ORGANIC NANO NPK FORMULATIONS FOR ENHANCING SOIL HEALTH AND PRODUCTIVITY

By

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DECLARATION

I, hereby declare that this thesis entitled **"ORGANIC NANO NPK FORMULATIONS FOR ENHANCING SOIL HEALTH AND PRODUCTIVITY"** 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
°C	-	Degree Celsius
AAS	-	Atomic Absorption Spectroscopy
B	-	Boron
B:C	-	Benefit : Cost
BD	-	Bulk density
Ca	-	Calcium
Cd	-	Cadmium
CEC	-	Cation Exchange Capacity
CD	-	Critical Difference
cfu	-	Colony forming units
cmol (p^+) kg^{-1}	-	Centimole per kilogram
cm	-	Centimeter
Cr	-	Chromium
CRD	-	Completely Randomized Block Design
Cu	-	Copper
DAS	-	Days After Sowing
DFF	-	Days to First Flowering
DMP	-	Dry matter production

DMSO	-	Dimethyl Sulphoxide
dS m^{-1}	-	Desi Siemen per Meter
EC	-	Electrical Conductivity
et al.	-	and other co workers
Fe	-	Iron
Fig.	-	Figure
FYM	-	Farm Yard Manure
g	-	Gram
g kg^{-1}	-	Gram per kilogram
ha	-	Hectare
HCl	-	Hydrochloric acid
HNO_3	-	Nitric acid
$HClO_4$	-	Perchloric acid
i.e.,	-	That is
K	-	Potassium
KAU	-	Kerala Agricultural University
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
LAI	-	Leaf Area Index
mg	-	Milligram
Mn	-	Manganese
mg kg^{-1}	-	Milligram per kilogram
mg $100g^{-1}$	-	Milligram per 100 gram

$Mg\ m^{-3}$	-	Mega gram per meter cube
Mg	-	Magnesium
N	-	Nitrogen
NaOH	-	Sodium hydroxide
NUE	-	Nutrient Use Efficiency
nm	-	Nano meter
NS	-	Non Significant
OC	-	Organic Carbon
P	-	Phosphorus
ppm	-	Parts per million
POP	-	Package of Practices
Pb	-	Lead
RH	-	Relative Humidity
S	-	Sulphur
SEM	-	Scanning Electron Microscope
SEm	-	Standard error of mean deviation
SOC	-	Soil Organic Carbon
$t\ ha^{-1}$	-	Tonnes per hectare
Viz.,	-	Namely
WHC	-	Water Holding Capacity
Zn	-	Zinc

Introduction

1. INTRODUCTION

In the present global scenario, human population is burgeoning at an alarming rate and is predicted to grow to 9 billion by 2050 (UN, 2015). In a developing nation like India, population explosion can copiously lobby the food and agriculture sector of the country. Besides restricted water, shrinking farm land, vagaries of climate change, low organic carbon and imbalanced fertilization; limited availability of agricultural resources can put pressure on the development of agriculture and allied sectors (Mukhopadhyay, 2014). The present situation thereby demands increased food production to attain food security in the country.

Improved productivity for feeding this mushrooming mankind population with ample, quality food using diminishing land, water and other agricultural resources has become a formidable challenge of the hour. Sustainable production can be achieved only through environment friendly cultivation practices that emphasizes on improvement of soil health and quality. With the advent of green revolution, the food grain production of the country has attained its self-sufficiency. Despite this fact, the problems such as reduced response to fertilization, imbalanced fertilization and environmental pollution came to light as the farmers blindly started to relay on chemical fertilizers and pesticides so as to attain more food grain yield. The reduction in humus content of the soil owing to excess use of synthetic fertilizers resulted in deterioration of soil health and fertility, thereby reducing crop yield over time.

Fertilizers, which are inevitable and a key input in augmenting food production in India, dictate one third of crop productivity besides influencing use efficiency of other inputs (Prasad *et al.*, 2012). Despite relentless efforts, the nutrient use efficiency (NUE) of crops remained to range from 35-50 per cent, 18-20 per cent and 30-35 per cent for N, P and K, respectively for the past four decades (Naderi and

Shahraki, 2013). In addition to this, multi nutrient deficiencies have resulted in 25-30 per cent of crop loss.

Agriculture needs to be revitalized and reinforced with innovative scientific technologies (Chen and Yada, 2011). Due to limitation in availability of arable land and quality water, resource use efficiency needs to be improved to attain development in agriculture sector. Incorporation of modern technologies can be a suitable tool in minimizing the environmental damage and for maintaining soil quality.

Nanotechnology, one of the frontier technologies of present day science has immense potential in bringing about appreciable improvements in agriculture sector. Considering environmental safety and resource use efficiency, nanotechnology can precisely detect and deliver accurate quantity of nutrients and pesticides to the crop, thereby reducing the residual effect of these chemicals in the soil and improves the crop productivity (Subramanian and Tarafdar, 2011). Nanotechnology has the ability to revolutionize agriculture, food science, aquaculture and fisheries. Nano agriculture focuses currently on the effect of nanosized compounds with unique characters and their application in farming that can boost up the crop and livestock productivity (Batsmanova *et al.,* 2013). Nanoparticles have size that ranges up to 100 nm which has tremendous advantages in agriculture sector.

Nanotechnology can also minimize the potential negative effects associated with fertilizer over dosage and nutrient toxicity in the soil. Another key benefit of nanofertilizers is that the frequency of application of nanofertilizers is much lower than other fertilizers, thereby reducing the labour cost and cost of cultivation. Nanotechnology could thus be a boon in achieving sustainable agriculture and for attaining food security especially in developing countries like India.

Green nanotechnology is an innovative branch of nanotechnology aimed reduction of negative externalities on the environment sustainability. Enhanced use of nano-materials and nano-products without harming the environment or human health can encourage the replacement of existing baneful technologies in agricultural sector. Green nanotechnology utilizes existing principles of green engineering and green chemistry in synthesizing eco-friendly nanoparticles under low temperature conditions using renewable inputs and less energy.

Nanofertilizers that are composed of nano sized particles can directly augment the supply of essential nutrients required for plant growth and development. Nanofertilizers are target specific and deliver the nutrients to the rhizosphere, thereby improving the nutrient use efficiency of the crop. The nutrient release pattern and efficiency of nanofertilizers in the soil are extraordinary compared to that of their bulk counterpart. Owing to the small size, nanoparticles have very high surface area, ion adsorption capacity, cation exchange capacity and complexation capacity (Mukhopadhyay, 2014). The propensity of nanoparticles to adsorb even on clay lattice prevents the fixation of nutrients and makes the nutrients available into the soil solution which can help in efficient nutrient uptake by the plants. They manifest an initial burst and a subsequent slow release, even 60 days after application. Thus nutrient release pattern of nanofertilizers gives them a clear edge over other commercial fertilizers.

Studies regarding utilization of nanotechnology in organic farming are still much limited and less explored. Research works for understanding the potential of organic nano NPK formulations will start the ball rolling for an era of enlighted and sustainable organic agriculture. Organic nano NPK is an innovative, first of its kind product that combines gluconated fertilizers, developed by Indian Council of Agricultural Research (ICAR) as '4G' Nano nutrient technologies. Organic nano NPK is a unique proteino-lacto-gluconate formulation with organic and chelated micro-nutrients, vitamins, probiotics, seaweed extracts and humic acid besides nitrogen, phosphorus and potash (Tarafdar *et al.*, 2013).

Pioneer research works that studied the effect of organic nano NPK formulations must be directed towards the crops which play an important role in our daily diet. Vegetables such as okra [*Abelmoschus esculentus* (L.) Moench] and amaranthus which are part of typical Indian meal, are rich sources of vitamins, minerals and antioxidants. In addition to this, the medicinal value of okra has significant positive impact on human health. So there is a need for further increase in production and quality maintenance of okra in our country. Okra is also one of the important warm season vegetables having high export potential. The average productivity of okra in India is 10.5 t ha^{-1} as against world's productivity of 6.6 t ha^{-1} (Varmudy, 2011). Okra is also an important vegetable crop of Kerala with the production of 26340 tonnes annually with a productivity of 10.45 t ha^{-1} (GOI, 2017). Being a short duration vegetable crop, its growth, yield and quality are largely influenced by the application of fertilizers. Varsha Uphar is a widely cultivated variety of okra in India. Amaranthus is a popular leafy vegetable grown throughout the season in southern states of India, of which red variety, Arun is highly preferred in south Indian markets.

In the light of all the above background, the present investigation was carried out with the following objectives;

- To characterize organic nano NPK formulations.
- To assess the nutrient release pattern under laboratory conditions.
- To study the effect of soil and foliar applications of organic nano NPK formulations on crop growth, yield, quality and soil health using okra as direct test crop and amaranthus as residual test crop.

Review of Literature

2. REVIEW OF LITERATURE

This thesis work on "Organic nano NPK formulations for enhancing soil health and productivity" was taken up to examine the effect of organic nano NPK formulations on soil health and productivity of crops. Literature for application of nano formulations and their effects on crop growth and yield have been reviewed in this chapter. It supplies a strong literature basis for understanding the topic and links how the suggested research is unique and innovative way forward in the development of formulations of nano organic slow release fertilizers for balanced crop nutrition.

2.1 Nanotechnology

Nanotechnology is a domain towards unification among material science, life sciences and information technology. It is a fascinating area of science useful in settling problems and issues that are hardly possible to attain in engineering or biological sciences. Nanotechnology deals with atom-by-atom manipulation and the processes or products that have developed through this technology are supposed to be most precised. The word "nano" refers to the dimension that measures one-billionth of a metre or one-millionth of a milli-metre (10^{-9} m). Further stimulus can be added to the extremely small size by saying that 10 hydrogen atoms make one "nano" and 10 "nano" make a dimension of a protein molecule and 10 such proteins will measure a size of a virus. Or else it can be said that each virus particle can be equally divided into 100 nano-particles. The surface area gets increased rapidly with the reduction in size. For instance, one gram of zeolite holds a surface area of 465 m^2 g^{-1} when it is in micro-scale and the surface area of the same materials was increased to 885 m^2 g^{-1} when it is reduced to nano dimension. As a result, the adsorptive sites available for nutrient exchange get increased immensely (Thirunavukkarasu, 2014).

2.2 Role of Nanotechnology in Agriculture

According to Royal Society, "Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometre scale" (Chinnamuthu and Boopathi, 2009). Baruah and Dutta (2009) stated the changing scenario of nanotechnology from the experimental area to the practical area. Nanotechnology has provided a base for the exploitation of nano scale materials that facilitates to enhance nutrient use efficiency by controlled release of fertilizers thereby reducing environmental pollution (Chinnamuthu and Boopathi, 2009).

Nanotechnology applications in agriculture have been showing a slower development while industrial and academic interest in this field is rapidly growing. Over the period, a series of appraisals have focused on the prospects for nanotechnology in fertilizer and advocating an increased awareness of the field's potential (Nair *et al.*, 2010 and Hong *et al.*, 2013).

Fertilizers encapsulated within a nanoparticle is considered to be new technology that can be done by three ways a) encapsulation of nutrient inside nanoporous materials, b) nanoparticle coated with a thin polymer film, c) and delivered the particle directly as nanoscale dimensions (Rai *et al.*, 2012). De-Rosa *et al.* (2010) pointed out that combination of nanofertilizers together with nano devices helped to synchronize the release of nutrients by the crops that leads to increase the NUE by eluding the interaction of nutrients with soil, microorganisms, water and air.

According to Batley and McLaughlin (2010) nanoparticles have greater reactivity, mobility and large surface to volume ratio. Surface area can be as high as 1000 m^2 g^{-1} which is much higher than conventional catalysts. Tarafdar *et al.* (2012a) concluded that fertilizers encapsulated in nanoparticles increased the nutrient uptake by plants and suggested that the release of the nutrients can be accelerated without harming environment at a particular speed for a desired period of time.

