpillar, *Parasa lepida*	9.68
Spodoptera litura	12.50
Disease	
Sigatoka leaf spot	9.70

DISCUSSION

5. DISCUSSION

An investigation titled 'Evaluation of a customised organic fertilizer in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana' was conducted from October 2014 to August 2016 at the College of Agriculture, Vellayani with the aim of evaluating the customised organic fertilizer obtained from biodegradable solid waste by rapid thermochemical conversion technology, in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana in agro-ecological unit 8 of Kerala. The results obtained are discussed in this chapter.

5.1 CHARACTERISATION OF DSW AND THE TRANSFORMED ORGANIC FERTILIZER

5.1.1 Composition of DSW

The composition of DSW segregated at source (Fig.1) showed that cooked food waste constituted 45 % and was the major component followed by spoiled vegetables (25%), overripe fruits (15%), fruit and vegetable peels / rinds (10%) and animal derived food waste (5%). Degradable solid waste of residential localities is dominated by cooked food waste (Pham *et al.*, 2015). Plant derived waste was observed to outweigh animal derived waste. This may be attributed to the predominantly vegetarian food habit of the Indian society compounded by the easily perishable nature of fresh fruits and vegetables. Song *et al.* (2015) found a high correlation of vegetables, rice and wheat food waste generation with its consumption behaviour. One third of the 41 million tonnes of food that is bought annually in the UK is wasted in the food chain, half of which was wasted in households (Pham *et al.*, 2015).

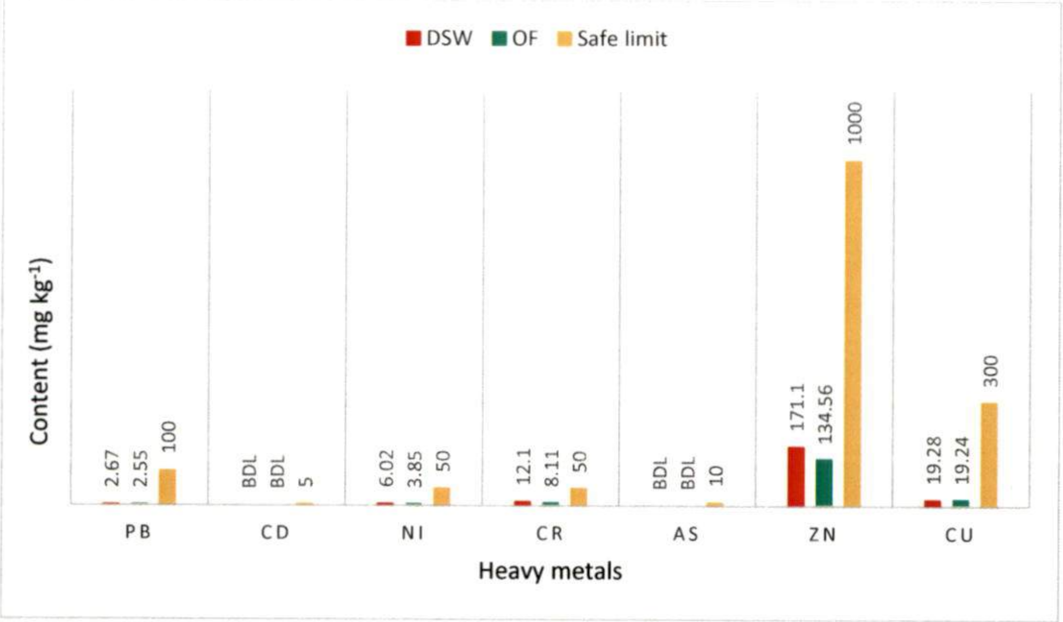
5.1.2 Characteristics of DSW and the OF Produced by Thermochemical Conversion

A colour variation was evident ranging from straw colour to light brown colour depending on the constituents with emanation of foul odour within 24 h of keeping in DSW owing to emission of volatile organic acids on fermentation (Du *et al.,* 2014). The OF on the other hand was devoid of any such offensive odour. DSW had a high mean moisture content of 70.56 %. Simon *et al.* (2013) observed 76.85 % moisture content in organic kitchen waste while 80.2 % moisture was seen in food waste biomass (Parshetti *et al.*, 2015). The OF had a lesser mean moisture content of 16.4 %. The optimum moisture range in the finished product is 15 – 25% (FAI, 2007) and too low and high moisture contents renders the manure difficult to handle (Saha *et al.*, 2010). Unlike the 95% constituents of OF, the particle size of more than 75 % constituents of DSW exceeded 4mm, the upper limit prescribed for city compost specified by FAI, 2007. The average bulk density was found to be 1.49 ± 0.32 Mg m $^{-3}$ which exceeded the permissible range of 1.0 Mg m^{-3} as per FAI specifications. However the bulk density of the organic fertilizer was in acceptable limits. High bulk density of DSW suggests that these fractions have less pore space and would be more compact. This might cause poor aeration, decrease water holding capacity and offer higher resistance to root penetration which would limit water and nutrient uptake by plants thus inhibiting plant growth (Soumare *et al.*, 2003).

The pH of DSW was acidic whereas the organic fertilizer had a neutral pH. The acidic nature may be attributed to the presence of high levels of organic acids like lactic acid, acetic acid, butyric acid and propionic acid in the DSW (Sundberg *et al.*, 2013). Thus unlike DSW, the organic fertilizer does qualify to suitability standards regarding pH (Tognetti *et al.*, 2011). There was a 71% reduction in EC in the organic fertilizer than in the DSW after thermochemical processing. Manohara and Belagali (2014) observed a reduction in concentration of ions during composting. The decrease in TOC content is indicative of the enhanced rate of degradation of organic materials during the production of organic fertilizer. There is a 13 % increase in the total nitrogen content of the thermochemically produced organic fertilizer which may be attributed to the content of N released as a result of mineralization from DSW during degradation and the relative enhancement of N. Bernal *et al.* (2009) reported 50% N loss in sewage sludge composting while there was more than 60% of N loss during city refuse composting. Thus loss of total N appears to be minimal in the rapid conversion technology process. The total N content of organic fertilizer was 1.47 times more than FYM and 2.94 times higher than ordinary compost (KAU, 2016). There was an increase of 70.97% and 55.42% in the total P and K contents of the organic fertilizer than in the DSW. Total phosphate content was higher than FYM, ordinary compost and vermicompost while total potash content was higher than FYM and ordinary compost. Urban solid waste was detected to have a higher P content (0.51%) than in agricultural waste (Rao *et al.*, 2008). The high Ca content of the organic fertilizer imparts an added advantage of having a liming effect on acid soils with a prospective use as soil ammendment to improve nutrient availability (Swarnam and Velmurugan, 2013). Among the micronutrients, B registered a 50% increase. The considerable increase in nutrient contents may be attributed to the loss in weight and organic matter decomposition. Comparable nutrient contents have been found by Swarnam *et al.* (2016); Zhao *et al.* (2016).

It is revealed that the concentration of the heavy metals Pb, Ni, Cr, Zn and Cu in the organic fertilizer produced by thermochemical conversion (Fig. 4) was within the safe limits specified by FAI (2007). Cd and As were below detectable levels. This might be due to the low concentration of heavy metals in DSW also which is consequential to the effective segregation of household waste at source owing to citizen consciousness. Hence soil application of the OF will in no way cause phytotoxicity and is environmentally safe to use.

The 38.14 % decrease of cellulose content in OF as compared to DSW brought about by the thermochemical degradation might be due to the breakdown of the 1,4-glycosidic linkage at high temperatures and acidic medium (Fig. 5).



(BDL: Below detectable level)

Fig. 4. Heavy metal concentration in DSW, OF and the safe limit

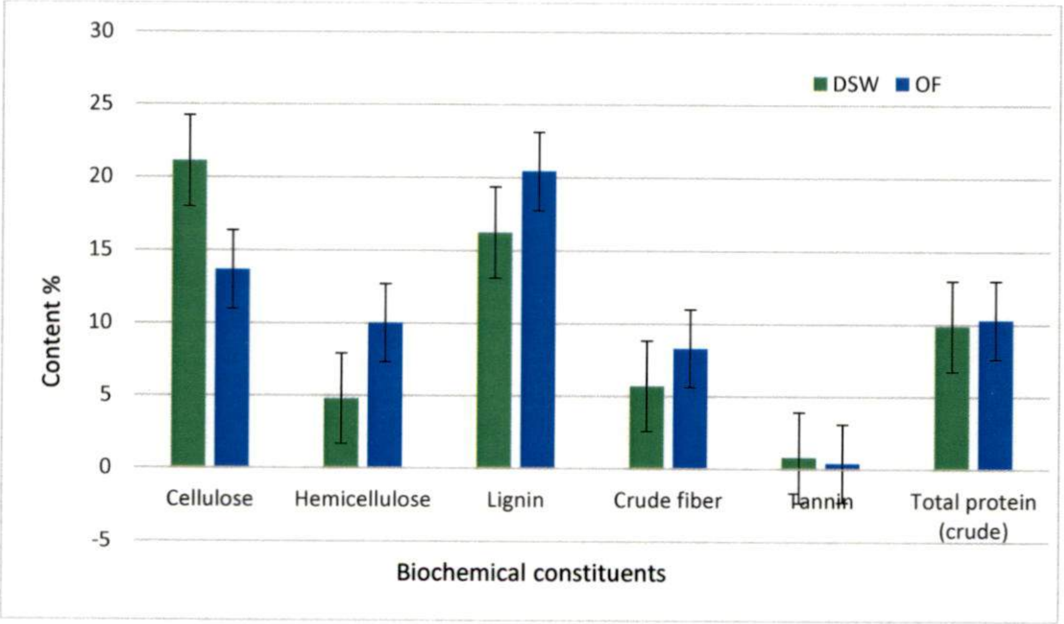


Fig. 5. Biochemical constituents of DSW and OF. Error bars indicate SE

Glucose units are progressively eliminated from the reducing end of the chain (Chandel *et al.*, 2012). Heating to 100°C in dilute acid medium can depolymerise the cellulose and hemicellulose fractions of DSW into reducing sugars (Jia *et al.*, 2015). Thermochemical conversion of DSW to organic fertilizer resulted in a relative increase of hemicellulose, lignin and crude fibre contents. Tannins on the other hand decreased by 50%. Moharana and Biswas (2016) also reported decreases in total C and cellulose and increase in total N, crude ash and lignin during maturation of city refuse compost. Priya (2008) reported that lignin content increases as humification advances and a higher lignin content is indicative of the maturity of the compost. Trzcinski and Stuckey (2015) observed 20% solubilisation of organic fraction of municipal solid waste by chemical hydrolysis in an acidic and oxidative environment.

5.1.3 Maturity Parameters of DSW and OF from Thermochemical Conversion

The C:N ratio is one of the foremost characterising factor which is indicative of the quality and maturity of compost. There is a remarkable decrease of 47 % in the C: N ratio of the DSW upon conversion to organic fertilizer. This may be due to loss of C during degradation (Moharana and Biswas, 2016) coupled with the increase in N content owing to mineralization. In well humified soils the C: N ratio is close to 10 and the addition to soil of materials with a C: N ratio below 20 may not alter the microbiological equilibrium of the soil. The soil and plant C: N ratios decreased linearly with increasing microbial population (Du *et al.*, 2014). Hence the C: N ratio of 16.26 of the organic fertilizer under study indicates its suitability for substituting conventional composts as a manure (Fig. 6a). This comes within the mandated C:N ratio of less than or equal to 25 put forth by CCQC (2001) for mature compost.

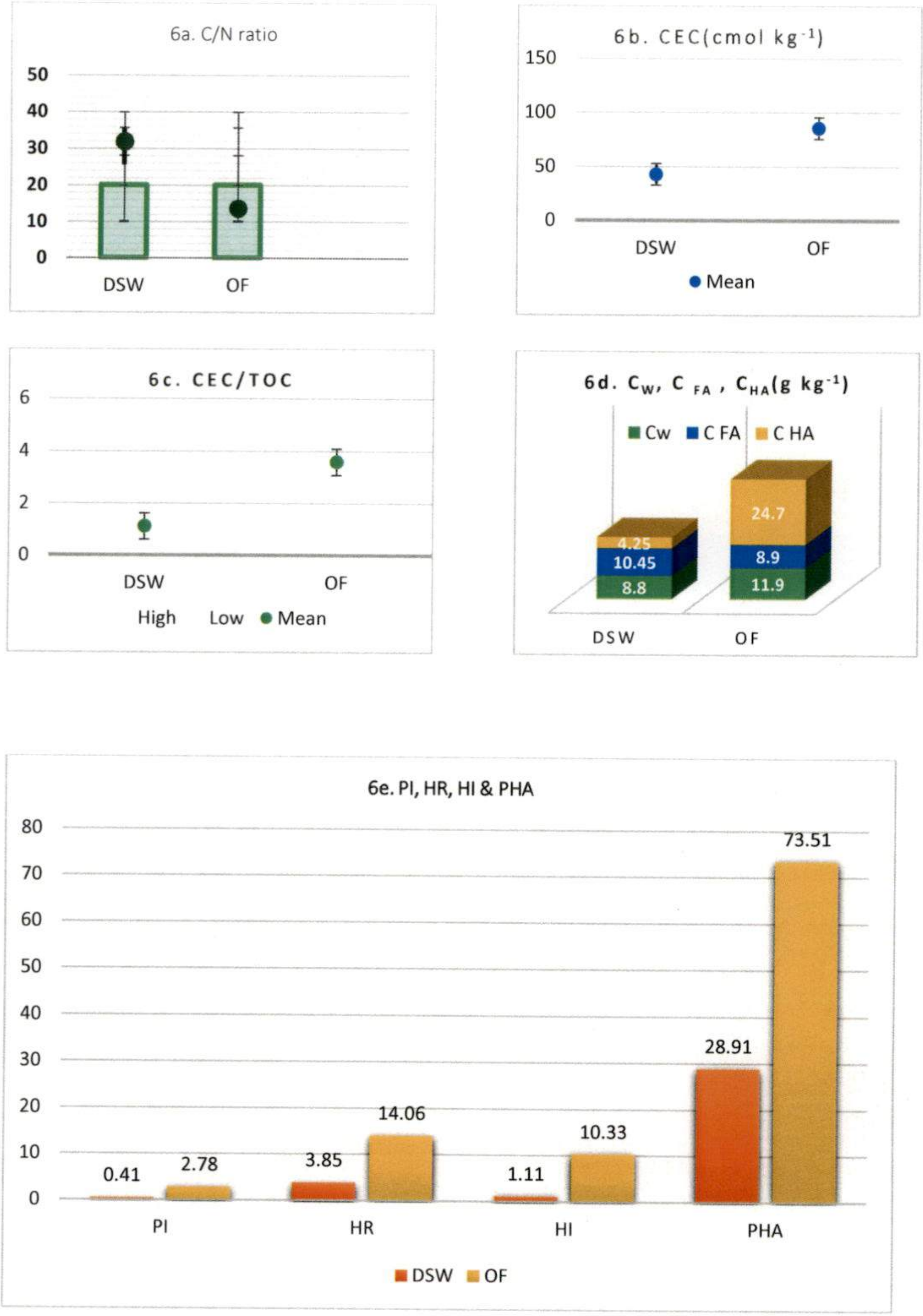


Fig. 6. Compost maturity parameters and indices C/N, CEC, CEC/TOC, C_w, C_{FA}, C_{HA}, PI, HR, HI and PHA of DSW and OF

The high CEC values which increased from 42.83 cmol kg^{-1} in DSW to 85.70 cmol kg^{-1} in the thermochemically processed OF (Fig. 6b) is a clear indication of the advancement in the humification process when carboxylic and phenolic functional groups are produced. Carboxyl groups are formed by the oxidation of lateral chain of the aromatic rings or hydrolysis of ester or lactones (Lax *et al.,* 1986). With progress in humification, release of negatively charged particles occur. The CEC attained were higher than the 60 and 67 cmol kg^{-1} reported by Harada and Inoko (1980) and Jimenez and Garcia (1992) respectively, as the minimum values for compost maturity in city refuse composts. Increase in CEC with advancement of composting has been reported by Rao *et al.* (2008).