Liu and Lal (2014) reported that nanofertilizers, are nanomaterials that can supply one or more nutrients to the plants, enhanced growth and yield when compared to conventional fertilizers.

2.3 Nanofertilizers

Nanofertilizers are nutrient carriers with the carrier material in nano-dimension. Nanotechnology has already led to innovations in many other fields other than agriculture such as medicine, material science and electronics. Clear possibilities exist for influencing agricultural productivity using nanotechnology. De-Rosa *et al.* (2010) stated that nanofertilizers are one of the potential outputs that could be a major innovation for agriculture; the large surface area and small size of the nano-materials could allow for enhanced interaction and efficient uptake of nutrients for crop fertilization (De-Rosa *et al.*, 2010). Improved release profiles and increased uptake efficiency can be achieved by applying nanotechnology in fertilizer products, leading to significant economic and environmental welfares.

Nanometer scale structures are important in many facets of plant biology. Plant cell walls have pore diameters ranging from 5 to 20 nm (Fleischer *et al.*, 1999). Pores in the order of one to a few tens of nanometers in diameter, important for ionic and molecular transport processes, have been detected in roots (Carpita *et al.*, 1979). Nanofertilizers can result in improved uptake of nutrients through these pores, or accelerate the uptake by complexation with molecular transporters or root exudates, creating new pores or ion channels (Rico *et al.*, 2011).

Jinghua (2004) reported that utilization of nutrients and uptake and by grain crops were increased through the application of a patented nano composite consisting of primary, micronutrients and amino acids.

Preetha *et al.* (2014) reported that nano-zeolite improved the nutrient use efficiency without harming the environment since it adsorbs and retains higher amount of nutrients because of its larger surface area and by release of anionic SO_4^{2-} in a slow and steady state.

Manikandan and Subramanian (2014) reported that pyrolysed biochar at low temperature was considered as the suitable adsorbent for controlled release of fertilizer thereby enhancing nutrient use efficiency.

2.4 Conventional fertilizers versus Nanofertilizers

Broadcasting and placement are the two commonly used methods for the application of conventional fertilizers on crops. The final concentration of the fertilizers that reach the plants is decided by the mode of its application. Applied fertilizers are subjected to various loss such as leaching, drift, runoff, evaporation, photolytic and microbial degradation before reaching the targeted site. It has been projected that about 40–70 per cent of nitrogen, 80–90 per cent of phosphorus, and 50–90 per cent of potassium from the applied fertilizers are being lost without reaching the plants, causing environmental pollution and economic losses (Trenkel, 1997; Ombodi and Saigusa, 2000). The indiscriminate use of fertilizers and pesticides has adversely affected the inherent nutrient balance, health and quality of the soil. According to an estimate by International Fertilizer Industry Association, world's fertilizer consumption increased sharply in 2009–2010 and 2010–2011 at the rates of 5–6 per cent in both campaigns and world fertilizer consumption was estimated to be 192.8 Mt during 2016–2017 (Heffer and Prudhomme, 2012). The extensive use of chemical fertilizers and pesticides has resulted in environmental pollution causing ecological imbalance. Tilman *et al.* (2002) reported that the excessive use of fertilizers and pesticides increased pests and diseases outbreak and reduced the biodiversity in the nature and may threaten the existence of life in the earth. Hence, it is important to rationalize the use of chemical fertilization in accordance with the crop requirements for the sustainable use. Right dose in right place at right time through right method should be our motto for sustainable agriculture which cares for our future generations (Miransari, 2011). The various studies revealed that the existing fertilizers have very less use efficiency and are getting lost to the environment causing pollution. Hence, there is a need for the development of slow release fertilizers to enhance nutrient use efficiency and sustainability.

Nano-composites were developed to supply ample amount of nutrients in desirable form to plants. Depending on soil conditions and the requirement of various crops, these compounds are capable of regulating nutrient supply. For the controlled release of nutrients to regulate plant growth, zinc–aluminum layered double hydroxides nano-composites were used (Hossain *et al.*, 2002).

Nanomaterials are porous, hydrated and are capable to control permeability, moisture retention and availability of plant nutrients. These nanomaterials also help to control the exchange of organic, inorganic and dissolved compounds between the soil solution and colloidal surfaces. The physico-chemical properties of nano-composites are unique and provide high reactivity to these particles and thereby helping in increased biological and abiotic processes in the soil (Navrotsky, 2004).

Liu *et al.* (2005) revealed that the addition of nano-composites increased fertilizer use efficiency due to the physical adsorption and chemical combination between nutrient elements and also due to the smaller size and high surface reactivity of nanocomposites. By enhancing nutrient absorption, reducing leaching loss and fertilizer fixation in the soil, nano-composites act as multifunctional fertilizer.

2.5 Synthesis of nano formulations

Nanomaterials were manufactured by two processes *viz.,* bottom up process and top to down approach. In bottom up process, the nanoscale materials are developed by the combination of atom to form molecules and in the top to down approach the nanoscale materials were synthesized by the breaking down of macro scale counter parts (Tarafdar *et al.,* 2013). Nano NPK formulation is a first innovative product developed by Indian Council of Agricultural Research (ICAR) using '4G' nano nutrient technologies that combines gluconated fertilizers. Nano NPK formulation is a proteino-lacto-gluconate formulation articulated with organic and chelated micronutrients, vitamins, probiotics, humic acid besides Nitrogen, Phosphorus and Potash.

2.6 Effect of nanofertilizers on crop growth

2.6.1 Plant height, number of branches per plant, LAI and DMP

Soil application of nano NPK fertilizers increased plant height more than that of foliar application (Rochester *et al.,* 2001). Ghormade *et al.* (2011) revealed that, application of nanofertilizers can regulate plant gene expression and associated biological pathways in the plant system, thereby resulting in better growth and production.

Lower concentrations of a mixture of SiO_2 and TiO_2 NPs increased the activity of nitrate reductase in the rhizosphere region of soybean and hence accelerated germination and growth (Lu *et al.,* 2002).

A study conducted by Liu *et al.* (2005) on the effect of Ca-NPs on peanut and found that calcium carbonate NPs (20-80 nm) at a concentration of 160 mg L^{-1} significantly improved the seedling growth compared to that of control.

Soils treated with metallic Cu-nanoparticles (130 and 600 mg kg^{-1}) when applied to lettuce seedling significantly improved the growth by 40 and 91 per cent, respectively (Shah and Belozerova, 2009).

Kottegoda *et al.* (2011) revealed that there was an increase in leaf area and photosynthetic activities in *Gliricidia sepium* due the application of nano urea with slow release nature.

Arora *et al.* (2012) reported that foliar spray of gold nanoparticles improved the growth and yield attributes in *Brassica juncea*. Also reported that titanium oxide nanoparticles applied at a concentration of 0.5 g L^{-1} enhanced the elongation and fresh weight of duckweed (*Lemna minor*) compared with the bulk TiO_2 solution.

Fresh weight of duckweed (*Lemna minor*) increased significantly when Ti-NPs applied at a concentration of 0.5 g L^{-1} compared with the bulk TiO_2 solution (Song *et al.*, 2012).

Salama (2012) showed that application of silver nanoparticles at lower concentrations enhanced plant growth while higher concentrations had an inhibitory effect. Use of silver nanoparticles up to a concentration of 60 ppm increased shoot and root length, leaf surface area, chlorophyll content, and protein contents in maize plants.

Suriyaprabha *et al.* (2012) claimed that application of silica nanoparticles enhanced the plant height, root length, leaf area and stem diameter in maize when compared to that of bulk fertilizers and control treatment.

Iron chelated nanofertilizers applied at 4 kg ha^{-1} to spinach plants resulted in increase in leaf area index by 58 per cent when compared to that of the absolute control plot (Moghadam *et al.*, 2012).

Song *et al.* (2012) observed shoot elongation and increase in fresh weight of duckweed (*Lemna minor*) with the application of Ti-NPs at concentration of 0.5 g L^{-1}, compared with the bulk TiO_2 solution and concentrations higher than 0.5 g L^{-1} were found to have an inhibitory effect on plant growth.

Ten days old chickpea seedlings were sprayed with 1.5 or 10 ppm aqueous solution of zinc oxide (ZnO) nanoparticles and their properties were compared with corresponding concentration of zinc sulphate. Treatment with 1.5 ppm ZnO nanoparticles showed extreme indorsing response for shoot dry weight, whereas adverse effects on root growth was observed for the treatment with 10 ppm. ZnO nanoparticles treated seedlings had increased biomass accumulation as compared to zinc sulphate and ZnO of normal size (Burmana *et al.*, 2013).

Sedgi *et al.* (2013) reported that significantly higher germination percentage and dry weight in soybean crop when seeds were treated with different concentrations poly ethylene glycol and nano zinc oxide under drought stress conditions.

Raliya and Tarafdar (2013) reported the effect of biologically synthesized ZnO NPs on phosphorous-mobilizing enzyme secretion in clusterbean. A significant impovement in dry matter (27.1 %), plant height (31.5 %), root length (66.3 %) and root area (73.5 %) were registered over control when treated with zinc oxide nanoparticles.

Liang *et al.* (2013) noticed that combination of carbon nanoparticles along with conventional fertilizer enhanced tobacco growth, as it was evident from significant increase in shoot length, leaf area and dry matter production.

The effect of zinc nanofertilizer in improving the yield in pearl millet studied by Tarafdar *et al.* (2014) reported that there was an enhancement in plant height (15.10 %), root length (4.20 %), root area (24.20 %), chlorophyll content (24.40 %), dehydrogenase (21.00 %), acid phosphatase (76.90 %), alkaline phosphatase (61.70 %) and grain yield (37.70 %) for the treatment that received zinc nanofertilizer when compared to control plot.

An experiment was conducted in glasshouse conditions to study the effect of conventional sulphur and surface modified nano zeolite based Sulphur. The studies concluded that plant height, number of branches, total chlorophyll content and number of root nodule during all the growth stages of groundnut was recorded to be the highest for the treatment where sulpur was applied as surface modified nano zeolite applied at 30 kg S ha^{-1} (Thirunavukkarasu and Subramanian, 2014).

Seed germination was compared using different concentrations (0, 20, 40, 60 and 100 mg L^{-1}) of zinc oxide nanoparticle treated seeds of mung bean (*Vigna radiata* L.) by Jayarambabu *et al.* (2014) and found the lowest germination per cent was reported for the treatment with nanoparticles of metal oxides at 20 mg L^{-1}. It showed good shoot and root growth compared to other concentrations due to their quick movement into the plant.

Manikandan and Subramanian (2015) reported that treatment which received recommended dose of nanozeourea recorded higher plant height, root length, DMP, grain yield (g) and crude protein content in maize plant when compared to that of urea applied pot. They also reported that the application of zeolite based nano nitrogen to maize plants increased the biomass production because of increased N availability and reduced nitrogen loss.

Chaitra (2015) studied the effect of nano ZnO formulations on the growth of maize plants and reported that spraying of nano zinc oxide up to 750 ppm had positive effect on growth in maize plant and further increase in the spray concentrations showed an inhibitory effect on crop growth.

Nanofertilizers are nano-materials which supply more plant nutrients resulting in growth promotion, yield and performance over conventional fertilizers (Liu and Lal, 2015).

Razzaq *et al.* (2016) studied the influence of silver nanoparticles on germination, growth and yield in wheat. Silver nanoparticles (10-20 nm size) used in the study were synthesized by chemical reduction of silver nitrate with tri-sodium citrate. A significant increase was observed in the number of seminal root, leaf area, root biomass, fresh weight and dry weight with 25 ppm followed by 50 ppm compared to control. High concentrations of silver nanoparticles in solution and their longer exposure leads to a negative effect on the seedlings.

Abdel-Aziz *et al.* (2016) noticed that treatment supplied with 10 per cent nano chitosan NPK exhibited an increase in root length, shoot length, plant height, leaf area, number of spikelet and grain yield per plant in wheat when compared with that of conventional fertilizer and control.

Gerdini (2016) pointed out that foliar application of potassium nanofertilizer applied at 2.5 ml L^{-1} resulted in improved plant height, number of branches per plant, fresh weight, dry weight and also increased the tolerance to pest and diseases in pumpkin even under the drought conditions.

Elizabath *et al.* (2017) noticed that application of nanoparticle in combination with zinc oxide nanoparticle @ 100 ppm and iron oxide nanoparticle @ 50 ppm resulted in increased plant height, leaf area, number of leaves per plant, root diameter, root length and root yield.

Pertaminingsih *et al.* (2018) reported that NPK fertilizer when applied in combination with Nano Chisil and NPK fertilizer with Nano silica increased plant height, number of leaves, wet weight, and dry weight. The results revealed that 25 per cent Nano Chisil along with 75 per cent NPK increased the plant height, number of leaves, wet weight, and dry weight of maize plant. Similarly, Barita *et al.* (2018) reported that combined application of Nano silica and NPK fertilizers improved the plant height, dry weight and wet weight in ganyong.

Suciaty *et al.* (2018) pointed out that, among various concentration of nano silica fertilizer appication in soybean, the maximum number of leaves and branches were recorded from 2.5 ml L^{-1} of nano silica treatment.

Application of nano NPK fertilizers 3 times resulted in enhanced plant height, dry weight and leaf area index when compared to 2 time application of nano NPK fertilizers in cotton (Sohair *et al.,* 2018).

El-Hamd and Elwahed (2018) revealed that foliar application of Lithovit nanofertilizer at 0.75 g L^{-1} resulted in the highest biometric characters such as plant height, number of branches per plant and leaf area in okra, while unsprayed plants recorded the lowest values.

2.6.2 Root length and root volume

Lin and Xing (2007) reported that application of 2 mg L^{-1} of zinc oxide nano particle increased root length of germinated radish (*Raphanus sativus*) and rape (*Brassica napus*) seeds than the control. ZnO NPs at higher concentrations (>2 mg L^{-1}) had negative effects on seedlings. Lin and Xing (2007) also reported that application of 2 g L^{-1} multi-walled CNTs enhanced root elongation in germinated rye grass seeds, rapeseed and corn compared with their respective control.

De-Rosa *et al.* (2010) pointed out that a new nutrient delivery system can be developed using nanoscale porous materials on plants for which carbon nanotubes and zinc oxide nanoparticles are considered to be the best examples which can pierce through tomato plant roots.

Mahajan *et al.* (2011) reported that low concentrations of zinc oxide nanoparticle improved the growth in mung bean and chickpea (*Cicer arietinum*) seedlings. For the mung bean seedlings, the best growth response for root (42 % increase in length and 41 % in biomass) and shoot (98 % in length and 76 % in biomass) were observed at 20 ppm concentration and for the chickpea seedlings, concentration of 1 ppm caused significant increases in root (53 % length and 37 % in biomass) and shoot (6 % length and 27 % in biomass) growth.

Tarafdar *et al.* (2015) reported that application of nanoparticle in pearlmillet increased the nutrient use efficiency, root length (32 %), root area (20.6 %) and biomass (10.2 %).

Application of ZnO nanoparticles at concentrations ranging from 250-1000 mg kg^{-1} on bean (*Phaseolus vulgaris*) had significant impact on root elongation (Dimkpa *et al.,* 2015).

Kisan *et al.* (2015) reported that application of zinc oxide nanoparticle at 500 ppm resulted in increased leaf length, leaf width, leaf surface and protein content in spinach when compared with that of control plot.

Sudha and Staline (2015) revealed that there was an increment in rice root weight due to application of zinc oxide nanoparticle and also resulted in higher nitrogen fixation and root enlargement, allowing the plants to uptake more nutrients.

Silver nano particles (SNPs) had a pronounced effect on number of seminal roots of wheat. There was higher production of seminal roots compared to control due to the application of 25 and 50 ppm of SNPs (Razzaq *et al.,* 2016).

Zinc oxide nanoparticle applied as foliar spray resulted in increased biometric parameters such as root length, shoot length and yield in tomato when compared to that of bulk zinc sulphate application as well as control plot (Khanm *et al.,* 2018).

Mohasedat *et al.* (2018) revealed that application of nano-biofertilizer applied at 1 g pot^{-1} in apple plants significantly increased shoot length, leaf number, leaf area index, chlorophyll a and b when compared to control treatment

2.7 Effect of nanofertilizers on physiological characteristics

2.7.1 Chlorophyll content

Su *et al.* (2009) showed that titanium oxide nanoparticles application could increase plant-photosynthesis, enzyme activity and thereby enhanced spinach growth.

Nekrasova *et al.* (2011) revealed that low concentrations (0.25 ppm Cu) of Cu-NPs stimulated plant photosynthesis rate by 35 per cent compared with that of the control from a three day incubation study using a type of water weed.

Interaction of nanoparticles with plants resulted in many morphological and physiological changes, depending on the properties of nanoparticles. Efficacy of nanoparticles is determined by their size, surface area, chemical composition, reactivity and concentration at which they are effective (Khodakovskaya *et al.*, 2012).

Ghafariyan *et al.* (2013) reported that application of super paramagnetic Fe nanoparticles at low concentration resulted in significant increase in the chlorophyll contents in sub-apical leaves of soybeans in green house hydroponic condition.

An experiment conducted by Elham *et al.* (2013) on the effect of titanium dioxide spray on corn (*Zea mays* L.) revealed that effect of titanium oxide nanoparticle had a significant influence on the chlorophyll (a and b) and total chlorophyll. The maximum amount of pigment was recorded when nano TiO_2 was applied as foliar spray at the reproductive stage in comparison with water spray as control.

An experiment conducted by Tai-bo *et al.* (2013) on the effects of carbon nanoparticles (CNPs) on the growth and nutrient buildup in tobacco plants revealed that application of CNPs increased the chlorophyll and soluble protein content.

Mohanraj (2013) reported that the chlorophyll content of rice increased up to flowering stage when NH_4^+-N loaded nano zeolite was applied. Application of nanofertilizers leads to increment in the physiological activities such as photosynthesis, resulting from the increasing chlorophyll content, which in turn leads to increase in dry weight in tomato (Tantawy *et al.,* 2014).

Jalali and Zargani (2014) examined the impact of nano Fe-chelate, non-nano Fe-EDDHA and $FeSO_4$ on growth attributes, chlorophyll a, b and total chlorophyll content in lettuce. It was observed that there was a significant difference in the performance of all indices by application of nano Fe-chelate at one per cent level. They also noticed a positive effect on chlorophyll a, b and total chlorophyll by the application of nano Fe-chelates.

When copper nanoparticles were applied to soil in pots copper nanoparticle (10, 20, 30, 40 and 50 ppm) significantly increased the growth and yield in wheat, compared to the control. However, 30 ppm copper nanoparticle resulted in the maximum chlorophyll content, leaf area, number of spikes/pot, number of grains/spike, 100 grain weight and grain yield (Hafeez *et al.,* 2015).

Mir *et al.* (2015) conducted a study to determine the effect of nano and biological fertilizers on quality parameters *viz.,* carbohydrate and chlorophyll content in forage sorghum and from the results revealed that the highest chlorophyll a (1.59 mg g^{-1}), chlorophyll b (5.31 mg g^{-1}), carotenoid (2.24 mg g^{-1}) and carbohydrate (3.24 mg g^{-1}) was achieved from combined use of bio-fertilizers (azetobarvar 1+ phosphorbarvar 2) and chelated nanofertilizers (Fe+k).

Raliya *et al.* (2017) conducted an experiment to study the adsorptive and photocatalytic removal of methyl orange dye using different oxide of nanomaterials such as titanium dioxide (TiO_2), zinc oxide and graphene oxide. ZnO NPs showed superior performance in degrading most of the dye, followed by TiO_2 and GO. It was also found that TiO_2 removes dye through mechanisms such as adsorption at higher concentrations of dye and through photocatalysis at its lower concentrations. The photocatalytic dye degradation was checked by varying the size of ZnO NPs and the smaller particle sizes (< 25 nm) were found to be more useful.

2.8 Effect of nanofertilizers on yield and yield attributes

Jinghua (2004) showed that the application of nano-composite consisting of N, P, K, micronutrient, manures and aminoacids enhance the nutrient uptake in grain crops. Studies also reported that fertilizer incorporation into chelated nano tubes improved crop yield.

An improvement in the yield and photosynthesis of peanut was noticed with the application of nanofertilizers (Liu *et al.*, 2005). Similarly, Sheykhbaglou *et al.* (2010) observed an increase in grain yield of soyabean by the application of foliar spraying of nanofertilizers like nano iron oxide particles.

Jian *et al.* (2008) conducted an experiment to explore the application effect of high amount of nano-synergism fertilizer on winter wheat and reported 12.34 per cent to 19.76 per cent increase in yield. The increase yield (2.31 %) was reported in wheat by the application of high amount urea fertilizer compared to low amount nano-synergism fertilizer (10 kg ha^{-1}).

Habib (2009) reported that the yield of wheat increased significantly by foliar application of zinc and iron either alone or in combination and the highest seed yield was recorded in the case of combined application of nano zinc and nano iron respectively.

Keshavarz *et al.* (2011) reported that the nano iron chelate fertilizer increment the yield in wheat because of complete uptake of fertilizer throughout the growing season and thereby improved the crop yield.

The highest fruit yield, shoot length, fruit length, fruit girth and number of branches per plant in brinjal was observed by foliar application of nano iron chelate fertilizer at the rate of 2 g L^{-1} (Bozorgi, 2012).

Priester *et al.* (2012) reported that the soybean plants grown on the soils mixed with ZnO and CeO_2 nano-particles showed a significant increase in their pod and seed biomass when compared to control, whereas, the reduced growth in case of CeO_2 nano-particles treated plants indicated the differential behavior of the soybean plants to the two types of nano-particles.

In groundnut, seed germination, seedling vigour, early flowering and higher chlorophyll content in leaf were found to be improved by the application of nano scale ZnO (25 nm mean particle size) at 1000 ppm concentration (Prasad *et al.*, 2012). The results revealed that 34 per cent higher pod yield per plant was obtained when compared to bulk $ZnSO_4$. Foliar application of zinc oxide nanoparticle 15 times lower rate recorded 29.5 per cent and 26.30 per cent higher pod yield when compared to the chelated $ZnSO_4$ during *rabi* season of 2008-2009 and 2009 -2010, respectively.

Tarafdar *et al.* (2012b) discovered that foliar application of nano-phosphorus at 640 mg P ha^{-1} (40 ppm spray concentration) enhanced the yield of cluster bean and pearl millet which is equivalent to the application of 80 kg P ha^{-1} through conventional fertilizers under arid environment.

The study on the effect of nano-iron on cowpea crop under irrigation by Afshar *et al.* (2013) evaluated the impact of deficit and observed significant increase in number of seeds per pod. It was also observed that increasing concentration of nano-iron increased the number of seeds per pod but decreased 1000-seed weight significantly in cowpea.

Morteza *et al.* (2013) reported that application of nano TiO_2 sprays increased maize crop yield significantly than control and other treatments in comparison.

Moosapoor *et al.* (2013) noticed peanut plant that were treated with Bohr nanofertilizer resulted a significant improvement in the yield, number of seeds per bush, number of matured pods and dry matter production.

A study by Armin *et al.* (2014) on the impact of different concentrations and different application times of nano-Fe fertilizer on wheat crop and found that increasing concentration of nanofertilizers and time of application had resulted in significant effect on tillers number, seeds per spike, grain yield, biological yield and 1000-grain weight.

Kumar *et al.* (2014) studied 21 the effect of nanofertilizers of gypsum and rock phosphate at the rate of 3 kg ha $^{-1}$ on wheat crop and reported that yield parameters and yield obtained at 50 per cent RDF with nano materials was almost statistically similar with 100 per cent RDF without nano materials.