While the CEC \ TOC ratio of 1.12 of DSW (Fig. 6c) was below the recommended value rendering it unsuitable for direct soil application, the organic fertilizer had a ratio of 3.99, higher than the prescribed minimum ratio of 1.7 put forth by Roig *et al.* (1988). The C_w content of 11.90 g kg^{-1} of the OF was well within limits of 4.1 -11.9 g kg^{-1} (Garcia *et al*., 2005); 17 g kg^{-1} (Bernal *et al.*, 2009). The C_w/TOC ratio of 0.5 and the C_{FA} content of 8.9 g kg^{-1} do not exceed the index value limit of 0.7 (Bernal *et al.*, 2009) and 12.5 g kg^{-1} (Hue and Liu, 1995). Higher proportion of C_{HA} which is rather slow to degradation with high CEC can be considered to be a measure of compost maturity (Goyal *et al.,* 2005). The C_{HA} / C_{FA} ratio increased from 0.41 in DSW to 2.78 in the organic fertilizer. Swarnam *et al.* (2016) proposed a C_{HA} / C_{FA} ratio of 1.5 to indicate compost maturity.

The extremely low levels of CO_2 production (4.83 mg CO_2 $kg^{-1}h^{-1}$ for OF and 9.16 mg CO_2 $kg^{-1}h^{-1}$ for FOF) as revealed by respirometric studies indicate that the microbial population is scanty. Hue and Liu (1995) have stipulated a maximum CO_2 evolution limit of 120 mg $kg^{-1}h^{-1}$. Hence it can also be inferred that the organic fertilizer will be devoid of phytotoxic pathogens.

However, the premise that the compost maturity can be interpreted in terms of nitrification does not hold good in the OF produced by thermochemical conversion. Though lower than in DSW, NH_4^+-N content of the OF exceeded the NO_3^- N content. It was much beyond the 0.04% limit stipulated for $NH4^+$ -N by Zucconi and de Bertoldi (1987) for a matured compost. The NH_4^+/ NO_3^- ratio of 3.09 also far exceeds the 0.16 ratio limit proposed by Bernal *et al.* (2009). The scope for such sort of a nitrification is limited in the thermochemical process.

5.1.4 Quality Indices of Organic Fertilizer from Thermochemical Conversion

The germination index (GI) of the organic fertilizer was observed to be higher than the 50% value ascribed for phytotoxin free compost (Zucconi *et al.*, 1985). This falls under the category of 'mature' compost rating of CCQC (2001). The fertilizing index of 4.7 categorise the organic fertilizer in Class A for marketability which is an indication of the potential of the nutrient supplying capacity of the fertilizer for enhancing crop production. The clean index value of 5.0 which is a measure of heavy metal quality control indicates that the application of the organic fertilizer will not cause any environmental hazard and is safe to use.

5.1.5 Correlation Studies between Various Maturity Parameters

The C/N ratio was found to have a high negative significant correlation with nine compost maturity parameters and a positive correlation at a lesser degree with C_{FA} and C_w/ N_{org}. This clearly indicates that lower the C/N ratio, the higher the compost maturity would be. The high positive correlation of CEC with C_w, C_{HA}, CEC/TOC, C_w/TOC and humification indices C_{HA}/C_{FA}, HI, HR and PHA exclusively qualify CEC to be a compost maturity parameter of the OF produced through thermochemical processing. CEC/TOC ratio too followed a similar trend as CEC. The positive significant correlation of lignin with C_{HA}, CEC/TOC, C_{HA}/C_{FA}, HI, HR and PHA is a confirmation of the attainment of matured compost like end product. Besides having a high correlation with C_w/TOC, C_w was also correlated with CEC, CEC/TOC, C_{HA} and humification indices, though at a lower level of probability. The very high positive inter correlation of C_w/ TOC, C_{HA} and humification indices C_{HA}/C_{FA}, HI, HR and PHA is a strong evidence of the interdependence of these factors and can be considered to be ideal indicators of OF maturity. C_{FA} showed inverse correlation with five parameters which shows that a high C_{FA} content is an indication of immaturity of composts. C_w/N_{org} showed a negative correlation with CEC and CEC/TOC. However, NH_4^+/NO_3^- ratio had significant correlation with none of the other compost maturity parameters.

5.2 INVESTIGATIONS ON NUTRIENT RELEASE CHARACTERISTICS OF THE CUSTOMIZED ORGANIC FERTILIZER

Organic agriculture relies on the use of organic manures for maintaining soil and plant health and for supplying plant nutrients. In contrast to chemical fertilizers, organic manures release nutrients slowly for a longer period of time. For effective utilization of these nutrients, their release should coincide with the crop requirement. If not utilized, the mineralized nutrients will be lost and may pollute the ecosystem. Although the nutrient release from manures depend on other factors such as soil, plant and climatic factors, the characteristics of organic manure is the most important factor among them. Hence it is imperative to study the nutrient release pattern of the COF before it is recommended for field application.

5.2.1 Kinetics of pH and EC

In the laboratory incubation study with FYM and COF treatments, contrasting patterns were observed for the kinetics of pH and EC. However, all the treatments exhibited a similar pattern of decline in soil pH up to 60 D (Fig. 7).This is expected since during the decomposition of organic manures different kinds of organic acids are produced which will decrease the soil pH (Gill *et al.*, 2016). Use of chemical fertilizers also have acidifying effect on soil causing a reduction in soil pH (Schroder *et al.*, 2011). As per the fertilizer recommendation schedule of Kerala Agricultural University which is based on Integrated Nutrient Supply System, application of inorganic fertilizers were used along with FYM and COF, which also might have caused acidification. Khan *et al.* (2014) reported application of sewage sludge increased organic matter content in soil which lead to production of humic and carbonic acids, thereby decreasing pH. Application of organic amendments alone or in combination with chemical fertilizers is reported to reduce the soil pH as compared to no manure control (Angelova *et al.,* 2013; Gill *et al.* 2016). In the present experiment the decrease in pH continued up to 60 D, after which it increased up to 90 D, levelled off, and again increased at 270 D. At the end of the study period all the treatments in which COF was applied basally, registered a pH same as or slightly higher than their initial value and the treatment F registered the same value.

Contrary to the pattern of variation observed in soil pH, soil EC exhibited a gradual increase up to 60 D in all the treatments, then decreased and again increased from 180 D up to 240 D (Fig. 8). Thereafter a slight decrease was observed in all the treatments. Electrical conductivity in soil gives an indirect estimation of soluble salt concentration. Degradation of organic manure together with chemical fertilizers releases soluble salts into the soil. The products which induced a decline in pH therefore resulted in an increase in EC. Increases in salt content and EC resultant to incorporation of composts have been reported by many workers (Angelova *et al.*, 2013; Roy and Kashem, 2014; Gill *et al*., 2016). Sarwar *et al.* (2008) opined that the acids or acid forming compounds released during decomposition of organic manures react with sparingly soluble salts present in soil and convert them into soluble salts. This increases the EC. As far as treatment F is concerned, an almost stable pattern was observed from 60 D to 270 D with a subsequent decrease. This temporal stability pattern is in absolute contradiction with the temporal pattern of pH for the same treatment F during the same incubation period. However it should be noted that the values of EC in all the treatments were well within the safe limits prescribed for plant growth (Table 19).