Reazaei *et al.* (2014) conducted an experiment to investigate the effect of foliar application of iron nano-chelated fertilizers on three wheat cultivars and the results revealed that foliar application of iron nano-chelated fertilizers resulted in significant increase in the yield attributes *viz.* spike number, grain per spike, 1000-grain weight, biological yield and harvest index besides the grain yield of wheat than control and other treatments in comparison.

Treatments using liquid nanofertilizer, Ferbanat applied at 4 L ha^{-1} recorded the highest yield and yield per plant in cucumber grown under green house condition while, the highest average fruit weight, fruit length, fruit girth, dry matter were recorded in the treatment provided with Nanonat applied at 4 L ha^{-1} (Ekinci *et al.*, 2014).

Laware and Raskar (2014) revealed that the onion plants treated with ZnO NPs at the concentrations of 20 and 30 μg mL^{-1} resulted in better growth and showed earliness in flowering when compared to that of the control. However, the treated plants showed significantly higher seeds per umbel, seed weight per umbel and 1000 seed weight over control plants.

Liu and Lal (2014) prepared hydroxyapatite NPs of 16 nm in size and evaluated its influence on soybean crop in an inert growing medium. The data revealed that application of hydroxyapatite NPs enhanced the growth rate and yield by 33 and 20 per cent respectively when compared to those with a regular P fertilizer. And also the production of biomass was enhanced by 18 and 41 per cent for the above and below ground portions, respectively.

Benzon *et al.* (2015) reported that when nanofertilizers were applied in combination with fully recommended dose of fertilizer (FRR-CF + FRR-NF) showed the highest number of reproductive tillers, number of panicle and total number of grains in rice. From the results also revealed that FRR-CF + FRR-NF recorded an increase over 9.10 per cent, 9.10 per cent and 15.42 per cent FRR-CF.

An increase in seed number per pod, pod number per plant, 100 seed weight and grain yield by 17, 48, 13 and 65 per cent respectively when compared with control applied nano iron chelate applied at 2 g L^{-1} (Valadkhan *et al.,* 2015).

A field experiment was conducted to evaluate the influence of nitrogen and K nanofertilizers on yield and yield attributes of tomato by Ajirloo *et al.* (2015). The results revealed that foliar application of K nanofertilizer in together with nitrogen fertilizer showed the highest plant height, stem diameter, number of fruits per plant, fruit weight, fruit diameter and fruit yield of tomato when compared with that of control. There was also enhanced nitrogen, potassium, calcium, magnesium and phosphorus uptake by plants supplied with K nanofertilizer.

Foliar application of Fe compounds as iron nano applied at 0.004 per cent resulted in the maximum spike weight (614.88 g), 1000 grain weight (36.10 g), biological yield (8830 kg ha^{-1}), grain yield (3639.5 kg ha^{-1}) and protein content (16.01%) of wheat when compared to that of absolute control (Bakhtiari *et al*., 2015).

Asadzade *et al.* (2015) reported that application of ZnO nanofertilizer increased head diameter, seed yield, 1000-seed weight and number of seeds per head significantly than other treatments and control plot.

An experiment by Dolatabadi *et al.* (2015) on the influence of exogenous application of nano- TiO_2 in annual medic (*Medicago scutellara L.*) with six concentrations of nano-TiO_2 (Control, 0.01, 0.02, 0.03, 0.04 and 0.06 %) and two stages of application *i.e.,* at pod stage and 10 per cent flowering stage reported that application of nano - TiO_2 resulted in significant increase in dry forage yield. Among the different stages of application of nanofertilizers, the seed yield of annual medic was significantly higher than yield at 10 per cent flowering stage.

Mosanna and Behrozyar (2015) conducted an experiment to evaluate the efficacy of foliar and soil application of zinc nano-chelate on morpho-physiological characteristics of maize (*Zea mays* L.) and the results revealed that there was significant improvement in 100-grain weight, number of seed per row, seed yield and harvest index than control plot and the other treatments.

Manasa (2016) reported that growth and yield of ground nut plants were enhanced by foliar application of nano iron oxides upto 1000 ppm concentrations and further increase in the concentrations had inhibitory effects.

Janmohammadi *et al.* (2016 b) noticed a decrease in the number of days to tuberization in potato by the application of nanofertilizers. From the evaluation for tuber yield components, it was clear that the highest number of tubers per plant, mean tuber weight and tuber weight per plant were obtained for the treatment with the application of nano chelated complete fertilizer applied at 1 kg ha^{-1}.

Roshdy and Refaai (2016) revealed that the application of nano NPK fertilizers each applied at 500, 250 and 250 g palm^{-1} year^{-1} resulted in increased yield per plant, total yield and fruit quality in date palm over control plot.

Narendhran *et al.* (2016) found that application of biologically synthesized zinc oxide nanoparticle showed less toxic effect and resulted in improved growth, yield, chlorophyll content and protein content in sesamum when applied at 0.5 g L^{-1}.

Application of nano SiO_2 along with high rate of FYM could reduce the duration of vegetative phase and days to flowering in barely. The time taken for 50 per cent flowering was slightly triggered for the treatments that received nano calcite application in rice (Kumara *et al.*, 2017).

Nanofertilizers show the slow and sustainable release of nutrients, has growth stimulator effect and act as carrier of nutrient which led to enhanced yield and yield attributing characters in chilli, soyabean and clusterbean respectively (Hatwar *et al.*, 2003; Liu *et al.*, 2009; Liu *et al.*, 2017).

Gomaa *et al.* (2018 a) revealed that the foliar application of nano NPK applied at 75 per cent resulted in increased yield and yield attributes in wheat when compared to that of conventional fertilizers.

Gomaa *et al.* (2018 b) concluded that foliar application of nano Fe applied at 3 L ha^{-1} along with nano Zn applied at 2.5 kg ha^{-1} significantly enhanced yield and yield attributes in two rice cultivars.

Shadravan *et al.* (2018) reported that zinc nano chelated fertilizer when applied at 30 kg ha^{-1} resulted in increased total biological yield, seed yield and number of pods per plant in chickpea.

El-Hamd and Elwahed (2018) pointed that foliar application of Lithovit nanofertilizer at 0.75 g L^{-1} recorded maximum yield characters such as pod length, pod diameter, yield and number of pods per plant in okra.

2.9 Effect of nanofertilizers on quality parameters

2.9.1 Crude protein

Qiang *et al.* (2008) conducted an experiment to evaluate the performance of slow, controlled release fertilizer made up of nano materials on quality of winter wheat and summer corn and reported that application of these nanofertilizers resulted in insignificant increase in protein content, whereas, soluble sugar content was found to be decreased insignificantly with the use of these fertilizers.

Ghafari and Razmjo (2013) evaluated the impact of foliar application of nano-iron oxide (2 and 4 g L^{-1}), iron chelate and iron sulphate on quality of bread wheat (*Triticum aestivum* L.) and reported significantly higher grain yield besides grain protein and iron content with application of 8 g L^{-1} iron sulphate followed by application of 2 g L^{-1} of nano-iron oxide.

Nadi *et al.* (2013) reported that increase of nano-iron concentration significantly influenced protein percent and chlorophyll content of faba bean. However, spraying at vegetative period had less effect on grain protein percent.

Ramesh *et al.* (2014) reported that treatment at low concentration of nano-ZnO in wheat significantly increased chlorophyll and protein content whereas, no changes was recorded with respect to bulk-ZnO and bulk nano-TiO_2 treated samples.

Manikandan and Subramanian (2015) evaluated the effect of zeolite based nitrogen nanofertilizers on maize crop in two greenhouse experiments of two distinct soil textures (Inceptisol – Periyanayakkanpalayam soil series – clay loam and Alfisols - Iregur soil series- sandy loam) and reported that the crude protein content of maize crop was significantly higher for nano-zeolite urea compared to conventional urea.

Soliman *et al.* (2016) reported that application of hydroxyapatite nanoparticle resulted in enhanced nitrogen uptake that directly leads to improved crude protein content in Baobab. This might be due to greater density and large surface area of nanoparticles.

Application of nanophosphatic fertilizers resulted in improved quality parameters such as crude protein content in pearl millet when compared to conventional fertilizers (Dhansil *et al.*, 2018).

Thirunavukkarasu *et al.* (2018) revealed that application of nano sulphur fertilizer to groundnut plants applied at 30 kg ha^{-1} resulted in enhanced crude protein and total free amino acid content when compared to that of conventional sulfur fertilizers.

2.9.2 Crude fibre

Application of nanofertilizers to forage resulted in improved crude protein content whereas crude fibre content was reduced (Sulc *et al.,* 2015). Similarly, application of a combination of Agricolle + Nagro resulted in decreased crude fibre content in alfalfa plants (Nikolova *et al.*, 2018).

Khater (2015) reported that titanium dioxide (TiO_2) nano-particles (NPs) resulted in significant increase in amino acids, total sugars, total phenols, total indols and pigments in coriander.

2.9.3 Ascorbic acid

Application of nano combination (Fe+Cu+Mn+Zn) as foliar recorded the highest ascorbic acid content of 8.1 per cent more than that of the absolute control treatment in Jerusalem artichoke (Al-Juthery and Saadoun, 2018; Saedpanah *et al.*, 2016).

El-Hamd and Elwahed (2018) pointed that the treatment with foliar application of Lithovit nanofertilizer at 0.75 g L^{-1} recorded the highest ascorbic acid content in okra fruit, compared to the control.

2.10 Incidence of pest and diseases

Jarrell and Beverly (1981) noticed that application of nano calcium reduced the incidence of gray mold symptoms and *Botrytis blight* in rose during the post harvest storage. Hua *et al.* (2015) stated that application of nano calcium carbonate increased the plant resistance against insect pests.

Kumara *et al.* (2017) reported that nano calcite application increased the crop biomass, productivity and also improved the resistance against pest and diseases in rice.

2.11 Effect of nanofertilizers on soil properties

2.11.1 Physical properties

Petrovic (1990) evaluated the optimum particle size of clinoptilolite under the laboratory condition and then added to golf course sand was between 0.1 to 1mm in order to improve the infiltration rate, water holding capacity, and aeration. Huang and Petrovic (1995) concluded that available water to plants increased when the particle size of clinoptilolite reduced and the application dosage increased in a sand medium.

Liu and Lal, 2012 revealed that fine grained zeolite when applied to the mined soil improved the silt and clay fractions and resulted in improved water holding capacity and lower bulk density.

Wehtje *et al.* (2003) reported that application of zeolite to soil increased the water holding capacity of soil when compared to that of the unamended soil thereby enhanced the performance of Bermuda grass (*Cynodon dactylon*).

2.11.2 Chemical properties

2.11.2.1 pH

Nano formulations were able to improve the physical condition of the soil because of the reaction between nano composite and natural organic mineral granules in the soil (Liu *et al.* 2006).

The mobility and aggregation of nanoparticles in soils are strongly affected by the surface charge of nanoparticles which is pH-dependent. As the pH reaches the point of zero, nanoparticles undergo self-aggregation and cause settling or precipitation of the particles (Illes and Tombacz, 2006).

The most important reaction pathways which may affect fate and behaviour of nanoparticles in soil are dissolution, aggregation, partitioning between solution and solid phase and mobility. Soil properties such as pH, ionic strength, clay and organic matter content affect the dissolution of nanoparticles through their effect on aggregation. High surface area and charge of manufactured nanoparticles result in strong adhesion of nanoparticles to the reactive surface of soil (Milani, 2011).

Collins *et al.* (2012) studied physico-chemical characteristics of nanoparticles (*viz.*, shape, size and surface charge) in soil. They noticed that soil properties *viz.*, pH, ionic strength, organic matter and clay content would improve physical and chemical processes of NP in soil resulting in dissolution and aggregation. The behaviour of nanoparticles in soil determines their mobility and bioavailability to soil organisms.