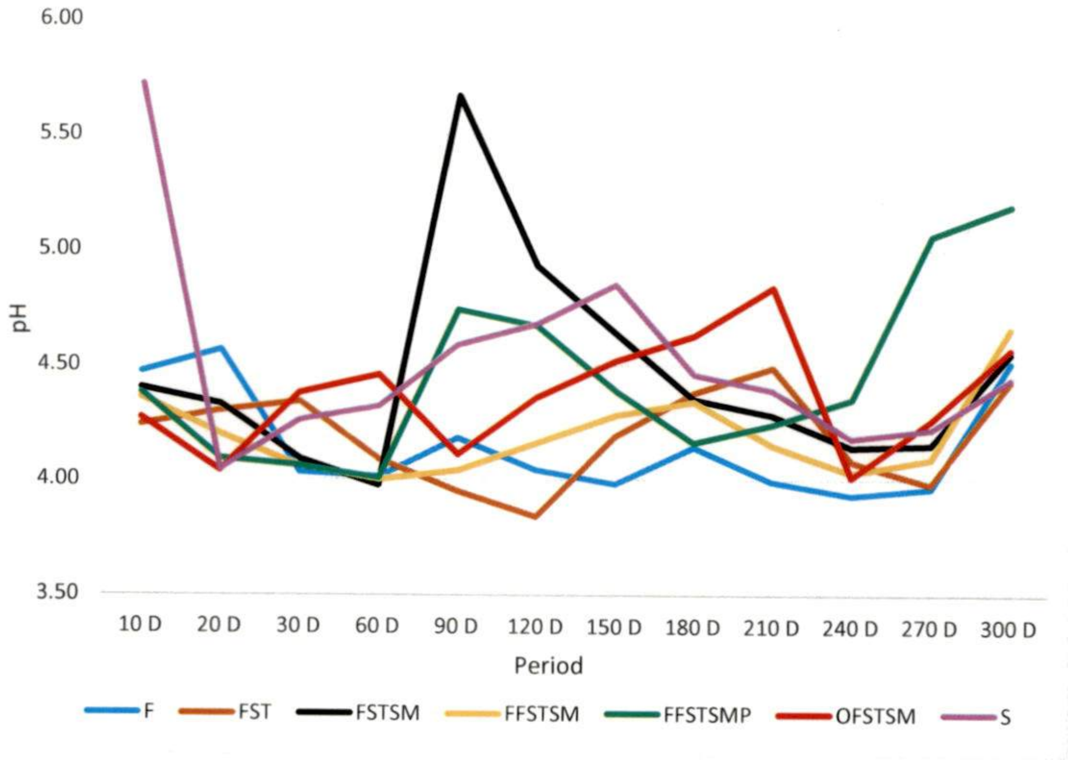


Fig. 7. Effect of treatments on temporal variation in soil pH

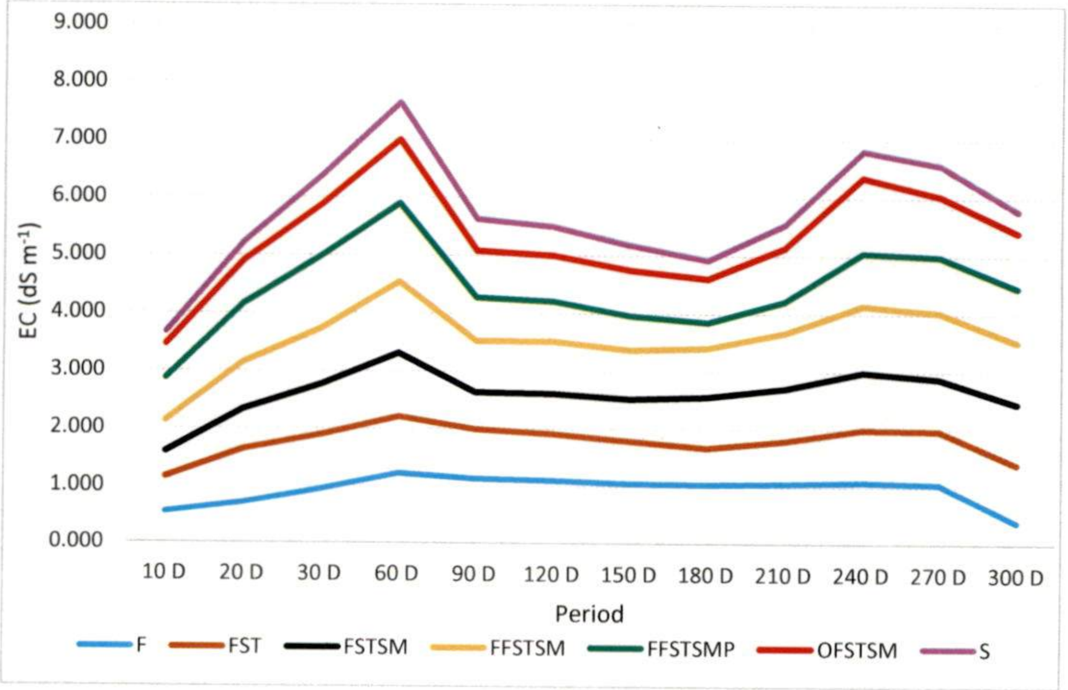


Fig. 8. Effect of treatments on temporal variation in soil EC

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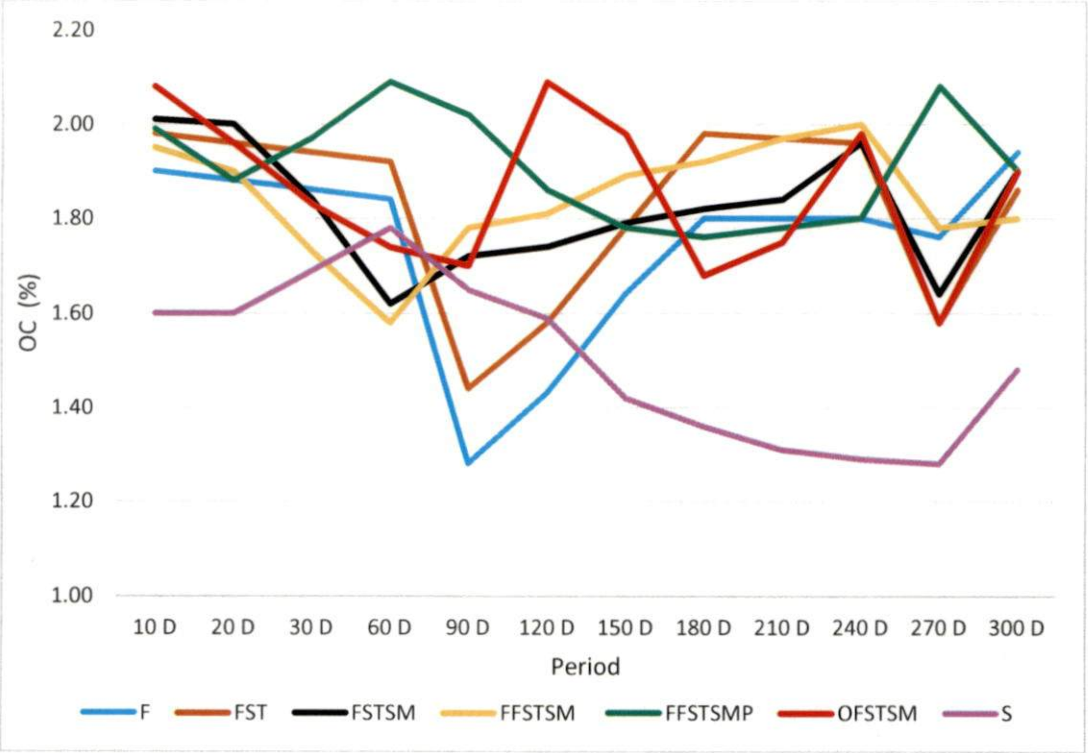

Fig. 9. Temporal variation in soil OC as affected by treatments

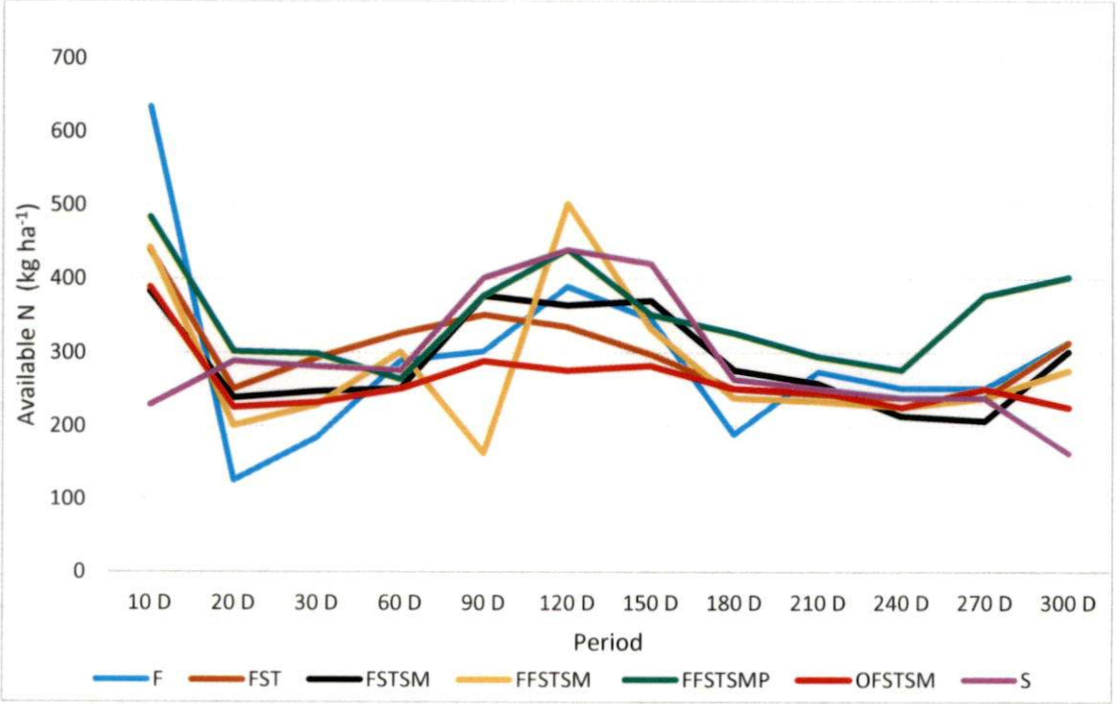

Fig. 10. Temporal variation in available N during incubation

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5.2.2 C and N mineralization dynamics

Significant difference between treatments was observed in the OC content of the soil during the study period. A general slow decrease in OC content was observed in all the treatments up to 20 D followed by varying patterns of decrease in different treatments. (Fig. 9). The treatments F and FST followed an identical pattern of OC kinetics. A phase of slow decrease up to 60 D was followed by a steep decline during 180 D. The phase of steady decline occurred at 60 D in the case of FSTSM and FFSTSM. Thereafter the increasing trend resumed until 240 D where again a steep dip up to 270 D followed by increase up to 300 D was observed. It is well known that application of organic matter stimulates soil microbial activity in response to the availability of C compounds. Organic amendments are reported to increase soil microbial biomass and activity (Chu *et al.*, 2007; Islam *et al.*, 2011). Zhang *et al.* (2015) reported manuring significantly increased PLFA biomass. The microbes utilise the C in these compounds for growth and multiplication. This will lead to a sudden immobilization of C which was reflected in the initial declining phase. With the multiplication of microbial population, the demand for C compounds increased and led to a stage where net immobilization occurred which coincided with the phase of steep decline.

In the case of OFSTSM treatment, the initial declining phase though gradual, progressed in a steady manner up to 90 D. The OC content increased after 90 D and was higher than all other treatments at 120 D. COF inherently had a high OC content than FYM owing to the method of production (Table 8). This might have helped to sustain an equilibrium between the rates of multiplication and diminishing of microbial population which is expressed by a relatively smooth line graph. It should be noted that the treatment S registered the lowest OC content at 300 D among the different treatments. An appreciable increase in OC content of S was observed only on 20 D. Thereafter both the S and FFSTSMP treatments showed a similar pattern of OC kinetics. OC attained a peak at 60 D in both the S and FFSTSMP treatments and thereafter entered a declining phase at a diminishing rate up to 270 D in the former and up to 240 D in the latter which increased subsequently. A key feature of the study of OC kinetics pertains to the fact that despite having the cyclic increase – decrease in release pattern, the final OC content at 300 D was almost similar to the initial level in all the treatments.

All the treatments exhibited a similar pattern of N dynamics (Fig. 10). A high N availability was recorded on 10 D but a sharp decline was observed thereafter up to 20 D. Mineralization of N is a biological process. Application of organic manure provides abundance of C and N compounds by which a sudden spurt in microbial population occurs in soil. Baldi and Toselli (2014) in an incubation study with different kinds of organic manures observed an increase in CO_2 evolution and N availability within twenty four hours after incubation. The CO_2 flux soon after addition of organic manures is indicative of flourishing decomposers. This spurge in population leads to immobilization of the released N by the microbes. The decline observed on 20 D may be due to N immobilization by the microbes. Soon after, a curb in microbial growth might have occurred due to scarcity of easily available N compounds and the N already immobilized by microbes get released. The gradual increase in N availability noticed after 60 D coincides with this phase, which attained a peak at 120 D. Similar results have been reported by many scientists (Abbasi *et al.*, 2015; Agele *et al.*, 2015; Masunga *et al.*, 2016). It can also be observed that the cycle is repeating after 120 D. In N mineralization studies with different organic amendments, Masunga *et al.* (2016) could not observe significant changes in PLFA concentration from day 40 to 97.

At the same time it should be noted that in the control (without manure) treatment the pattern was just the reverse that of treatments with organic manure. Agele *et al.* (2015) reported that C and N dynamics differed in plots with and without addition of manure. The result thus clearly shows that sufficient time gap should be given between manure application and planting so as to avoid net immobilization. Moreover, the N mineralized will be lost by leaching if it is not taken up by crop, causing environmental pollution (Eriksen *et al.*, 2015).

The type of organic manure did not have significant influence on the magnitude of N release throughout the study period. No relation was observed between the N content and rate of N_{min}. But the magnitude of N_{min} varied with treatments (Fig. 10). On 10 D, 34 - 50 % N_{min} was observed in different treatments. The quantity of N released depends on properties of manures like C:N ratio, nature and complexity of C compounds and the nature of soil microbes (Mohanty *et al.*, 2011). Manures containing high levels of N with low C:N ratio are able to release sufficient quantities of N for crop growth without causing a net immobilization (Cordovil *et al.*, 2005). FFSTSM and FFSTSMP had the same content of initial N. But the pattern of N release was different, because of the presence of PGPR. When a sharp decline and peak was observed in the treatment FFSTSM, the effect was smoothed out, may be due to the effect of PGPR. Rousk *et al.* (2016) studying the microbial control of soil organic matter mineralization and N release, showed selective mining of N in accordance with the availability of labile C that triggered catabolic responses of the residential microbial community.

All the manured treatments registered high values of OC and N_{min} compared to untreated control S. In OFSTSM the N availability remained relatively constant indicating a steady supply of N to plants throughout the cropping period. The N_{min}% in this treatment remained low but steady throughout the period of study. This shows that the COF contained a high proportion of stable, recalcitrant materials. The main aim of composting is to stabilize organic compounds, reducing the proportion of soluble forms of C and N (Wong *et al.*, 2016). It is interesting to note that in spite of the variation in initial N content, the final (at 300 D) rate of release observed was the same in both these treatments (FFSTSM and OFSTSM).

In S the final level of N and OC were far lower than the initial. The N_{min}% was the highest in S during the entire period of study. This shows that the microbial population build up was not sufficient or absent for causing immobilization, indicating the pronounced effect of organic manures on stimulating microbial activity in the rhizosphere. Only after 83 % of the N was mineralised, there was a slow build up of microbes as shown by the slow rate of immobilization after 120 D. In this condition, there will be huge loss of native N to the surrounding environment by leaching or volatilization. On 300 D the level of N release was lowest indicating near exhaustion of native N. This points to the need of adding organic manures to prevent net immobilization that occurs as the cycles repeat in unmanured treatment S (Masunga *et al.*, 2016).

The four soil test based treatments (FST, FSTSM, FFSTSM, and FFSTSMP) exhibited a more or less similar trend. N_{min} ranged between 16.84 and 25.27 % at 20 D for the soil test based treatments. The FFSTSMP treatment maintained a constant high supply throughout the study period. The soil test based treatments, though not the highest gave a steady supply throughout. On comparison of the COF based treatments, although FFSTSM and FFSTSMP treatments had almost the same content of initial N, there was an apparent difference in the pattern of N release obviously owing to the presence of PGPR. Pseudomonas is the major genus in PGPR. They have special ability for nutrient mobilization (Pandya and Saraf, 2015). A major factor limiting microbial growth is availability of organic matter (Billah and Bano, 2015). In FFSTSMP organic matter is available in plenty providing a favourable environment for the growth and multiplication of PGPR. COF is nutrient fortified. Beneficial interaction of PGPR and nutrient enriched compost had been demonstrated by Shahzad *et al.* (2014).

The drastic effect of organic manures on retention and slow and constant rates of release of N over long periods is evident from the Fig. 10. The rate of N_{min} from the organic manures is critical for their efficient use for crop production. The different rates of N_{min} in different treatments showed that mineralization potential varied with the type of manure. After initial immobilization, a net mineralization happened only after 60 D. This throws light to the fact that application of organic manures should be done at least two months before planting so as to synchronize the N availability with crop uptake. All the treatments had the highest content of N release at 10 D. If this is not utilised by crop, this will be lost in rainfall, since the planting time coincides with the monsoon in Kerala. When the organic manure treatments are compared, in OFSTSM, the magnitude of release remained almost constant during the entire period of study. After the initial sharp peak and steep decline, N_{min} got stabilised indicating the stabilisation of microbial population in the treatment OFSTSM. This shows that OFSTSM was able to provide the N requirement of soil microorganisms without affecting crop uptake. Since the OFSTSM contained N from organic and inorganic sources the N availability remained constant. Application of composts enriched with inorganic fertilizers is found beneficial for plant growth (Adamtey *et al.*, 2010). The treatment thus is able to provide a stabilised supply of N to crops throughout the growing period without chances of net immobilization. It also implies that undue loss of N can be minimised thereby reducing environmental pollution to a considerable extent.

The rate of release of N was the highest in S during the entire period of study. The highest mineralization in S (83.31%) was observed at 120 D which was three times higher compared to treatments with organic manure addition. Thereafter the mineralization exhibited a continued downward pace till 300 D when it reached the lowest value of 30.94% indicating near exhaustion of native N. The sustenance effect of organic manures manifested by the degree of retention and gradual steady rate of release of N over fairly long periods, 300 days in this study, which could potentially be harnessed for crop growth, is inexplicably outlined in Fig. 11.