The pH of the phosphorous nanofertilizer treated soil was higher than control while that of potassium nanofertilizer incorporated soil was lesser (Rajonee *et al.*, 2017).

2.11.2.2 Electrical conductivity

Ming and Boettinger (2001) opined that application of zeolite to the soil increased EC and nutrient retention capacity of the soil. Similarly Mia *et al.* (2010) and Rus *et al.* (2004) reported that EC of the nanofertilizer treated soil increased due to its high dissolution rate and salty nature.

Zeolite application to the soil had increased its EC which indicates the increased nutrient retention capacity of the treated soil (Mia *et al.*, 2010; Rus *et al.*, 2004).

2.11.2.3 Organic carbon

Organic macro molecules are ubiquitous in the soil environment and have significant effects on the surface reactions and mobility of nanoparticles in the soil. The physico-chemical nature of organic matter can determine the stability of nanoparticles in the soil. The dissolved organic matter in soil can be sorbed on to the nanoparticle surfaces and affect their surface speciation and charge through steric or charge alteration and increment hydrophilicity of the surfaces (Ghosh *et al.*, 2008).

Yang *et al.* (2009) observed that coating of metal oxide (TiO_2, Al_2O_3, ZnO) nanoparticles with humic acids decreased their zeta potential and enhanced electrostatic repulsion between nanoparticles thereby increasing their stability in the environment.

Mia *et al.* (2010) reported that due to the high dissolution rate of nano silica and their salty nature there was an increase in the conductivity and OC content of the soil. Similarly organic acid present in the nanofertilizers improved the micronutrient chelation rate thereby maintaining the soil fertility (Tavakoli and Khoshkam, 2013).

2.11.2.4 Nitrogen

Organic nitrogen compounds, ammonium (NH_4^+) ions, and nitrate (NO_3^-) ions are the three forms of nitrogen which is available to plant. Since nitrate form of nitrogen does not have higher affinity for soil particle surfaces, most of the nitrogen is not available to plant completely.

Perrin *et al.* (1998) reported that clinoptilolite zeolite improves the nitrogen fertilization efficacy by reducing the leaching of nitrate by inhibiting the nitrification process. Similar results by Junxi *et al.* (2013) reported that the release of nanofertilizer from the soil is slowed due to the tight bond of the ammonium ions in the nano pores of zeolite.

Li (2003) verified the feasibility of using surfactant modified zeolite (SMZ) as slow release fertilizer and reported that SMZ had great potential as fertilizer to control the release of nitrate and other anions.

Slow and steady release of nitrogen can be achieved by impregnating nano zeolite with urea. NH_4^+ ions occupying the internal channels of zeolite slowly liberate N permitting progressive absorption by the crop (Fujinuma and Balster, 2010).

Tarkalson and Ippolito (2010) found that application of zeolite mineral clinoptilolite (CL) influenced the amount of NO_3-N and NH_4^+-N in the leachate and soil. Application of clintoptilolite release available nitrogen slowly because of decreased activities of microbial immobilization and nitrification.

Nanofertilizers formulations that contain nitrogen was studied for the nutrient release pattern (Subramanian and Rahale, 2009). The nanoformulation capable of releasing nutrients like nitrogen slowly for about 40 days resulted in enhancement of crop growth regardless of soil texture (Manikandan and Subramanian, 2014).

Manikandan and Subramanian (2015) pointed out that nanozeolite contain large surface area and when it was blended with conventional nitrogenous fertilizers they release nitrogen and which served as a good slow release fertilizer by releasing nitrogen in a sustained manner.

Hussein *et al.* (2015) revealed that nanofertilizers have both positive and negative charged binding site thereby reducing the loss of nutrients and increases uptake of nutrients by the crop.

Rajonee *et al.* (2016) reported that application of nanofertilizers to kalmi plants resulted in enhanced nitrogen availability in the soil than absolute control plot.

Application of nanophosphatic fertilizers in pearl millet resulted in improved nitrogen and phosphorous status of the soil when compared to conventional fertilizers and also revealed that 40 per cent of the conventional fertilizers can be reduced (Dhansil *et al.*, 2018).

2.11.2.5 Phosphorous

Kallo *et al.* (1986) revealed that zeolite containing both macro and micronutrients, provide large surface area on which the chemical reactions taken place by slow release of ammonium nitrate, potassium, magnesium, calcium as well as trace elements as and when it is needed by the plant. Correspondingly, Perez-Caballero *et al.* (2008) reported the application of zeolite improved the concentration of P, K and Ca content in the soil because of its ability to adsorb nutrients from the fertilizer as well as reduce the leaching loss. Subramanian and Rahale (2010) studied the PO_4^- release pattern using various nanoclays and zeolite in which zeolite showed an increase in the availability of phosphorus to the plant.

Liu and Lal (2012) suggested the application of phosphate based nanoparticles for remediation of heavy metal, by subjecting them to highly insoluble and stable phosphate compounds and also elaborated its scope as a P nanofertilizer.

Fertilizers play pivotal role in the agricultural production as it is a major factor controlling 35-40 per cent of the productivity. Nanofertilizers is considered to be the best alternative to improve the nutrient use efficiency. Reports suggest that nanofertilizers are far more efficient than normal fertilizers and there have been attempts to synthesize nanofertilizers, especially for phosphorus, so that the release of phosphorous can be regulated depending on the requirement of the crop. Foliar application of nano particles observed an enhanced production (Raliya *et al.*, 2013).

In a leaching study conducted by Sarkar *et al.* (2014) to evaluate efficacy of fertilizer loaded with nano-clay polymer composites (NCPCs) as a slow release carrier of nutrients and made available to plants. Smectite nanoclays based composites loaded with di-ammonium phosphate (DAP) showed significantly higher P recovery than that from conventional fertilizers.

Rajonee *et al.* (2017) reported that the release of phosphorous was actually steeper in nanofertilizer than conventional fertilizer. The release of more amount of phosphorus by nanofertilizer was due to incorporation of KH_2PO_4 onto natural zeolite. The P supply from nanofertilizer was available for longer time because of its slow release pattern when compared with that of the conventional fertilizer.

Giroto *et al.* (2017) revealed that thermoplastic starch/urea nano-composites provided a controlled release of urea and increased the release of phosphorus from hydroxyapatite particles in citric acid solution. The thermoplastic starch/urea nano-composites also showed lower NH_3 volatilization compared to control. The hydroxyapatite present in the urea matrix resulted in reduced adsorption of phosphorous thereby providing higher phosphorous availability even after 4 weeks of incubation study in the soil.

2.11.2.6 Potassium

Zhou and Huang (2007) stated that potassium from nanozeolite was released in slow and steady manner. This property of K may be due to the ion exchangeability of the zeolites with selected nutrient cations. Zeolites act as an excellent medium for plant growth thereby improving plant roots with extra imperative nutrient cations and anions. The supplements were given in a moderate release, plant root demand driven style through the method of dissolution and ion exchange reactions.

Li *et al.* (2010) reported that potassium (K^+)-loaded zeolite (K-Z) was used as a slow-release fertilizer and examined the growth characteristics of hot pepper along with the changes in the nitrogen and potassium contents of tested soil.

Subramanian and Rahale (2010) fabricated a slow release potassium (K) fertilizer and conducted a leachate experiment using percolation reactor to study the desorption pattern of nutrients. The release of potassium from all the nano-clays was rapid and attained a static at about 216 hours, after which slow release was observed. In the case of potassium chloride, the entire K was exhausted after 216 hours and reached below detectable concentration. While, the release of potassium from nano-zeolite continued even after 1176 hours, with a concentration of 110 mmol L^{-1}.

Rajonee *et al.* (2017) revealed that the per cent release of potassium from the conventional fertilizer and nanofertilizer showed a decreased trend but the nutrient release was consistent at higher level for nano till the end of the incubation period due to their slow release nature. Similar explanations were given by Li *et al.* (2013) who pointed out that the available K in the soils were maintained at high level when the potassium integrated zeolite than control treatment.

Since very limited literatures are available for potassium as slow release fertilizer, in this thesis, it has been included as a source for developing nano formulations.

2.11.2.7 Secondary nutrients

Pandya and Bhatt (2008) revealed that available sulphur was improved when nano-composites were externally applied. Application of nano composite has increased the availability of secondary nutrients in the soil (Preetha, 2011).

Thirunavukkarasu *et al.* (2018) stated that application of nano S applied at 30 kg ha^{-1} recorded higher sulphur use efficiency by reducing the conventional sulphur by 25 per cent.

2.11.2.8 Micronutrients

Mazur *et al.* (1986) pointed out that nanofertilizers had significantly increased the availability of Fe, Mn, Zn and Cu content in the soil than the conventional fertilizer application. This might be due to their higher reactivity and higher bioavailability.

Sheta *et al.* (2003) reported that zeolite especially clintopillonite have the high sorption potential of Fe and Zn due to the less soluble nature of the minerals and the effect of sequestration of the exchanger, thus causing slow release of micronutrients to the exchange site of zeolite where there availability improved and resulted in enhanced uptake of micronutrients.

A study by Subramanian and Rahale (2012) reported that nano zeolite loaded with zinc sulfate showed the highest sorption among native and ball milled zeolite and nano clays such as montmorillonite, halloysite and bentonite. The results showed that highest sorption of 429.5 mg kg^{-1} was observed for nano zeolite and the zinc adsorption increased with increase in zinc concentration. When the concentration reached 400 ppm saturation is achieved. The study shows that nano zeolite loaded with zinc has capacity of metal ion-exchange as well as greater adsorption.

Kim *et al.* (2011) revealed the concentration of zinc in the soil treated with zinc nanoparticles were more than that of soluble zinc treated. The better retention of nanoparticles in the soil reduces the phytotoxicity and increases the zinc reserve in the soil.

Zhao *et al.* (2013) observed that zinc oxide nanoparticle applied to the soil it dissolved continuously released Zn to the soil solution to replenish the Zn ions and were absorbed by roots compared to soil treated with alginate which promotes the assimilation of Zn in corn plant tissues.

Subbaiah (2014) reported that the post harvest nutrient availability of zinc in the soil increased due to the foliar nano ZnO spray and maximum content was recorded with the application of nanoparticles applied at 1,000 ppm indicating translocation of zinc from leaves to soil through the plant body system and accumulated in the soil. The soil zinc content had shown high significant differences among treatment.

2.11.3 Biological properties

Rahale (2010) reported that application of nanofertilizers improved the microbial population and colonization. Raliya and Tarafdar, (2013) revealed that nanoparticles induce plant growth due to the mobilization of nutrients and also increase the microbial population especially in the rhizhosphere.

Collins *et al.* (2012) monitored the concerns of the application of copper nanoparticle and zinc oxide nanoparticle to the experimental soil that were maintained as that of the field condition. The release of the nanoparticles were monitored for a period of 162 days and the changes in microbial communities were also observed. The results revealed that both nanoparticle enter through soil matrix at different rates and copper oxide nanoparticle retained in the soil matrix at a higher rate when compared to that of zinc oxide nanoparticle.

2.11.4 Biochemical properties

Rai and Yadav (2011) reported an increment in dehydrogenase and urease activity in soil due to increased microbial population. They also concluded significant correlation between both enzymes and organic carbon content in soil.

Wang *et al.* (2012) reported enhanced root growth by oxidized nano carbon tubes due to improved dehydrogenase activity in roots.

Raliya and Tarafdar (2013) reported that application of zinc oxide nanoparticle improved the rhizospheric microbial population, acid phosphatase and alkaline phosphatase activity over control in 6 week old clusterbean.

The influence of metal oxide nanoparticle incubation on soil enzyme activities resulted in increased soil bacterial community as reported by You *et al.* (2017). They concluded that ZnO NPs had a synergistic effect on soil enzymatic activities than when treated with $nTiO_2$, and nFe_3O_4. They also reported more susceptibility of saline-alkali soil to metal oxide nanoparticles than black soil.