5.2.3 Nutrient release characteristics

The pattern of nutrient release remained similar in all the treatments all over the study period. Highest nutrient release was recorded on 10 D. In the case of N, K, Ca and Mg, a 120 day mineralization – immobilization cycle was observed. The highest release of N and K was from the treatment F. But contrary to the mineralization of N, a near uniformity was observed in the P release pattern of all the treatments (Fig. 12). A unique phase of net immobilization of the nutrient spanning from 180 D to 240 D was evidenced invariably in all the treatments inclusive of all FYM based, COF based and control treatments. P mineralization rates slumped to levels lower than the inherent content during this phase. McGill and Cole (1981) reported that P mineralization from organic sources was not related to C and N mineralization. It proceeds not through biological, but through biochemical pathways by the action of extracellular phosphatases. This theory suggests that P mineralization dynamics should be different from C and N mineralization because as organic P accumulates in soil, extra cellular enzyme production slows down and mineralization is suppressed. Although extracellular phosphatases have an important role in P mineralization, inorganic P may have been removed from soil solution through sorption on soil surfaces and precipitation with secondary minerals as well as immobilization in microbial biomass (Whalen *et al.*, 2001). An appreciable gain in P release was subsequently noticed up to 270 D before decreasing up to 300 D. This might be due to the P release from organic compounds as suggested by Spohn and Kuzyakov (2013). They reported that mineralization of P in soil is driven by the C need of soil microbes. Microorganisms extract C from the phosphorylated sugars but take up only very small amounts of P leaving the mineralized P in the soil solution. The final content of P release was however lower than the initial content. It is interesting to note that the untreated control (S) exhibited the same pattern as that of treatments. This is due to the natural release of fixed P from the soil used for incubation. The soil used was an Ultisol and had a high P status of 180 kg ha^{-1}.

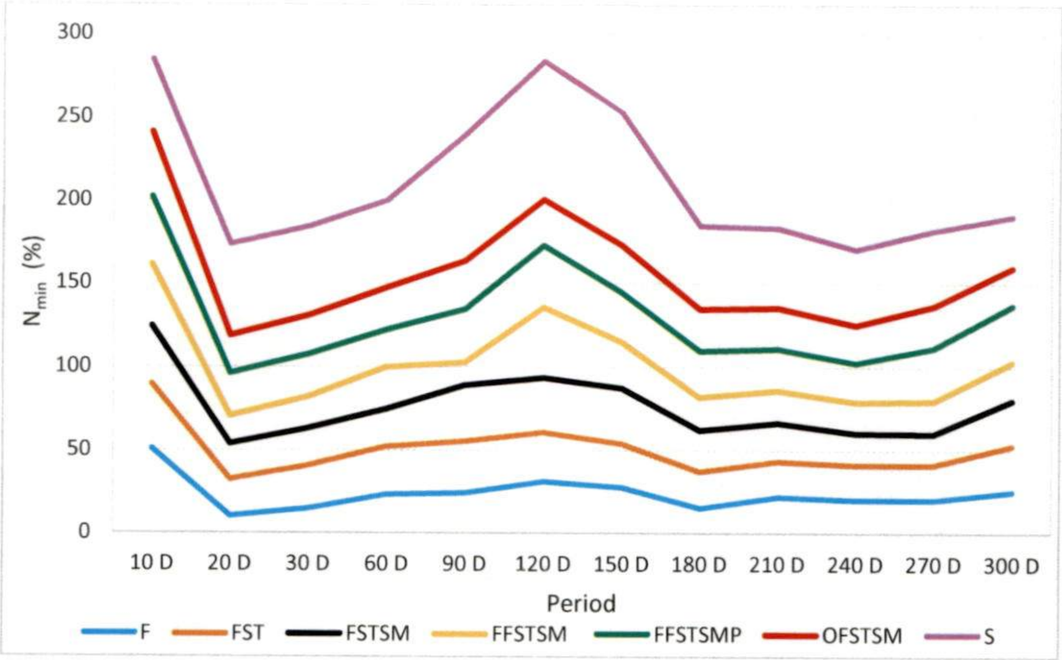

Fig. 11. Temporal variation in N_{min} in different treatments

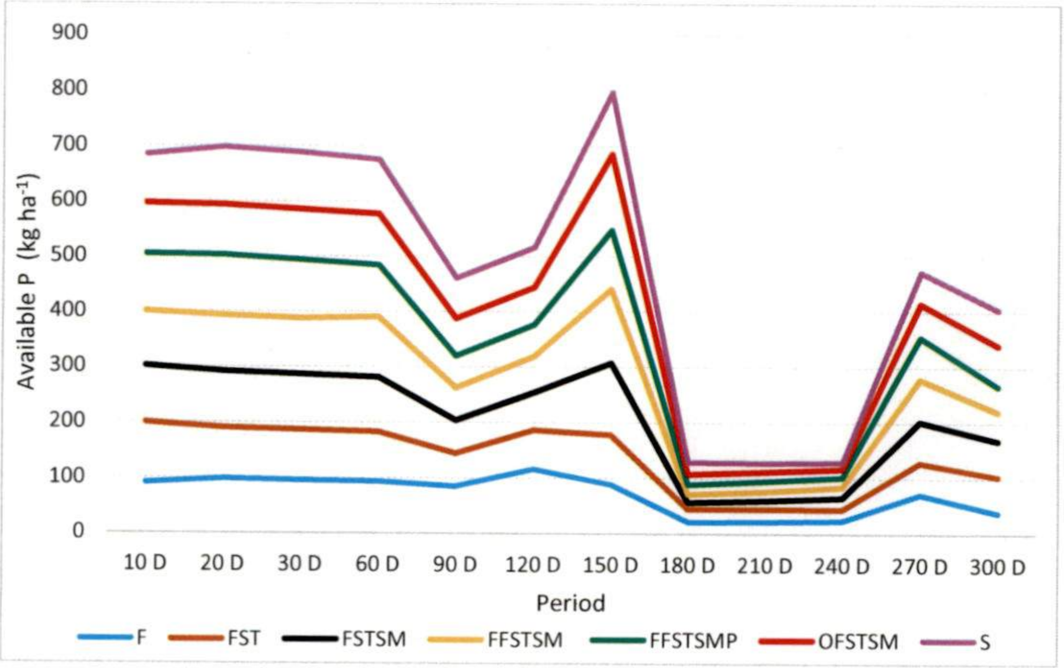

Fig. 12. Effect of treatments on temporal variation in available P content

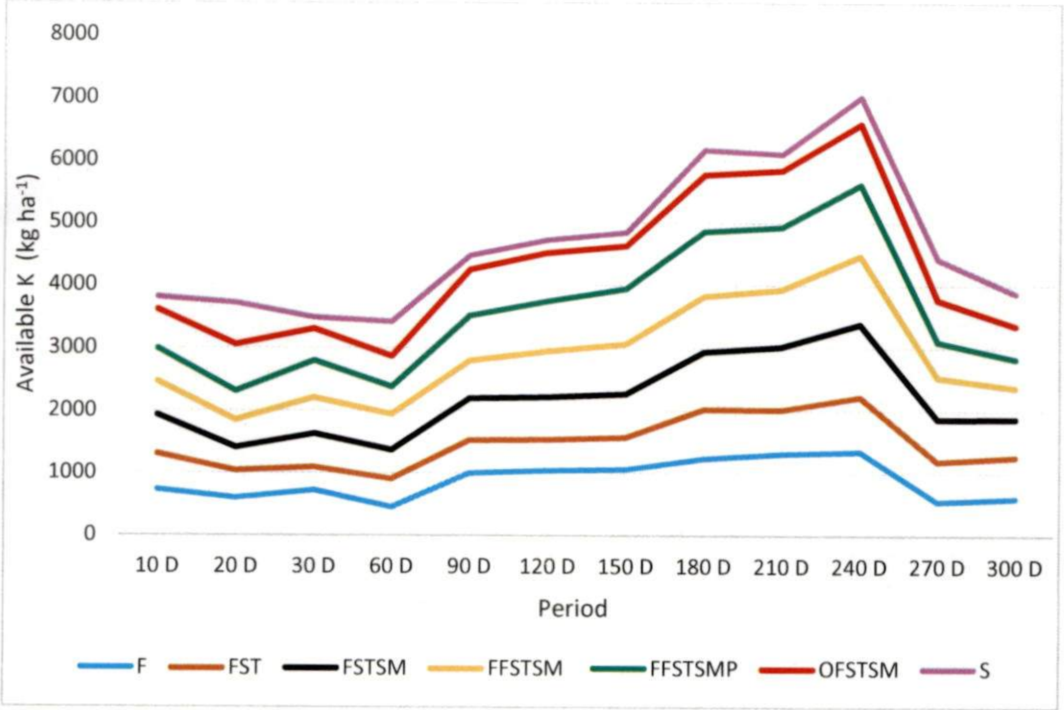

Fig. 13. Temporal variation in available K content during incubation

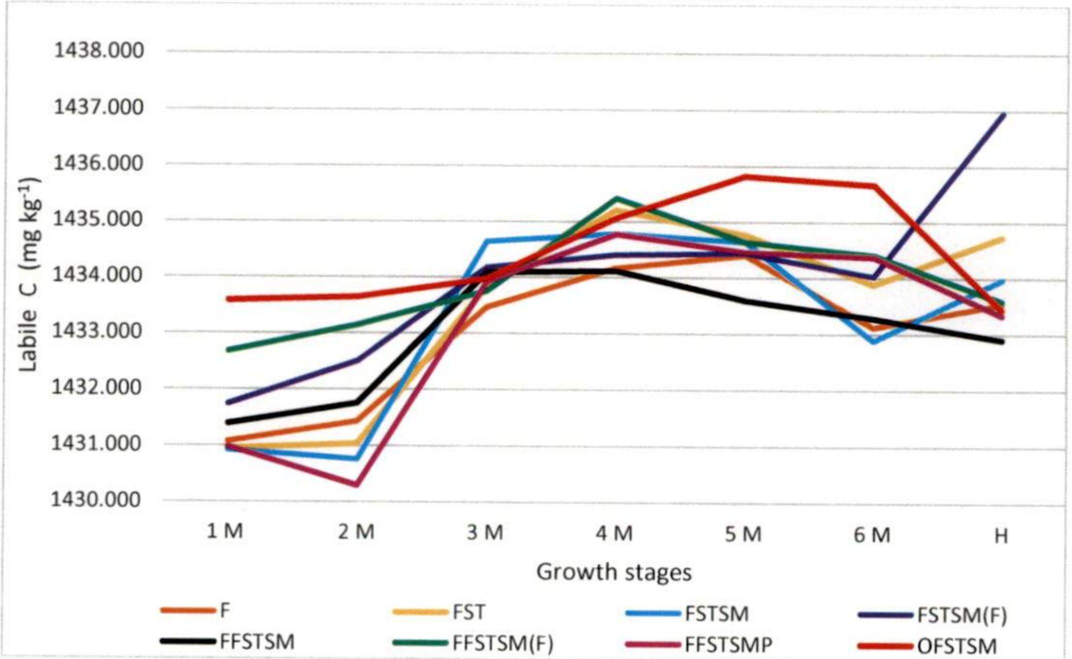

Fig. 14. Labile carbon dynamics at different growth stages of banana

The P mineralization pattern clearly shows that until 180 D there is no need of external fertilizer application for P, indicating that for crops of duration less than 5 months, external P application can be skipped for one season. However, it cannot be skipped for longer as there was a net immobilization during the 180 D. Based on the plots it can be interpreted that the P release in Ultisols is determined by the changes in pH of the soil. It should thus be inferred that organic manure addition did not have an influence on P release kinetics. It is well known that in highly weathered soils like Ultisols P forms sparingly soluble complexes with Fe and Al hydroxides or oxy-hydroxides (Rodrigues *et al.*, 2016).

The release pattern of K on the 20 D was identical for all the treatments except the control and OFSTSM treatments (Fig.13). When in all the other treatments K availability decreased, an increase was observed in these treatments. But after 20 D, the pattern was same as others in the OFSTSM treatment whereas the S (control) kept a unique pattern. In all the manured treatments K availability increased up to 240 D. However at the end of the experiment the status remained the same as initial. This result is in conformity with the findings of Srinivasan *et al.* (2016) where they reported an increase in K availability in manured treatments compared to control. They observed a decrease in K mineralization on 20 D which increased later with time of incubation. Organic manures release nutrients very slowly (Ramesh *et al.*, 2009) over a period of time compared to mineral fertilizers.

Among the secondary nutrients, Ca release pattern was practically similar to P and opposite to that of K. Following a decline at 150 D, an increase was noticed at 210 D which decreased again at 270 D and increased and levelled off. The result is in agreement with the finding of Escobar and Hue (2008), who observed an increase in Ca content with addition of organic manures and a decrease with incubation time. The content at the end of the study period was lower in all the treatments. But a reverse trend was observed for Mg. After the initial decline up to 90 D, the Mg release increased up to 300 D. Cattanio *et al.* (2008) also observed a slow release of Mg and the highest release was during the 14th week of incubation. In all the treatments the Mg content at the end of the study period was higher than initial. The S release pattern was opposite to that of

Ca but almost similar to N. This is expected because S mineralization is closely associated with N as both nutrients are present in the soil organic pool (Ali *et al.*, 2015). The highest release was observed from 120 M to 150 M. The result is in agreement with the findings of Ali *et al*. (2015).

There was no significant variation among treatments in micronutrient release as observed by the uniformity of release curves. The Fe and Mn availability, although increased with incubation, kept a similar pattern of release for all the treatments including S. Since the soil tests revealed high status of availability of these nutrients, Fe and Mn were not applied in any of the treatments. Rostami and Ahangar (2013) reported an increase in exchangeable Fe and Mn with application of cow manure. But the availability of Zn in the same experiment was reduced due to its strong bonding to the inorganic soil colloids mainly Fe and Al oxides by specific adsorption. Cu, though not applied, showed a general decreasing pattern in all the treatments except OFSTSM. Application of organic manures increases the adsorption and complexation of Cu in soil thereby increasing the organic-bound fraction and decreasing the soluble and extractable Cu fraction (Bolan *et al.*, 2003). But the content of all other micronutrients increased with days of incubation. Kamaraj *et al.* (2010) reported that fortification of organic manures with micro nutrients is more beneficial because chelation of the added nutrients by organic manures helps in slow release according to the crop need. It is interesting to note that the mineralization- immobilization cycle repeated several times during the study period in the case of micro nutrients and resulted in a lower level of Mn, Cu and Zn and higher level of Fe and B in all the treatments at the end of the incubation period. The results obtained are in conformity with the observations of El-Naggar *et al.* (2015). From the results obtained in the study, it can be deduced that the availability of nutrients at any given time is proportional to the product of nutrient content and soil microbial population. This means that either by increasing the nutrient content or by doubling the microbial population at any given time, the availability can be doubled and can be expressed by the equation

$A = A_0 e^{-kt} \cos \omega t$, where A = availability at any given time, A_0 = initial availability, t = time, ω = measure of periodicity and k = measure of decaying rate.

The laboratory incubation study thus reveals the efficiency of COF compared to FYM in binding of plant nutrients and their slow release in rates which could efficiently be used by plants. The study clearly proves the superiority of COF over FYM.

5.3 EFFECT OF COF ON LABILE CARBON DYNAMICS AND YIELD OF NENDRAN BANANA

5.3.1 Kinetics of pH and EC

The soil of the experimental site was acidic in reaction with 1.69 % OC. Nutrient availability status was medium in N and high in P and K. Among secondary nutrients, only Mg was deficient. B was the only deficient micronutrient. In contrast to the results obtained under laboratory conditions, a gentle decrease in pH was observed in all the treatments in the field experiment. At harvest stage the values reached below the initial values. A decrease of 0.53 to 1.57 units in different treatments was observed. The decrease was drastic in F. The decreasing effect is due to the production of organic acids (Li-Xian *et al.*, 2007) during decomposition and mineralization of organic manures. Meng *et al.* (2005) also reported similar results in a long term study with organic amendments. But it should be noted that in the treatment OFSTSM where COF was applied basally a gentle decrease of 0.57 units was recorded. This is because COF, besides having a neutral pH, was enriched with lime which would have provided a buffering effect. The temporal change in EC followed the same pattern in all the treatments, peaking at 4 M except in FFSTSM (F). In the first 4 months EC values increased and then decreased in all the treatments. The trend observed corresponded well with the release pattern of N, K, Mg, S, Fe, Mn and B in different treatments. Soil EC is a measure of soluble nutrients in soil and gives an indication of the rate of mineralization of organic matter (De Neve *et al.*, 2000). Significant increase in EC with application of different types of organic manures had been reported by many scientists (Selvakumari *et al.* , 2000 ; Courtney and Mullen, 2008 ; Dikinya and Mufwanza, 2010; Azeez and Van Averbeke, 2012; Anand *et al.,* 2015; Meeinkuirt *et al.*, 2016; Moran-Salazar *et al.*, 2016).

5.3.2 SOC, C Pools and C Sequestration Potential

The SOC dynamics in the field experiment exhibited a slightly different pattern compared to that of the laboratory incubation study. Instead of several short cycles, longer duration cycles represented by smooth curves were observed in field study. Organic matter decomposition is a biological activity. The laboratory conditions provide constant temperature and moisture conditions by which the organic matter decomposition rates are optimized (Risk *et al.*, 2008; Rinkes *et al.*, 2013). Microbial functional behaviour under laboratory conditions are thus homogenized as against heterogenous behaviour under field conditions (McGuire and Treseder, 2009). In the field experiment, a gentle decline in SOC content was observed up to 4 M after which a slow increase was recorded except in OFSTSM, where the decline continued up to 6 M.

But as in the case of laboratory incubation, the SOC content in all the treatments except OFSTSM reached the initial status at harvest stage. Initial rise and later decrease in SOC content with application of organic residues has been reported by Roy and Kashem (2014). In the case of OFSTSM, the status continued in the rising trend indicating that it would take more time to reach the initial status because the initial value in this treatment was higher than the others. This is indicative of a larger pool of easily decomposable C fractions available in this treatment (Follett *et al.*, 2007). Three phases of organic matter decomposition have been discerned, the first phase which shows a short turnover time with a loss of about a quarter to two-thirds of the initial C (Jenkinson and Ladd, 1981), followed by a phase of slow decomposition, with a total loss of about 90% OM and finally a third phase with very slow decomposition rates and long turnover times of about 100 to more than 1000 years. This slow or refractory soil OM pool is responsible for the long term stabilization of C in soils (Falloon and Smith, 2000). The COF produced by the thermochemical treatment contained easily decomposable materials which could immediately be used by microorganisms once applied to soil. This point is underlined by the high status of labile C in this treatment throughout the crop growth period (Fig. 14).The turnover rate of labile C fraction decides the nutrient dynamics and the soil physical factors, especially soil structure (Whitbread, 1995). Three types of binding agents namely transient, temporary and persistent binding agents act in the formation of soil structure. The high labile C in OFSTSM denotes that it has a high quantity of transient binding agents like extra cellular mucilages or gums produced by microbial activity and root exudates. The lower labile C in F might be due to the formation of stable complexes between the lignin and polyphenols in FYM with proteins that make it more resistant to decomposition and less labile (Tian *et al.*, 1992).

However, the lability and lability index (Fig. 15 and 16) were lower in COF than the other treatments indicating that the non labile C fraction (Fig. 17) was also high in COF. Non labile fraction represents humic substances slowly decomposable due to their high molecular weight or their aromatic structures or their association with the clay minerals (von Lutzow *et al.*, 2006). Sollins *et al.* (1996) identified three major mechanisms for protection of OM from decomposition; the molecular character of soil OM (recalcitrance), low accessibility for microorganisms, and interactions with mineral particles. The decomposition stage is followed by condensation and polymerization reactions that create new larger molecules from the small molecules released during decomposition. Though these are largely biologically driven, there is also significant evidence for abiotic condensation and polymerization reactions at mineral surfaces. Consequently, the nature of the soil biotic community and the mineral phases present in the soil are key factors in the alteration process.