Kwak *et al.* (2017) investigated the long term effect of ZnO NPs at varied concentrations of 50 and 500 mg kg^{-1} on the activities of enzymes in the soils such as dehydrogenase, urease, acid phosphatase, aryl-sulfatase, and β-glucosidase.

2.12 Effect of nanofertilizers on nutrient use efficiency

The Nutrient Use Efficiency (NUE) of nanofertilizers are 51-58 per cent, 15-16 per cent for SSP and DAP, respectively. Nanofertilizers are more advantageous when compared to that of conventional fertilizers (i) Nutrient Use Efficiency increased by 3 times (ii) 80-100 times less requirement to chemical fertilizers (iii) crops can tolerate stress by 10 times (iv) complete bio source so it was ecofriendly (v) nutrient mobilization improved by 30 per cent (vi) crop yield improved by 17-54 per cent and (vii) improved the soil aggregation, moisture retention and carbon bulid up in soil (Tarafdar, 2013).

Dwairi (1998) reported that nano zeolite applied with urea can be used as slow release fertilizer. The study also demonstrated that ammonium loaded zeolite reduce nitrogen leaching in sandy soil thereby leading to sustained growth of sweet corn and increasing nitrogen use efficiency when compared with ammonium sulphate.

Nano clay and zeolites were group of naturally occurring minerals with a honey comb like layer which were responsible for increasing the nutrient use efficiency (Chinnamthu and Boopathi, 2009). Its pores can be filled with N, P, K, Ca and trace nutrients. Thereby, act as a nutrients source which were slowly released according to the crop demand.

The use of nanofertilizer in soil leads to improved efficiency of the nutrients, thereby reduce the toxicity of excessive application of nutrients in the soil, and thereby reduce the bulk quantity of fertilizers (Naderi *et al.,* 2011). Various research works have shown the ability of these nanofertilizers for controlled release as well as in maintaining nutrient use efficiency.

According to Preetha *et al.* (2014) noticed that nanozeolite which adsorbed more amount of nutrients because of its large surface area retain and release anionic SO_4^{2-} in a slow and steady manner thereby improving the use efficiency without associated environmental hazards.

The nanofertilizer was prepared by adopting a new technique which uses microbial enzymes for the breakdown of respective salts into its nano-form. When compared to chemical fertilizers, the newly developed fertilizer is two to three times less expensive, improves nutrient use efficiency and provides stress tolerance (Tarafdar, 2013). It was the pioneered work on nanofertilizers in India and first to biosynthesize nanofertilizers.

A study on the effect of silver nano particles (SNPs) on N, P and K use efficiency of wheat by Jhanzab *et al.* (2015) revealed that high use efficiency was recorded with the application of 25 ppm of SNPs. Further increase in concentration of SNPs was accompanied by significant reduction in use efficiency.

Adhikari *et al.* (2015) conducted a comparative study to evaluate the effect of conventional $ZnSO_4$ and nano ZnO, which were supplied at same concentrations to maize seedlings. It was identified that for both form of Zn, enhanced growth characteristics were observed under higher concentration of 0.50 ppm. Among these, plant supplied with nano ZnO formulation showed better growth characteristics compared to conventional $ZnSO_4$ under both concentrations. When nutrient molecules are provided to the crop plants as nanoparticles, there will be greater bioavailability and bioaccessibility of nutrient molecules. Thus nutrient use efficiency of crop plants is enhanced which results in better growth characteristics.

Nanofertilizer enhances the NUE because the nutrients were released at a slower and steady rate throughout the crop growth thereby reducing the rate of leaching of nutrients. Nano composites consist of primary and trace nutrients that increases the utilization of nutrients and uptake of nutrients by crops (Guru *et al.*, 2015).

Kale and Gawade (2016) conducted a field experiment on brinjal and revealed that zinc oxide nanoparticle showed a synergistic effect on plants when applied at 4500 mg ha^{-1} and resulted in increased nutrient use efficiency.

The effectiveness of the use of micronutrients are hardly more than 3-5 per cent. Since the micronutrients fertilizers are highly soluble, they are lost through leaching and fixation by clay minerals. Nano zeolite based micronutrient fertilizers are the best source to improve the effectiveness of the use of fertilizers applied in addition to reduce losses.

2.13 Effect of nanofertilizers on uptake of nutrients

2.13.1 Uptake of primary nutrients

Liu and Liao (2008) observed enhanced uptake of N, P and K of water clusters and accumulation of biomass due to the application of nanomaterials.

Rico *et al.* (2011) reported improved uptake of nanofertilizers through the pores or ion channels increased nutrient uptake and utilization by grain crops were observed due to the application of a nano-composite containing primary, trace elements and amino acids (Jinghua, 2004).

When the fertilizers were encapsulated with nanoparticles it improved the uptake of nutrients in pearl millet improved the nutrient release (Tarafdar *et al.,* 2012 b). Combined application of nitrogen fertilizer and nano-carbon in saline-alkali soil resulted in significant increase in deliverability of soil nutrition, uptake of nitrogen by plants, dry matter accumulation and yield of rice crop due to more absorption and saved the N fertilizer without wastage in crop production (Lili *et al.,* 2012).

Tai-bo *et al.* (2013) observed increased nutrient uptake efficiency and promotion of nutrient absorption and accumulation in tobacco plant by the application of carbon nanoparticles.

Studies conducted by Ashrafi *et al.* (2013) revealed that integrated use of compost, farmyard manure, nano-silver fertilizers and chemical fertilizers increased grain nitrogen, phosphorus and potassium uptake in soybean.

Chitosan nanoparticles application resulted in increased uptake of nitrogen, phosphorous, potassium, calcium and magnesium in robusta coffee plants (Van *et al.,* 2013).

Application of nanoparticles resulted in improved seed germination, roots, plant growth and photosynthesis. Nanofertilizer affect both macro and micronutrients status under different irrigation treatments (Hussein *et al.,* 2015). Uptake of nutrients improved with application of nano phosphorous under both stress as well as irrigated condition. The interaction effect of nanofertilizer on various growth stages of cotton plants was studied and it was concluded that the application of 0.5 g L^{-1} nano-P applied promoted the nutrient uptake at budding stage, while application of nano-P fertilizer at 1 g L^{-1} enhanced the nutrient uptake under missing irrigation at flowering condition.

There was a significant increase in total nitrogen content in maize plant parts due to the application of nanozeourea fertilizer (Manikandan and Subramanian, 2015).

Rajonee *et al.* (2016 and 2017) reported that application of nanofertilizers resulted in enhanced phosphorus uptake in kalmi plants than that of the absolute control plot.

Dhansil *et al.* (2018) pointed out that application of nanophosphatic fertilizers enhanced the nutrient content and uptake in pearl millet when compared to conventional fertilizers.

Hagagg *et al.* (2018) revealed the application of nano NPK fertilizers at 0.2 per cent resulted in increased uptake of N, P and K when compared to control plot.

2.13.2 Uptake of secondary nutrients

In plant uptake, solutes translocated by the process of diffusion or mass flow to the external surface of plant roots are taken up by movement across the cell wall and water filled intercellular spaces (Marschner, 1995).

There was an increment in sulphur uptake of mustard due to the application of surface modified nano zeolite which enhanced amino acids and amide accumulation leading to translocation thereby enhancing the growth (Dongarkar *et al.*, 2005).

Ma *et al.* (2010) revealed that the interactions of nano particles in higher plants occur by adsorption onto the root surfaces, incorporation into the cell walls and uptake into the cells.

Thirunavukkarasu and Subramanian (2014) reported that, surface modified nano-zeolite based sulphur release nutrients slowly and steadily during critical growth period thereby improving growth and biochemical parameters besides higher sulfur uptake by groundnut.

2.13.3 Uptake of micronutrients

The application of zinc nanoparticles increased the uptake of nutrients by plants. Particles size of nanoparticle may affect agronomic efficiency of applied Zn. As the particle size decreased, specific surface area of fertilizer increased, thereby increasing the dissolution rate of fertilizers with low solubility in water such as zinc oxide (ZnO) (Mortvedt, 1992).

Sheta *et al.* (2003) proposed that application of clintopillonite which resulted in high potential release of nutrients in a slow manner. Slow release Zn is released to the exchange sites of soil, where they were more available for uptake by plants.

The nutrient efficiency of Ca and Fe improved the seed germination, plant growth and development when treated with Muti Valled CNTs (MWCNTs) (Villagarcia *et al.*, 2012; Tiwari *et al.*, 2014).

Le *et al.* (2014) reported that presence of SiO_2 nanoparticles in the xylem sap of plants and roots were identified using transmission electron microscope and revealed that the presence of SiO_2 nanoparticles found on the shoot of Bt- cotton.

Jitao *et al.*, 2015 revealed that integrated use of microscopic and spectroscopic techniques were adopted to comparatively evaluate the uptake of zinc oxide nanoparticle and Zn^{2+} ions uptake by the maize plants. The plants took up Zn in the form of Zn^{2+} and were stored as zinc phosphate.

2.14. Economics

Kumar *et al.* (2014) revealed that effect of nanofertilizers of gypsum and rock phosphate at the rate of 3 kg ha^{-1} on the wheat. The B:C ratio obtained at 50 per cent RDF with nano-materials was almost statically similar with 100 per cent RDF without nano-materials.

Janmohammadi (2015) revealed that combined application of nanofertilizers along with FYM provided balanced nutrition for the crops and facilitated profitable crop production when compared to that of conventional fertilizers.

Materials and Methods

3. MATERIALS AND METHODS

To meet the objectives set in chapter 1, characterization of granular and liquid organic nano NPK formulations, laboratory incubation study and field experiments were conducted at College of Agriculture, Vellayani during the period July 2017 to February 2019. The main objective of the investigation was the characterization of organic nano NPK formulations, to assess the nutrient release pattern of granular nano NPK formulation under laboratory conditions and to study the effect of organic nano NPK formulations on crop growth, yield, quality and soil health using okra as direct test crop and amaranthus as residual test crop. The investigation comprised of three parts.

PART I. Characterization study of granular and liquid organic nano NPK formulations

PART II. Incubation study to assess the nutrient release pattern from granular organic nano NPK formulation under laboratory conditions

PART III. Field experiments to study the effect of soil and foliar applications of organic nano NPK formulations on crop growth, yield, quality and soil health

The materials used and methods adopted for the present investigation are briefly described in this chapter.

PART 1

3.1 CHARACTERIZATION OF GRANULAR AND LIQUID ORGANIC NANO NPK FORMULATIONS

Commercially available granular and liquid organic nano NPK formulations were used for the study. Characterization of granular and liquid organic nano NPK formulations was done to determine physical, physico-chemical, chemical and biochemical properties as per standard procedures (Table 1).

Table 1. Methods for analysis of granular and liquid organic nano NPK formulations

Sl. No.	Parameter	Method	Reference
1	Particle size analysis	Zeta sizer analyzer	Asadi *et al.* (2009)
2	Zeta potential	Zeta potential analyzer	Asadi *et al.* (2009)
3	Surface area	Surface area analyzer	Wang *et al.* (2012)
4	Morphology	Scanning Electron Microscope	Kliewer (2009)
5	pH	pH meter method	Jackson (1973)
6	EC	Conductivity meter method	Jackson (1973)
7	Organic Carbon	Walkley and Black's rapid titration method	Walkley and Black (1934)
8	Total Nitrogen	Microkjedhal digestion and distillation	Jackson (1973)
9	Total Phosphorus	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using spectrophotometer	Jackson (1973)
10	Total Potassium	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using flame photometer	Jackson (1973)
11	Total calcium and magnesium	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using Versanate titration method	Hesse (1971)
12	Total Sulphur	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and turbidimetry	Massoumi and Cornfield (1963)
13	Total Micronutrients Fe, Mn, Zn, Cu	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using AAS	Jackson (1973)
14	Total Boron	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, filtration and estimation by Spectrophotometry	Roig *et al.* (1988)
15	Heavy metal	HNO_3:$HClO_4$ (9:4) acid digestion and emission spectroscopy (ICP-OES)	Wei and Yang (2010)

Characterization of granular nano NPK formulation

The particle size, surface area, zeta potential, morphology, pH, EC, organic carbon, humic acid, total nutrient contents (N, P, K, Ca, Mg, S, Cu, Zn, Fe, B and Mn), total amino acid and heavy metals (Cd and Pb) of granular nano NPK formulation were estimated as per standard procedures.