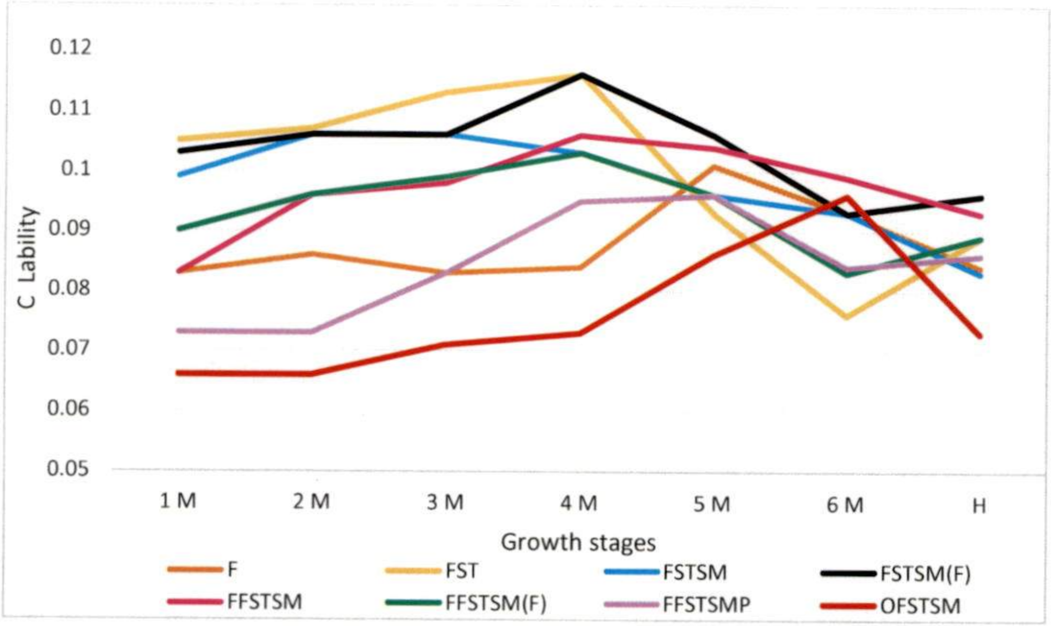

Fig. 15. Soil carbon lability at different growth stages of banana

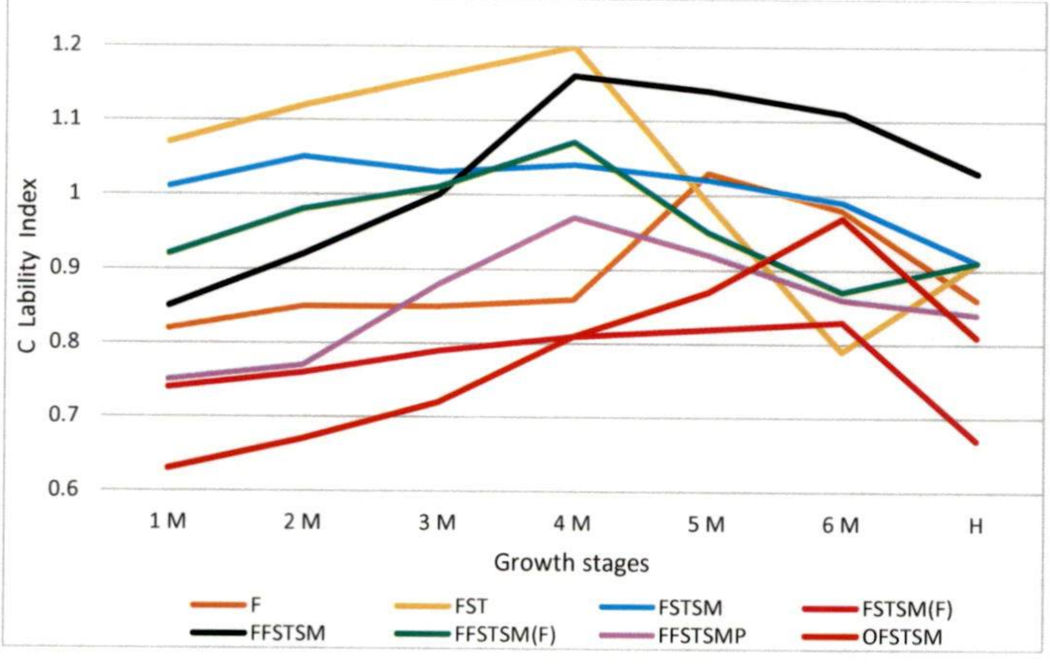

Fig. 16. Soil carbon lability index at different growth stages of banana

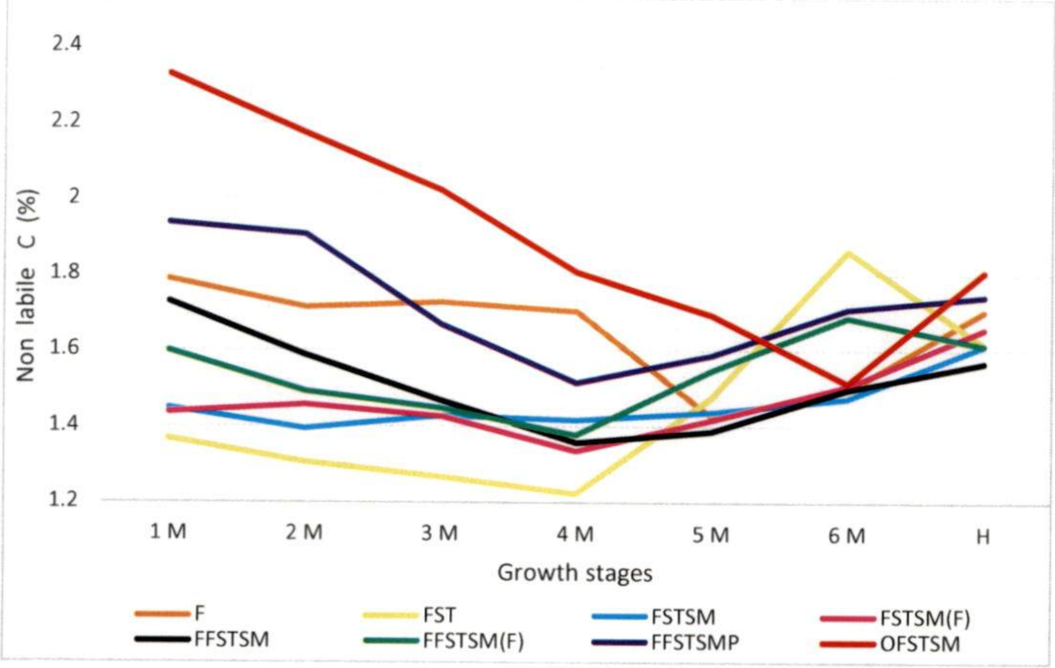

Fig. 17. Non labile carbon at different growth stages of banana

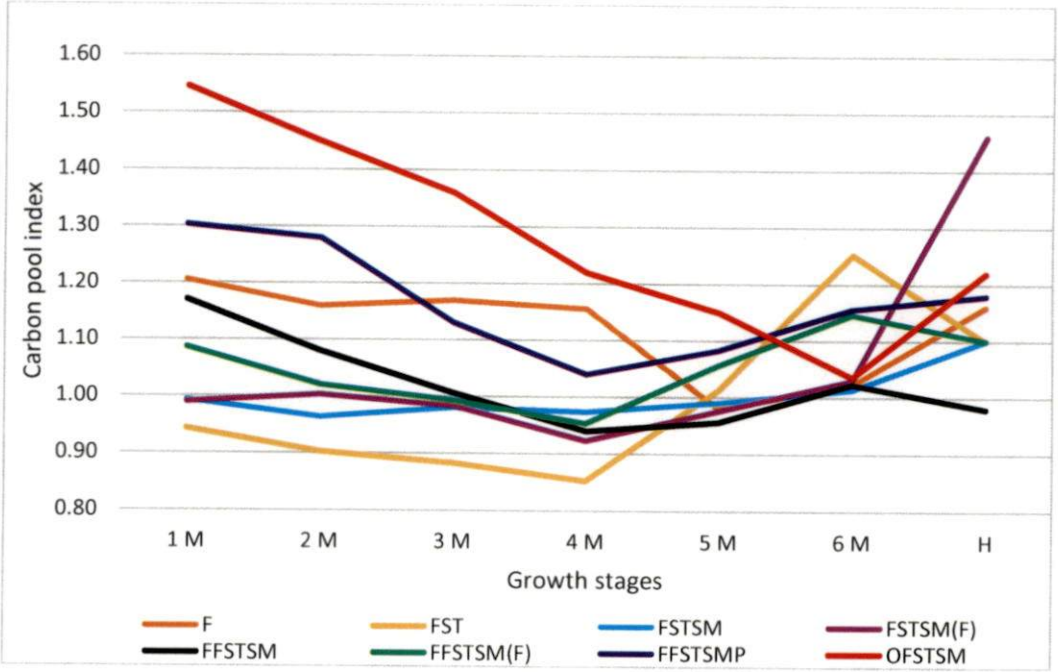

Fig. 18. Soil carbon pool index at different growth stages of banana

It is interesting to note that the two dominant and frequently studied groups of soil microorganisms, fungi and bacteria, differ in their SOC sequestration potentials. Though the mechanisms are not correctly understood, it is thought to be related with the difference in Carbon Utilization Efficiency (CUE) of the two groups. Bacteria have been reported to be having lower CUE than fungi (Hodge *et al.* 2000). Hence bacteria respire a greater proportion of metabolized C as CO_2 and thus contribute less to stabilization of SOC pools than fungi. They also differ in the nature of the extracellular enzymes they produce. Large amounts of phenol oxidases, lactases, and peroxidases are produced by fungi which help them to decompose lignin compounds and promote condensation reactions. Bacteria, on the other hand, produce more lipases and cellulases needed to break down non lignitic materials. The constituents of humic materials are mostly the monomers derived from degradation of lignitic materials and hence an abundance of fungi in the soil indicates a high humification potential. At the same time, the activity of extracellular enzymes which decompose the non labile fractions, have only a limited life span in soils (Amonette *et al.* 2003). These enzymes are adsorbed by soil solids, with varying effects on their ability to catalyse decomposition. Although enzyme sorption to minerals limits access to potential substrates and restricts decomposition to regions near the source of the enzyme (George *et al.* 2007), longevity and total activity over the life of the enzyme increase (Boyd and Mortland 1990; Shen *et al.* 2002). However, sorption of the enzyme to the substrate is the key process. Schimel and Weintraub (2003) suggested that a limited number of sorption sites exist on a substrate surface and hence, once these sites are saturated by enzymes, additional enzymes must diffuse farther from the source and return less product to the microorganism that synthesized them. This negative feedback loop, obeying Michaelis–Menton equation, regulates the production of extracellular enzymes by microorganisms. From these it can be inferred that a high lignin content in COF contributing to a higher non labile fraction in OFSTSM supports fungi population in preference to bacteria. A high labile C fraction in COF points to its ability to feed a large group of rhizosphere population, and the higher content of non labile fractions indicate its ability for favourable organic matter – mineral interactions leading to its protection from decomposition. Thus a higher concentration of non labile C together with this type of protection might have helped to sustain a high CPI in OFSTSM. A higher CPI in OFSTSM compared to the FYM treatments show that application of COF reduced soil C loss and retained a higher status of SOC. Hence this treatment is effective in imparting a better quality to soil for a longer period. But though the OFSTSM exhibited the highest value up to 5 M, the non labile C fraction and CPI followed the same pattern in all the treatments. The treatment FFSTSMP also exhibited same trend in all these parameters and closely followed OFSTSM in different C fractions and CPI (Fig.18).

Build-up of OC in soil is the result of an imbalance between addition and loss of C from soil organic matter stocks. Carbon sequestration occurs when a positive disequilibrium is maintained over some period of time, with the system eventually achieving a new, higher steady state. Because storage of SOC in soils is dynamic, the residence time (τ) of C in the soil is a major determinant of the capacity of a soil to sequester C (Luo *et al.* 2003). An increase in τ can sequester SOC even without an increase in external inputs. The non labile fraction of COF thus helps to enrich the SOC stock in soil. Application of composts is reported to raise the SOC stocks compared to manures (Fliessbach *et al.*, 2007). Enrichment of C in soil is affected not only by stability of SOC pools but also by supply of nutrients such as N (Beedy *et al.*, 2010). The combined effect of inorganic and organic nutrient pools in OFSTSM releasing nutrients over a longer period in a sustained manner support the rhizosphere population over the entire cropping period. Zhao *et al.* (2016) reported that in unfertilized soils or in soils where balanced fertilizer application was not followed, the nutrient availability was low which limited crop growth and productivity. The C inputs by way of rhizodeposits were low in such cases because they are used for sustaining microbial activity (Kuzyakov, 2010). This indicates the importance of application of nutrients in amounts needed by the crop for maintaining a high crop growth rate by which a part of the biomass formed could be returned to the soil to sustain a significant C sequestration rate. The high quantity of non labile fraction in OFSTSM thus proved that it was able to maintain a stable concentration of polysaccharides to ensure aggregate stability and sustain an active rhizosphere microbial population for a longer cropping period. This shows the superiority of COF over the conventional manures like FYM, wherein at rates five times lower than FYM, COF can support longer duration crops with an enhancement in yield. We can see that there is a significant correlation with these parameters and yield. Crop production with balanced fertilization and C supplementation has been reported to increase SOC content and crop productivity (Majumder *et al.*, 2007).

5.3.3 Mineralization of Nutrients and their Soil Availability

The N mineralization in all the treatments except FST followed the same trend as that of labile C. But when compared to the laboratory incubation study, the N mineralization pattern was different in the field experiment. Under laboratory conditions N mineralization followed a constant rate without any increase or decrease. But under field conditions N_{min} was more efficient as is evident from Fig. 19. This may be because of the rhizosphere priming effect under natural cropping conditions. The magnitude of variation among the treatments was the highest in OFSTSM. The release of N from organic manures is decided mainly by its chemical composition (Mohanty *et al.*, 2011) and the nature of soil microorganisms. Organic manures with high N content and low C:N ratio mineralize N in sufficient quantities for plant use (Cordovil *et al.*, 2005). The treatments F, FFSTSM and FFSTSMP exhibited same pattern throughout the crop growth period. Although the pattern was similar, actual N availability was high in FFSTSMP. This treatment was enriched with PGPR in addition to the essential nutrients. PGPR inoculation benefits the plants in several ways. It is reported to have capability of nitrogen fixation, thereby improving the N availability in soil. It produces several types of secondary metabolites like antibiotics and hormone like substances which enhances plant growth. Kohler *et al.* (2009) observed that PGPR not only contributes to nutrient availability but they can also bind soil particles into stable aggregates thereby improving soil structure and reducing erosion potential. Stimulation of root growth by inoculation of PGPR has been reported by Lucy *et al.* (2004). Mung bean yield was significantly increased with application of bio fortified (PGPR) organic matter (Ahmad *et al.*, 2012). It has been reported that an abundant supply of N in soil reduced C pools in the microbial biomass (Powlson *et al.*, 2010) and lowered metabolic quotient, thus favouring soil C retention and the process of humification. Slow rates of N_{min} in soils amended with stabilized manures had been reported (Romanya *et al.*, 2012).

A steady increase in P availability was observed in all the treatments up to 4 M after which a steep increase was recorded up to the harvest stage. FYM and COF release P slowly and in right proportions for uptake (Fig. 20). The increased availability may be attributed to the P release from Fe and Al compounds by the chelating action of organic anions (Reddy and Reddy, 2005). In banana the fertilizers are applied up to six months which coincide with stages of active uptake and as a result after six months even if the P availability in soil is high, it will not be properly utilized by the plant. K availability also remained high up to 4 M in all treatments other than OFSTSM where the status remained high up to 6 M. However the values at harvest stage were lower than the initial in all treatments. The nutrient uptake pattern in the treatments in relation to the growth parameters shows that the internal nutritive condition in the initial stages of growth resulted in active growth of plants. Sharma *et al.* (2013) reported that organic sources of nutrients hastened translocation of assimilates from source to sink as influenced by growth hormones. The foliar nutrient concentrations and their rate of changes during vegetative and transitional period between vegetative and the reproductive phase determine the bunch yield in banana (Vanilarasu and Balakrishnamurthy, 2014).

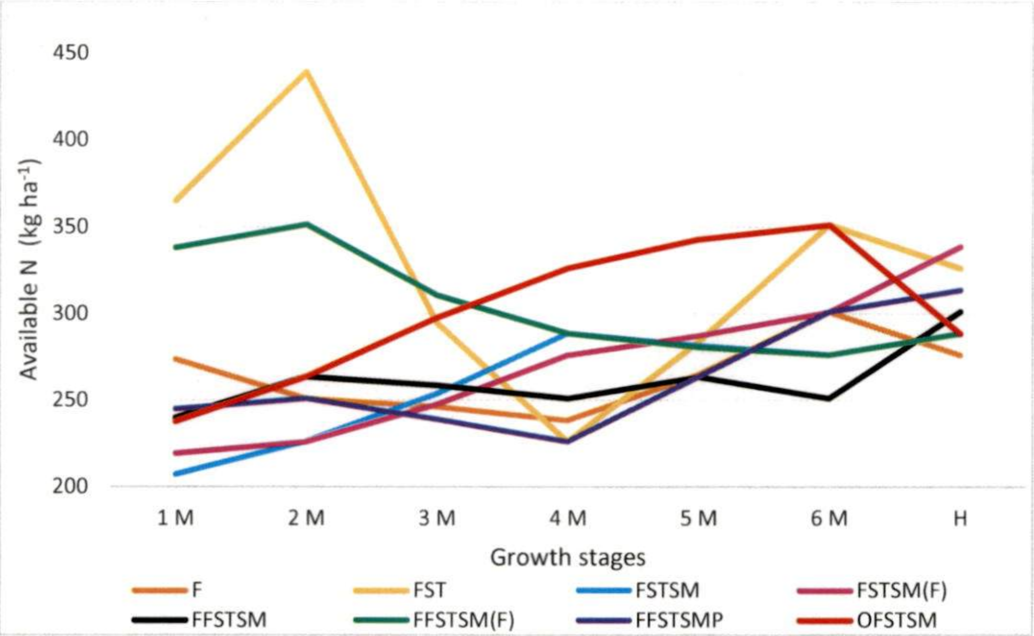

Fig. 19. Content of soil available N at different growth stages of banana

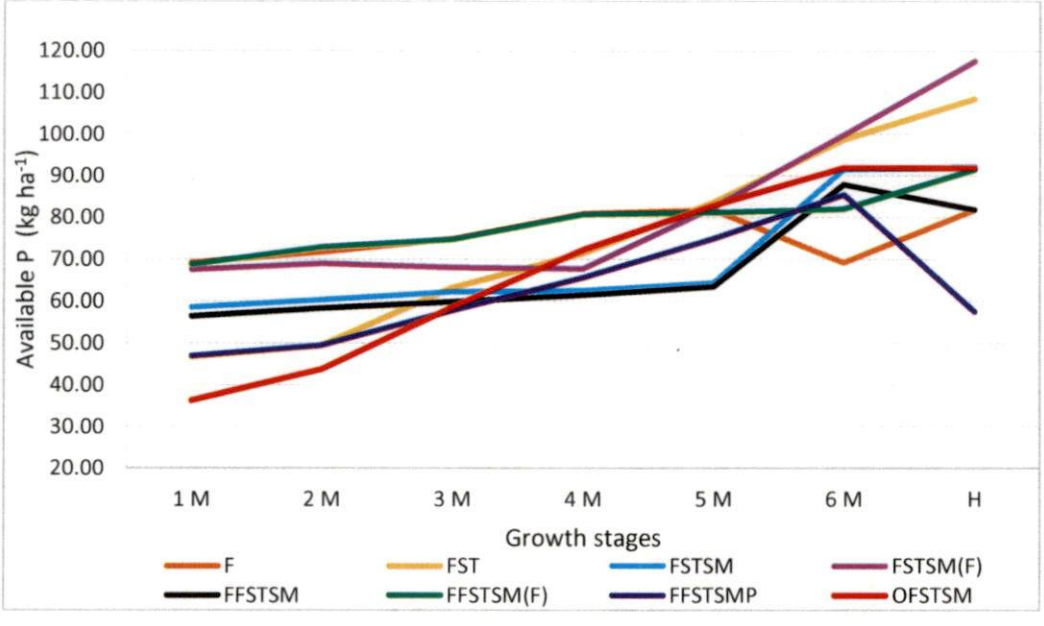

Fig. 20. Soil available P at different growth stages of banana

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The Ca availability was low up to 6 M after which an increase was recorded. In OFSTSM, the Ca availability at 6 M was high. Then it decreased up to harvest stage. This is a clear indication of K:Ca antagonism. But the final values were higher than initial in all the treatments. Mg availability increased steadily up to 4 M after which a decrease was observed and the values fell below the initial values at harvest stage. S availability in all the treatments increased up to 4 M after which it decreased steadily and reached lower than initial values at harvest. An increase in major nutrients Ca, K and Mg in soil with application of organic manures have been reported by Bulluck *et al.* (2002). An increase in soil Mg availability was reported by Herencia and Maqueda (2016) when vegetables were cultivated with organic manures. The increase in availability of Ca and Mg was expected since COF was enriched with these nutrients.

The availability of micronutrients also registered an increasing trend except in B where the values gently decreased to the lowest at the time of harvest. The status of Zn did not vary much between the initial and final values. An increase in micronutrient concentration in soil has been reported (Herencia *et al.*, 2008) with application of organic amendments. Formation of stable complexes by chelation between functional groups of organic compounds and metals block their sorption increase their concentration in soil solution (Madrid, 1999).