Characterization of liquid nano NPK formulation

The particle size, pH, EC, total nutrient contents (N, P, K, Ca, Mg, S, Cu, Zn, Fe, B and Mn), total amino acid and heavy metals (Cd and Pb) of liquid nano NPK formulation were estimated as per standard procedures.

3.1.1 Particle size analysis

Measurements of particle size of granular and liquid nano NPK formulations were done using Zetasizer instrument (Zeta sizer, nano 383 issue 5.0, Malvern, England) (Plate 1). A range of particle size 0.6 nm - 6μm could be determined using diluted samples here. Malvern software was used in the computer system for controlling the instrument as well as analyzing the results.

The particle size measurements were determined as follows: one gram of the powdered sample was carefully weighed out and then dispersed in 10 ml of ethanol. The suspension was stirred by mechanical stirrer for at least 10 minutes in order to break powder agglomerates resulting fine, colloidal particles completely dispersed in ethanol. A small portion of the sample was taken into a disposable cuvette and placed in the instrument for measurement. It was important to avoid getting air bubbles in the sample while filling the cuvette (Asadi *et al.,* 2009).

3.1.2 Zeta potential

The surface charges of granular nano NPK formulations were determined by measuring the zeta potential. About 0.5 mg of sample was added to 20 ml of deionized

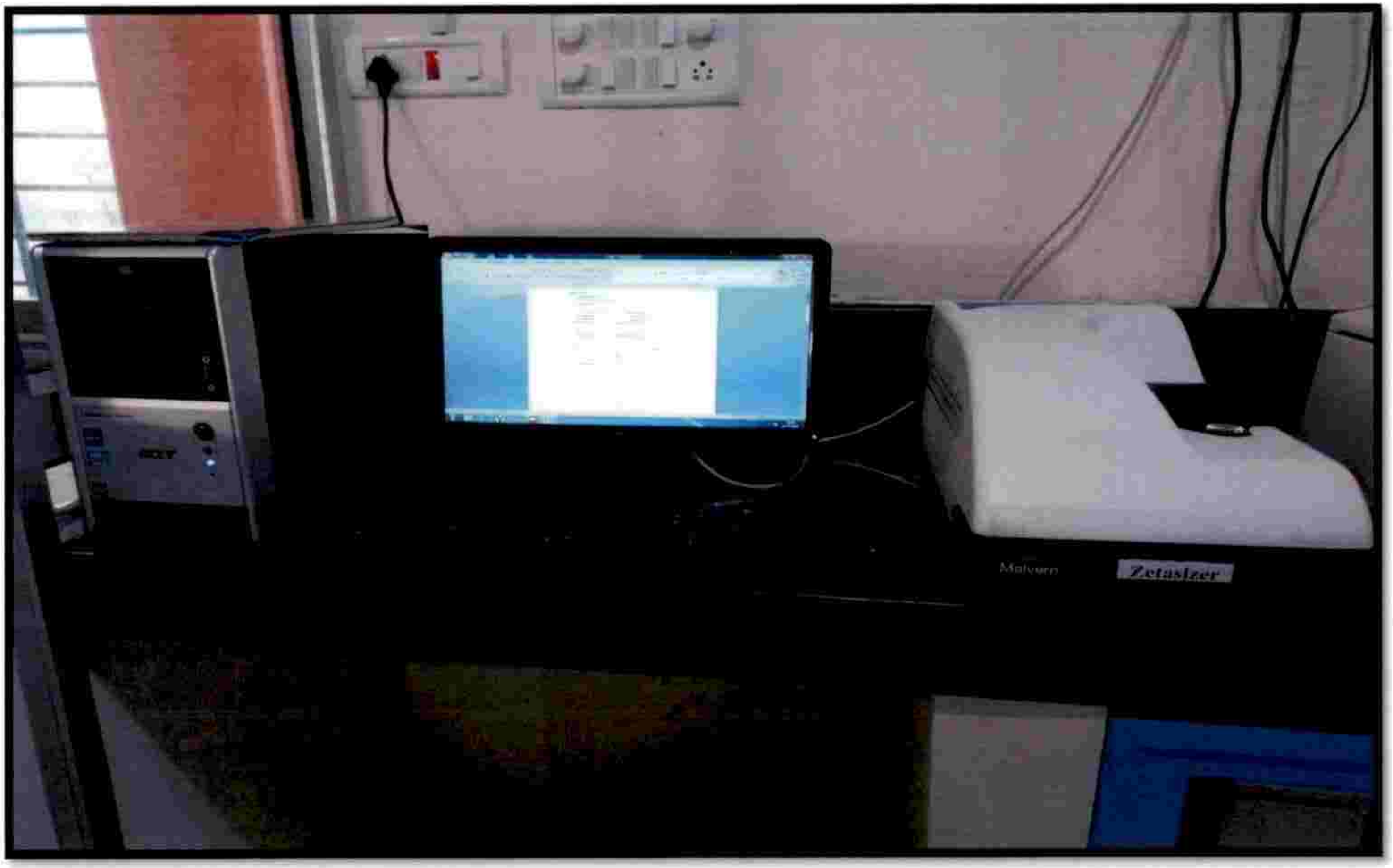


Plate 1. Zetasizer

water and the solution was then sonicated using ultra-sonicator for 20 minutes. The zeta potential of supernatant solution was determined using zeta potential analyzer (Zetasizer Nano ZS90, Malvern Instruments, United Kingdom) (Asadi *et al.,* 2009).

3.1.3 Morphology of granular nano NPK formulation

In the present work, morphology of the granular organic nano NPK formulation was investigated using Scanning Electron Microscope (SEM) (FEI Quanta 250, Netherlands) (Plate 2). Sample was lightly dusted on to the carbon tape embedded over the stub of the SEM. The stub was then mounted on the sample stage for imaging

SEM as the name indicates is an electron microscope which scans the sample surface with high energy beam of electrons and produce images. Information about the surface topography of the sample was obtained from the signals which were produced as a result of interaction between electrons and atoms of sample. Prevention of scattering of the electrons by stray air was achieved by performing observations in the vacuum condition. Pumping out of air from the SEM chamber which contained the sample was the basic process applied here. It was followed by emission of high energy electrons beam from an electron gun placed at the top of the set-up. Focusing the beam to a very fine spot was done by the traveling down of beam through a series of magnetic lenses. The focused beam hits the sample surface producing secondary electrons which were attracted and collected by a detector and then translated into signals. These signals were then amplified, analyzed and translated into images for the surface topography of the sample (Kliewer, 2009).

3.1.4 Surface area

Surface area of nano NPK formulations was analyzed by using surface area analyzer (Wang *et al.,* 2012) (Quantachrome Nova touch) (Plate 3). Brunaver, Emmett and Teller (BET), was the most common method used to describe surface area. Before analysis of surface area of the nano formulation, sample should be heated under

Plate 2. Scanning Electron Microscope (SEM)

Plate 3. Surface area analyzer

vaccum at 150 ^{0}C for 3 hours in order to remove the moisture and organic matter present in it.

3.1.5 Organic fractions (Humic acid, Fulvic acid and Humin)

Method suggested by International Humic Substance Society was used for the extraction in which mild alkali is used for the removal of humic acid. The separation of organic matter into fractions of mixture with similar chemical properties was achieved using alkaline extraction (McBride, 1994).

In the present study 0.5 N NaOH was used as extractant. Twenty gram of the sample was agitated with 200 ml of 0.5 N NaOH for a period of 12 hours. The entire content was filtered to separate the humic acid and the residue left was the insoluble humin. The humic acid which was extracted is quantified gravimetrically. The acid soluble fraction collected during the separation of humic acid is evaporated and estimated as fulvic acid.

3.1.6 Total amino acid

100 mg of weighed sample was homogenized well by adding 5 ml of 80 per cent ethanol with pestle and mortar for 10-15 minutes. Decanted the supernatant in a clean test tube. Re-extracted two times with 2 ml 80 per cent ethanol, decanted the supernatant, combined and made up to 10 ml. Centrifuged and pipetted out the supernatant for estimation. Pipetted out 1 ml of supernatant for estimation and then added 1 ml of 2 per cent ninhydrin reagent and closed the tubes with stopper and kept in boiling water bath for 20 minutes. Cooled and added 6 ml of water – isopropanol mixture (1:1). Mixed and measured the absorbance at 570 nm after 10 minute (Sadasivam and Manickam, 1992).

PART II

3.2 LABORATORY INCUBATION STUDY

The incubation study was conducted under laboratory condition for a period of 75 days from 3-11-2018 to 17-01-2019 (Plate 4). The objective of the incubation study was to assess the nutrient release pattern of granular organic nano NPK formulation at periodic intervals *viz.,* 0^{th}, 7^{th}, 15^{th}, 30^{th}, 45^{th}, 60^{th} and 75^{th} day of incubation under laboratory conditions.

3.2.1 Collection and preparation of soil sample for incubation study

Soil sample for the incubation study was collected from the Model Organic Farm under the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. Soil samples collected were thoroughly mixed, air dried under shade and sieved through 2 mm sieve. Ten kilogram of soil was filled in plastic buckets and treatments were imposed as per technical programme. Field capacity was maintained throughout the study period by replenishing the moisture lost by evaporation which was found out by calculating the weight differences. The details of experiment are presented below.

3.2.2 Design and Layout of the Experiment

Design : CRD

Treatments : 8

Replications : 3

3.2.3 Treatment Details

T_1: Soil alone

T_2: Soil + FYM (12 t ha^{-1})

T_3: Soil + nano NPK (12.5 kg ha^{-1})

T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})

T_5: Soil + nano NPK (25 kg ha^{-1})

T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})

T_7: Soil + nano NPK (50 kg ha^{-1})

T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})

The layout of the laboratory incubation study was presented in Fig.1

R_1T_1	R_2T_2	R_3T_8
R_1T_5	R_2T_6	R_3T_5
R_1T_6	R_2T_4	R_3T_7
R_1T_2	R_2T_3	R_3T_6
R_1T_8	R_2T_7	R_3T_1
R_1T_4	R_2T_5	R_3T_3
R_1T_7	R_2T_1	R_3T_4
R_1T_3	R_2T_8	R_3T_2

Fig. 1 Layout of incubation study

3.2.4 Soil Sampling

Samples were drawn at 0th, 7th, 15th, 30th, 45th, 60th and 75th day of incubation and analysis was done for the following parameters.

3.2.5 Analysis of the samples

Parameters *viz.*, pH, EC, organic carbon, available N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu were determined as per standard procedures to study the nutrient release pattern during the different intervals of incubation period.