5.3.3 Plant Nutrient Concentration and Yield

Wide variation was obtained on the foliar concentration of nutrients at different stages of crop growth. N tended to accumulate in F as evidenced by a high concentration even after 6 M, whereas P and K concentration were lower than OFSTSM. N, P and K which are the primary major nutrients are required from the initial stages to harvest, but the main period of uptake is during leaf and pseudostem growth (Thangaselvabai *et al.*, 2009). Phyllochron or the rate of leaf production is an important factor to be considered during vegetative growth. N influences the number of leaves produced, time taken for unfolding and longitudinal growth of petioles (Gonge e*t al.,* 2015; Navaneethakrishnan *et al.*, 2015; Ramesh and Ramassamy, 2015). The number of leaves during the first four months is positively correlated with the bunch size (Hazarika *et al*., 2015). Thicker pseudostem give better anchorage for the plant protecting them from strong winds. Pseudostem thickness is directly related to banana bunch size (Hazarika and Ansari, 2010). The foliar nutrient concentration varied closely related to their availability in soil. In the case of P, the foliar concentration was highest in the initial stages and after 6 M. A sufficient supply of P is necessary for production of healthy rhizome and a strong root system. It also influences flower setting (Yuan *et al.*, 2013; Kalaivanan *et al*., 2014).

K:Ca antagonism was very much evident as shown in Fig. 21 and 22. K absorption was also high in the initial stages which decreased up to 6 months and then increased. Banana is a high K demanding crop. The high uptake after 6 M was necessary for proper translocation of assimilates to the sink for proper finger development (Kuttimani *et al.*, 2013). K improves size of fingers and quality of fruits. Banana is known for high content of K in pseudostem. Hence part of the K absorbed after 6 M might have deposited in pseudostem.

The rate of uptake of secondary nutrients was high up to 6 M after which Ca concentration decreased up to harvest. At a certain stage, deficiency symptoms started appearing on the leaves (Plate 7) in all the treatments which necessitated foliar spray of calcium nitrate @ 2 g L^{-1}. Sufficient quantity of Ca is important for the proper uptake and utilization of N and micronutrients (Raghupathi *et al.*, 2002). Mostafa and Abd El-Kader (2006) reported the beneficial effect of Mg and S on the growth and yield of banana. Hence an increased uptake of these elements in treatments OFSTSM and FSTSM had promoted plant growth leading to higher yield. The main repositories of Ca and Mg are leaves, pseudostem and corm (Raghupathi *et al.*, 2002). The uptake of Mg and S was continued after 6 M. Uptake of Mg and S even after 6 months has been reported by Raghupathi *et al.* (2002). It is worth noting that Mg deficiency was observed in treatment F and FST where Mg was not supplied (Plate 8). However it should be noted that there was no leaf symptom even when severe deficiency symptoms were manifested in the pseudostem. Development of Mg deficiency in the pseudostem of banana as a result of upsetting of K:Mg ratio has been reported by Sathiamoorthy and Jeyabaskaran (2001).

Among the micronutrients, Fe absorption was the highest at 6 M which coincided with the flag leaf formation. The uptake pattern of Mn and Zn on the one hand and Mg and B on the other, were very much similar pointing to the synergistic effects of these nutrients in their uptake. Uptake of Mn, Zn and B were higher at the flowering and fruit setting stage. This is because these nutrients have vital roles in flower and fruit initiation. The effect of Zn and B in increasing fruit set and number of fruits have been reported by Saadati *et al.* (2016). But Cu was mainly absorbed at the vegetative phase. Cu is reported to increase the vegetative growth of plants (Kanwal *et al.,* 2016). Micronutrient application had a significant influence on bunch yield as seen in the treatments FSTSM and OFSTSM as compared to F and FST. Micronutrients Fe, Mn and Cu are essential for photosynthesis, oxidation-reduction reactions, electron transport, chlorophyll synthesis, synthesis and activation of various enzymes etc. The effect of micronutrients on enhancing various metabolic processes influencing higher yield had been reported by many workers (Borges and Caldes, 2004; Mahouachi, 2007).

A study on partitioning of nutrients in banana revealed that sulphur was evenly distributed in the plant whereas Fe was mainly concentrated in root or stem and majority of Mn, Zn and Cu was found mobilized in leaves (Raghupathi *et al.*, 2002). The plant growth parameters like number of leaves, plant height, girth thickness etc. were significantly higher in FSTSM and OFSTSM compared to others. The greater number of leaves might have helped in achieving more photosynthetic efficiency by providing larger leaf area for harvesting maximum sunlight. This was well reflected in bunch yield (Table 69). Significant positive correlation has been reported between pseudostem girth and bunch yield of banana (Wairegi *et al.*, 2009). There was a strong correlation between these two parameters in the present experiment also (Table 70).

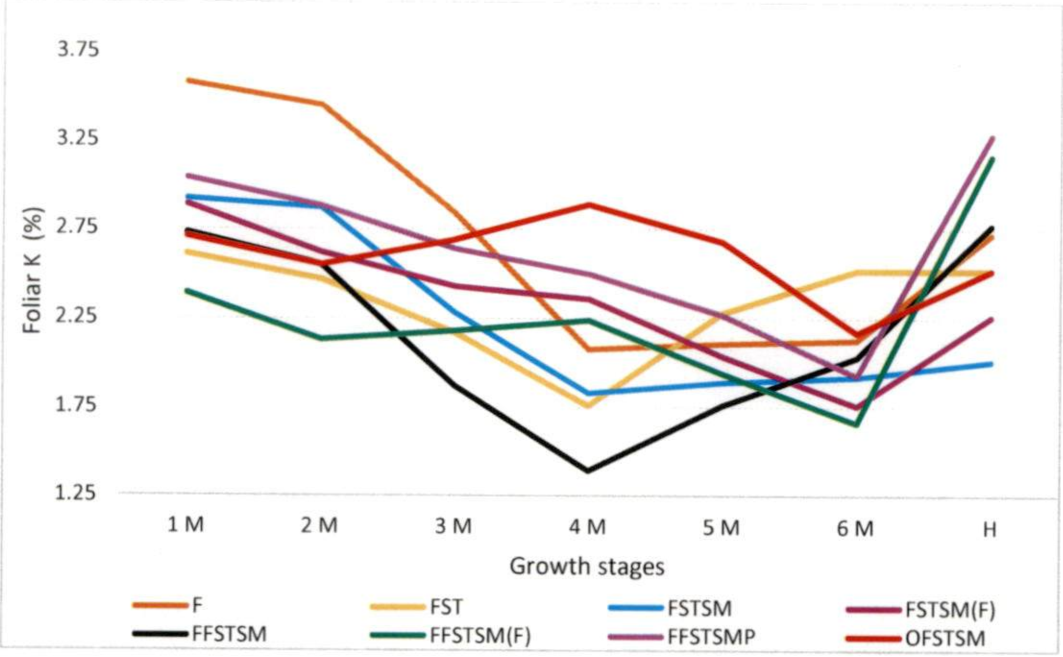

Fig. 21. Foliar K concentration at different growth stages of banana

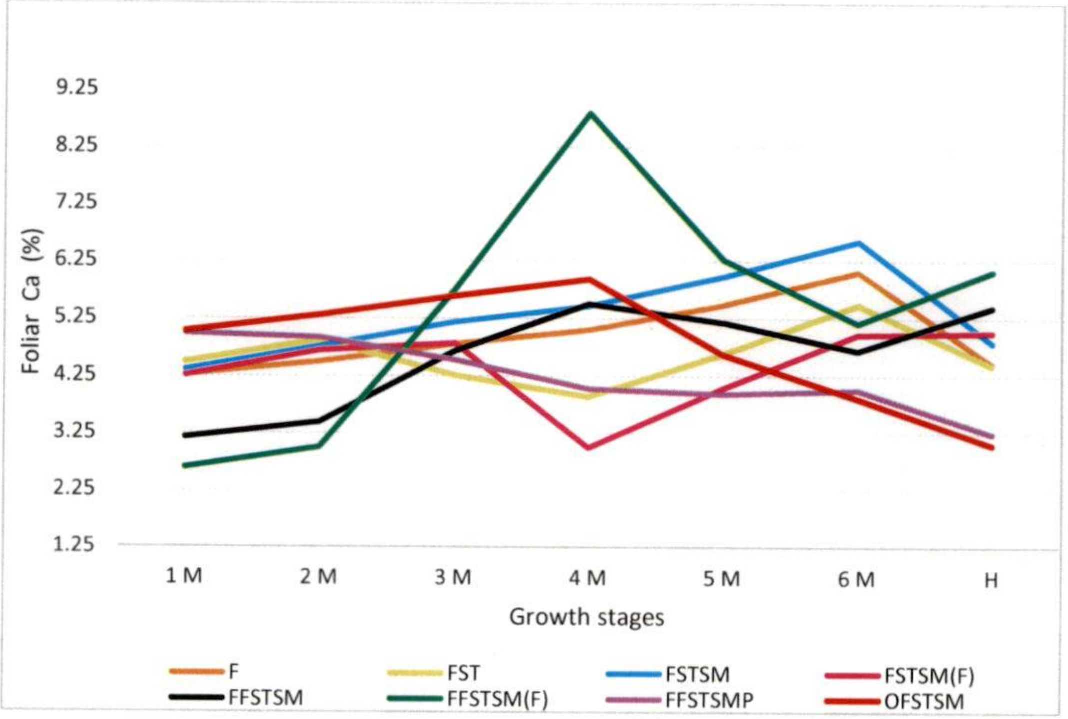

Fig. 22. Concentration of foliar Ca at different growth stages of banana

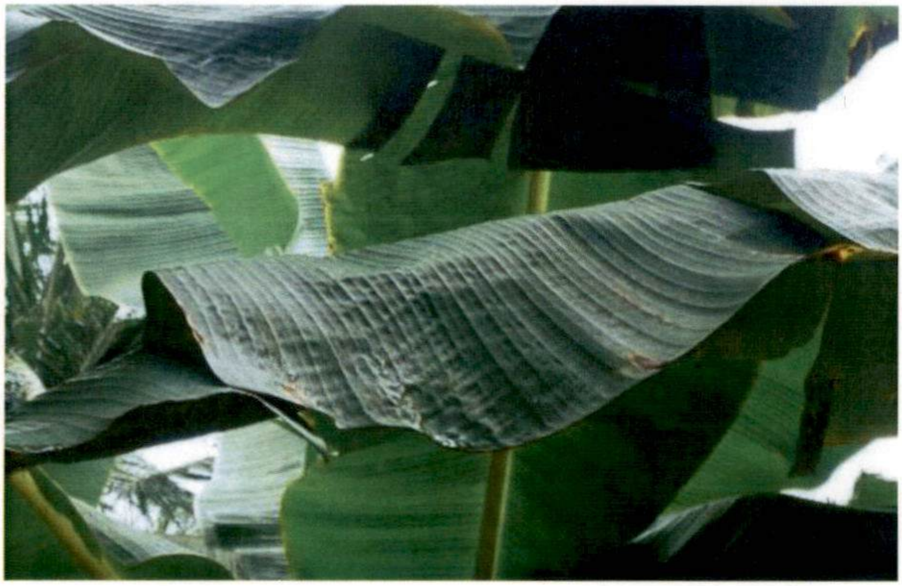

Plate 7. Ca deficiency symptom observed in the field

Plate 8. Mg deficiency symptom observed in the field

SUMMARY

6. SUMMARY

The study entitled 'Evaluation of a customised organic fertilizer in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana' was undertaken during October 2014 to August 2016 at the College of Agriculture, Vellayani with the objective of evaluating the customised organic fertilizer obtained from biodegradable solid waste by rapid thermochemical conversion technology, in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana in agro-ecological unit 8 of Kerala. The study comprised of characterisation and assessment of compost maturity parameters of the organic fertilizer obtained from degradable solid waste by rapid thermochemical conversion technology and evaluation of the customised organic fertilizer in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana in agro-ecological unit 8 of Kerala. A summary of the salient results of the study are presented.

Characterisation studies of DSW and OF

- Compositional assessment revealed the dominance of cooked food waste (45 %) in the DSW from households.
- Physical characterisation studies showed that DSW had very high moisture content (70.56%), high bulk density (1.49 Mg m^{-3}), had only 25 % of particles less than 4 mm in size and emitted a foul odour on keeping. More than 95% particles in OF were less than 4 mm, with low moisture content (16.4 %) and bulk density (0.76 Mg m^{-3}) and was devoid of any obnoxious odour.
- Chemical analytics proved that DSW was acidic in reaction with high EC and TOC whereas processed OF had a neutral pH, low EC and TOC.
- The content of major nutrients in OF exceeded that of DSW but the status of secondary and micronutrient contents of both DSW and OF were sufficient.

- Heavy metals Cd and As were below detectable levels and Pb, Ni, Cr, Zn, Cu were within safe limits and as such OF does not pose any environmental hazard.
- Biochemical analysis revealed that the rapid thermochemical processing resulted in a 38.14 % decrease in cellulose content and a decline in tannin content. However an increase in hemicellulose, lignin, crude fibre and total protein contents were observed.
- Evaluation of maturity parameters revealed that unlike in DSW, OF recorded a C:N ratio of 13.7, CEC of 85.70 cmol kg^{-1} and CEC/ TOC ratio of 3.99, in conformity with prescribed standards. Even though $NH4^+ / NO_3^-$ ratio of OF was lower, it exceeded the index value.
- The higher content of C_w, C_{EX}, C_{HA} and lower C_w/TOC ratio and C_{FA} in OF than in DSW is an indication of the degree of humification of the OF as compared to DSW.
- The indices indicating the degree of humification *viz.*, Polymerisation Index (2.78), Humification ratio (14.06), Humification Index (10.33) and Percent of Humic Acids (73.51) recorded values higher than prescribed minimum standards.
- Respirometric studies yielding very low CO_2-C (6.11 mg CO_2 $kg^{-1}h^{-1}$), high GI (84%) and absence of microbial colony forming units in serial dilution and plate count tests bear testimony to the non phytotoxic nature of OF.
- Correlation studies showed that the CEC and CEC/TOC ratio had high positive correlation with maturity parameters whereas C/N ratio had a high and significant negative correlation.
- The fertilising index value of 4.7 and a clean index value of 5.0 which indicate the nutrient supplying potential and eco friendliness of organic fertilizers, qualify OF to be a Class A marketable organic fertilizer.

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Soil incubation experiment to study the nutrient release characteristics of COF

- COF based treatments OFSTSM and FFSTSMP recorded the highest pH at various stages of incubation whereas temporal variations in the EC pattern exhibited a trend contrary to pH, with treatment F registering the highest EC.
- OC content remained high in all the manured treatments throughout the incubation period, regardless of source, than in soil alone indicating the importance of organic manure addition.
- A steady and constant OC release pattern was seen in the OFSTSM treatment. Though there was a gradual initial decline in OC up to 90 D, it increased thereafter in the OFSTSM treatment.
- The N release pattern was characterised by a 120 day cycle in which a net N mineralization was observed on 10 D and a net immobilisation on 20 D.
- N release rate was high throughout in soil alone treatment while OFSTSM yielded a steady and constant release pattern throughout 300 D of incubation which points to the efficiency of the organic fertilizer with fortification.
- The highest P mineralization was recorded at 150 D but a phase of total immobilization was observed from 180 to 240 D in all treatments irrespective of the nature and source of organic manures. However the highest P availability was noticed in the COF based treatments.
- The K release pattern exhibited two short spells of mineralization and immobilization up to 60 D, which then progressively mineralized reaching highest at 240 D. The F treatment showed the highest K release while it was lowest in the control treatment.
- A homogeneous Ca release pattern with a Ca mineralization – immobilization cycle of 120 days was observed in all treatments. The Ca release pattern was almost similar to P release pattern.
- The highest Ca release was registered by the OFSTSM treatment. FYM based and soil alone treatments accounted for lowest Ca availability at all periods of incubation.

- While the F and FST treatments dominated the availability of Mg in the former half, it was the COF based treatments which yielded highest Mg in the latter half. A similar mineralization pattern was observed for K and Mg.
- The temporal variation in S mineralization was found to be identical to that of the N release pattern. A net mineralisation at 150 D was noticed invariably in all treatments with PGPR applied COF treatment FFSTSMP registering the highest availability. F and FST treatments registered lowest availability throughout the incubation period.
- Among the micronutrients, the kinetics of Fe release was characterised by mineralization-immobilization cycles in consecutive repetition at an interval of 60 D, with the COF based treatments registering the highest availability.
- Mineralization of Mn and Zn was the highest on 20 D. COF based treatments dominated in both the cases especially when there was a net Zn immobilization at 60 to 150 D.
- OFSTSM, FFSTSM and FFSTSMP treatments recorded higher Cu release values.
- COF based treatments registered the highest B availability at all stages while the FYM based treatments along with the soil alone treatment recorded the lowest mineralization. As much as 80 % of the cumulative B release at 60 D was constituted by the COF based treatments.

Effect of customised organic fertilizer on labile carbon dynamics and yield of Nendran banana

- An obvious difference was observed in the temporal variation of SOC under lab and field conditions. Longer duration cycles represented by smooth curves reflecting heterogenous and buffered field conditions was evident in the field contrary to the homogenous lab conditions.
- Temporal dynamics of the different carbon pools revealed a high content of labile C, non labile C and carbon pool index in OFSTSM which indicated

an immediate energy source for rhizospheric microorganisms, reduced soil C loss with the prospect of maintaining a higher status of SOC.

- It was observed that the soil pH and WHC of COF treatments and EC of FYM treatments increased with the growth stages. The COF treatments FFSTSMP and OFSTSM recorded the highest WHC.
- Soil nutrient analysis revealed the superiority of the COF based FFSTSMF and OFSTSM treatments which yielded the highest available N and K in most of the stages while P availability was highest in FYM treatments.
- The release pattern of Ca remained low up to 6 M and then increased attaining higher than initial value with FYM treatments being dominant which is an indication of K: Ca antagonism.
- The kinetics of available Mg and S showed a steady increase up to 4 M and then declined to lower than initial values at harvest with highest availability in COF based treatments.
- Temporal variation in micronutrient availability generally displayed an increasing trend except in B which showed an overall decreasing trend.
- Domination of the COF based treatments in availability of Mn, Zn and Cu was observed. Fe and B availability was highest in FYM based treatments up to 4 M and in COF based treatments thereafter.
- An enhanced dehydrogenase activity was observed in OFSTSM in initial stages and in FFSTSM (F) at the later stages of crop growth whereas the FYM treatments registered the lowest activity at all stages.
- In the case of foliar N content , COF based FFSTSM treatment dominated up to 4 M of crop growth of banana while the COF based FFSTSM and FFSTSMP treatments had highest P content up to 4 M.
- Foliar K concentration was the highest in COF based OFSTSM and FFSTSMP treatments from 4 M.
- The COF treatments OFSTSM and FFSTSM(F) recorded highest Ca content while FFSTSMP and FFSTSM (F) recorded highest S content.
- Among the micronutrients, foliar Fe concentration was highest at 6 M stage which coincided with the flag leaf formation in banana whereas the foliar

concentration of Mn, Zn and B were higher at the flowering and fruit setting stage.

- Foliar concentration of Mn and Zn on the one hand and Mg and B on the other were very much similar indicating the synergistic effect of these nutrients in their uptake by the crop.
- The temporal variation in leaf Cu concentration clearly confirms the role of Cu in the crop vegetative growth and development.
- Among the plant growth and yield characters in banana, the COF based OFSTSM treatment recorded the highest plant height, pseudostem girth, number of leaves per plant, dry leaf weight, rhizome weight, fruit weight and total dry matter production.
- The COF based OFSTSM treatment was on par with the FYM based STB treatment FSTSM with regard to pseudostem weight, bunch weight, number of fingers per bunch, length of peduncle and girth of index finger.
- OFSTSM, the treatment with COF and STB based basal and split applications in banana was superior with regard to the number of hands per bunch, weight of index finger and length of index finger as compared to all other treatments.
- The OFSTSM treatment also recorded highest ascorbic acid content and highest shelf life of fruits.
- With a B:C ratio of 2.75, the OFSTSM treatment proved to yield the highest net returns as compared to all the other COF and FYM based STB treatments.

CONCLUSION

Organic fertilizer produced through rapid thermochemical processing is a class A marketable organic fertilizer conforming to physical standards, nutrient and heavy metal contents, various maturity parameters and is non phytotoxic. Customisation of organic fertilizer on the basis of soil test results proved to be effective in correcting soil pH and providing a steady and constant supply of OC and available N without a net immobilization or mineralization. Sustained releases

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of P, Ca, S, Fe, Mn, Zn, Cu and B all throughout and Mg in the latter half stages of incubation were found to exist in these treatments as compared to the FYM treatments. An enhancement in the labile carbon pool ensuring immediate energy source for the rhizospheric microorganisms and the non labile carbon pool which helped augmenting long term carbon sequestration was evident. Consequently the physical, chemical and biological properties of soil were favourably modified which enhanced various yield attributes ultimately resulting in a higher yield, superior fruit quality and higher net returns.

FUTURE LINE OF WORK

- Enumeration of microorganisms in the rhizosphere with and without addition of OF in comparison with popular organic sources to be carried out.
- Rhizosphere priming effect on the decomposition and nutrient release pattern of OF has to be carried out.
- In the light of emerging theories, the possibility of humus formation by abiotic polymerisation reactions in the case of OF has to be investigated.
- Crop response of banana to higher rates of OF application needs further study.
- Standardisation of the rate of application of OF with regard to other crops and intercrops.

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APPENDICES

Appendix –I

A. Criteria for assigning weighing factor to fertility parameters

	Score Value (S_i)					Weighing factor (W_i)
	5	4	3	2	1	
Total Organic C (%)	>20.0	15.1-20.0	12.1-15.0	9.1-12.0	<9.1	5
Total N (%)	>1.25	1.01-1.25	0.81-1.00	0.51-0.80	<0.51	3
Total P (%)	>0.60	0.41-0.60	0.21-0.40	0.11-0.20	<0.11	3
Total K (%)	>1.00	0.76-1.00	0.51-0.75	0.26-0.50	<0.26	1
C:N	<10.1	10.1-15	15.1-20	20.1-25	>25	3
Respiration activity (mg CO_2- C/g VS d)	<2.1	2.1-6.0	6.1-10.0	10.1-15	>15	4

B. Criteria for assigning weighing factor to heavy metal parameters

Heavy metal (mg/kg)	Score Value (S_i)						Weighing factor (W_i)
	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	1.1-20	2.0-4.0	>4.0	5
Pb	<51	51-100	101-150	151-250	251-400	>400	3
Ni	<21	21-40	41-80	81-120	121-160	>160	1
Cr	<51	51-100	101-150	151-250	251-350	>350	3

Appendix –II

Weather parameters during the cropping period (October 2014 to August 2015)

Month and year	Temperature (^{0}C)		Relative Humidity (%)	Rainfall (mm)
	Maximum	Minimum		
October, 2014	30.52	23.82	84.67	230.20
November, 2014	30.18	23.38	82.85	137.30
December, 2014	31.2	23.25	86.30	133.50
January, 2015	30.61	21.56	79.44	8.00
February, 2015	31.53	22.34	78.25	0.00
March, 2015	32.42	23.65	78.53	56.10
April, 2015	32.74	24.48	83.50	182.60
May,2015	32.14	25.31	87.00	406.00
June, 2015	31.43	24.47	86.97	346.90
July, 2015	31.31	24.6	84.49	53.50
August, 2015	31.68	24.57	82.97	80.20

Appendix –III

Cost of cultivation of Nendran banana under different FYM and COF based treatments

Treatments	Cost of cultivation	
	(₹ ha^{-1})	(₹ plant^{-1})
F	611640	245
FST	561610	225
FSTSM	570660	228
FSTSM(F)	571285	229
FFSTSM	690660	276
FFSTSM(F)	690660	276
FFSTSMP	697660	279
OFSTSM	436360	175

F: FYM + NPK; FST: FYM + Soil Test Based (STB)$_{NPK}$; FSTSM: FYM + STB $_{NPK+Sec+Micro}$; (F): Foliar application of micronutrients; FFSTSM: FYM + COF; FFSTSMP: FYM+COF +PGPR I; OFSTSM: COF only

ABSTRACT

EVALUATION OF A CUSTOMISED ORGANIC FERTILIZER IN RELATION TO LABILE CARBON DYNAMICS NUTRIENT RELEASE CHARACTERISTICS AND PRODUCTIVITY OF BANANA

by

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Abstract of the thesis

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ABSTRACT

A study entitled 'Evaluation of a customised organic fertilizer in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana' was carried out at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, during 2013-16. The objective of the study was to evaluate the customised organic fertilizer obtained from biodegradable urban garbage by rapid thermochemical conversion technology, in relation to labile carbon dynamics, nutrient release characteristics and productivity of banana in agro-ecological unit 8 of Kerala.

Characterisation and assessment of the maturity parameters of degradable solid waste and the organic fertilizer produced from it were done. Organic fertilizer produced by thermo chemical treatment was odourless, with a particle size of < 4mm, low moisture content and bulk density compared to raw waste. It recorded a neutral pH, low electrical conductivity and total organic carbon. The content of major nutrients was higher in the organic fertilizer. Status of secondary and micronutrients was sufficient and heavy metal contents were within safe limits. Cellulose content in organic fertilizer decreased by 38.14% whereas hemicellulose and lignin contents increased. Organic fertilizer recorded lower C:N ratio, C:P ratio, $NH4^+/NO_3^-$ ratio, water soluble carbon/total organic carbon ratio and a higher cation exchange capacity in comparison to degradable solid waste. The humification indices were higher and was non phytotoxic. Fertilizing Index of 4.7 and Clean Index of 5.0 qualify it to be a Class A marketable organic fertilizer.

Customisation of the organic fertilizer was done on the basis of soil test and crop requirement for Nendran banana in AEU 8. A laboratory incubation experiment to study the nutrient release characteristics of the customised organic fertilizer was done for a period of 300 days with seven treatments, of which three were FYM based, three customised organic fertilizer based with a soil alone (control) treatment.

Regardless of the source of organic manure, the organic carbon content remained high in all the manured treatments than in soil alone. N release pattern indicated steady and constant supply of the nutrient. A phase of total immobilization of P was observed from 180 to 240 days in all treatments. Ca also exhibited a similar trend. The release pattern of K and Mg was identical with a progressive mineralization up to 240 days. Trend in release pattern of S was almost similar to N with a 90 days immobilization-mineralization cycle. Micronutrient kinetics exhibited a series of shorter mineralization-immobilization cycles at 60 days interval. However an increasing trend in release of B and Fe was observed till the end. Mn and Zn followed a homogenous release pattern with highest availability at 20 days after incubation.

A field experiment of Nendran banana was laid out with 8 treatments in RBD to study the effect of customised organic fertilizer on labile carbon dynamics and yield. Temporal variation in organic carbon revealed long duration cycles with smooth curves representing heterogeneous and buffered field condition. The treatment in which customised organic fertilizer was used for basal and top dressing, contained high labile carbon, non labile carbon and carbon pool index. Soil reaction (pH) and water holding capacity of customised organic fertilizer based treatments and EC of FYM treatments increased with the growth stages. Antagonism between K and Ca was evident. The availability of micronutrients increased initially and reached the lowest at harvest stage. B steadily decreased up to harvest. Application of customised organic fertilizer enhanced dehydrogenase activity. Foliar concentration of N and P were highest in the initial stages in these treatments while that of K was highest at the later stages of crop growth. Foliar Ca and S also recorded higher values in these treatments. A synergistic effect was observed in the uptake of B and Mg and similarly between Mn and Zn. While Cu absorption was more during vegetative phase, Fe absorption coincided with flag leaf formation. The treatment where customised organic fertilizer was used for basal application as well as top dressing recorded highest plant growth characters, total dry matter production, shelf life of fruits and

B:C ratio but was on par with the treatment which received FYM (soil test basis) in bunch weight, number of fingers per bunch and length of peduncle.

Hence it can be concluded that the customised organic fertilizer obtained from degradable solid waste is of class A marketable quality, capable of a steady and constant supply of all essential nutrients to banana and realising profitable net returns, ensuring immediate energy source to rhizospheric microorganisms and promoting long term carbon sequestration in agro-ecological unit 8 of Kerala.