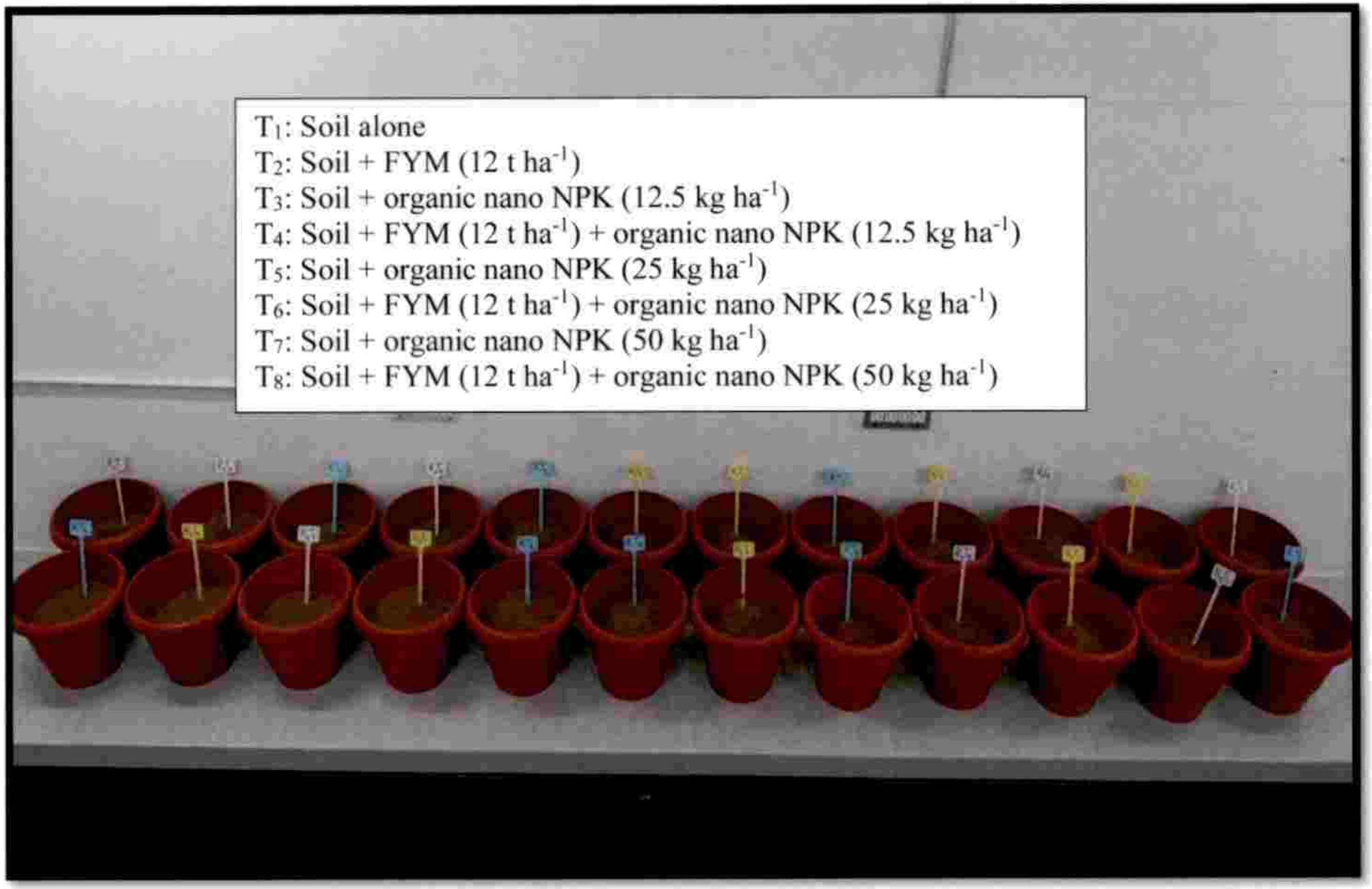


Plate 4. General view of the incubation study

3.2.6 Statistical analysis

The data collected from the laboratory experiment were subjected to statistical analysis as per standard procedure using R package (Dalgaard and Peter, 2001).

PART III- FIELD EXPERIMENTS

Four field experiments were conducted at College of Agriculture, Vellayani to study the effect of organic nano NPK formulations on crop growth, yield, quality and soil health using okra as direct test crop (Plate. 5 and 6) and amaranthus as residual test crop (Plate. 7). The field experiment on okra (Plate. 8) followed by amaranthus (Plate. 9) was repeated for confirmatory results as designated as experiment No: I, II, III and IV.

Experiment No	Crop	Season (Period)	Remarks
I	Okra	03-10-2017 to 05-01-2018	First direct test crop
II	Amaranthus	15-01-2018 to 24-02-2018	Residual crop
III	Okra	15-05-2018 to 20-08-2018	Second direct test crop
IV	Amaranthus	27-08-2018 to 04-10-2018	Residual crop

3.3 EXPERIMENTAL SITE

3.3.1 Location

Field experiments were conducted in the Model Organic Farm (Block V of Instructional Farm) under the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. The site is situated at 8°25'38" N latitude and 76°59'14" E longitude and at an altitude of 19 m above MSL (Plate. 10).

Plate 5. Layout of the experimental field

Plate 6. General view of the field experiment No: I

Plate 7. General view of the field experiment No: II

Plate 8. General view of the field experiment No: III

Plate 9. General view of the field experiment No: IV

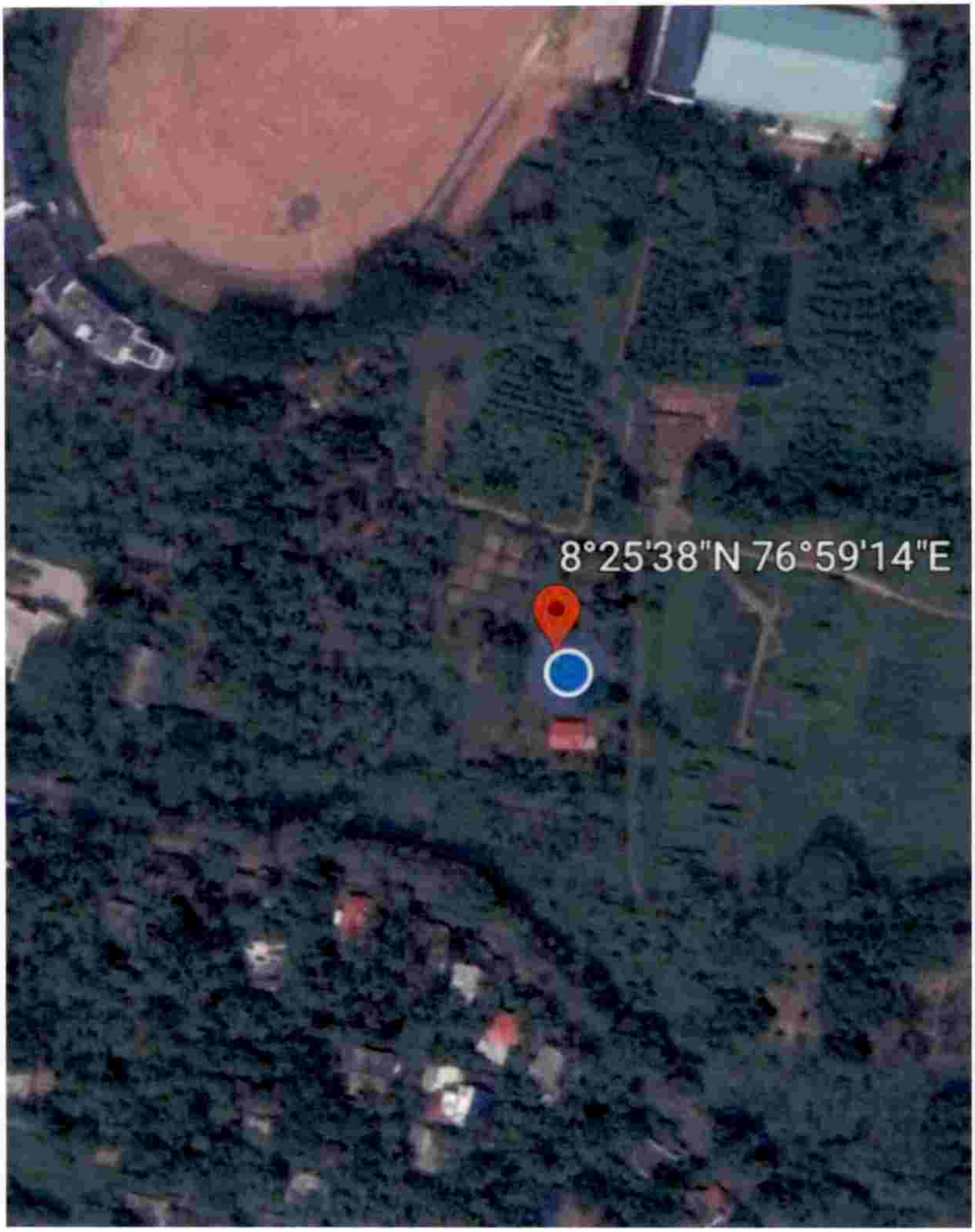


Plate 10. Aerial view of the location of the experimental field

3.3.2 Climate and season

The field experiments were conducted during September 2017 to October 2018.

3.3.3 Weather Parameters

Experiment No.	Mean air temperature (° C)		Relative humidity (%)	Total rainfall (mm)
	Minimum	Maximum		
I	24.15	31.22	87.83	585.5
II	22.81	3[illegible].17	83.80	0.00
III	24.15	30.86	86.44	111.2
IV	24.36	32.19	82.13	115.3

The weather parameters during the cropping period were collected from the Department of Agricultural Meteorology and are presented in Fig. 2, 3, 4, 5 and Appendix I a, I1b, I c and I d.

3.3.4 Soil

Soil of the field experiment site was sandy clay loam belonging to the taxonomic class Loamy Kaolinitic Isohyperthermic Typic Kandiustult.

3.4 MATERIALS

3.4.1 Crop and Variety for direct test crop

The okra variety Varsha Uphar was used as the direct test crop for field experiment. Varsha Uphar variety was released by Chaudhary Charan Singh Haryana Agricultural University, Hissar by inter varietal hybridization between 'Lam Selection 1' and 'Parbhani Kranthi' following pedigree selection in 1996. The seed material was obtained from Instructional Farm, College of Agriculture, Vellayani.

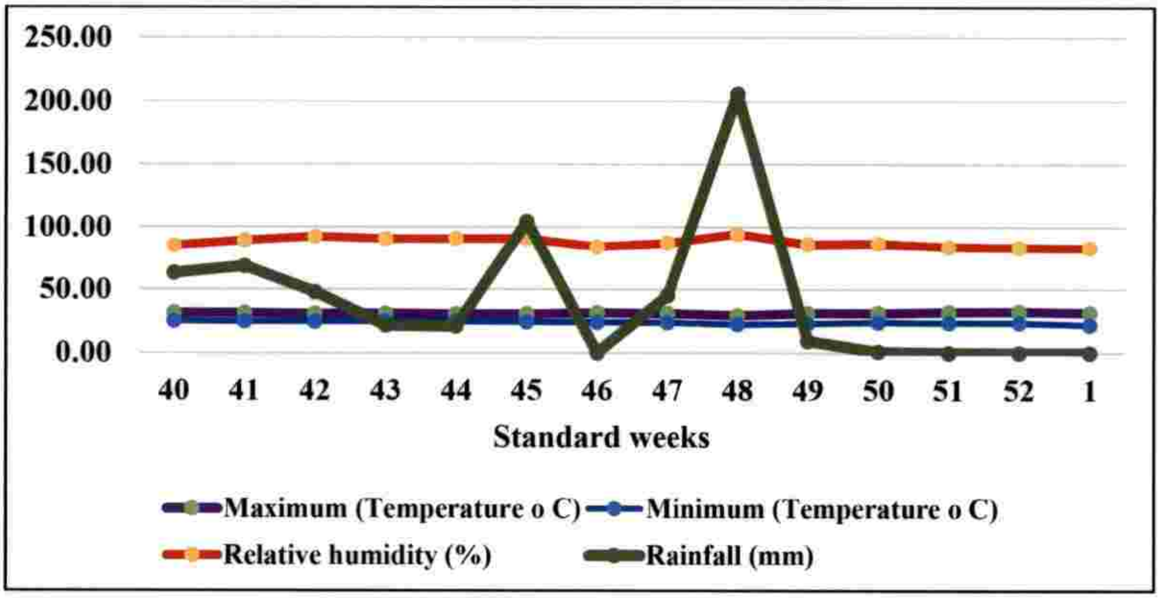


Fig. 2. Weather parameters during the field experiment No: I (03-10-2017 to 05-01-2018)

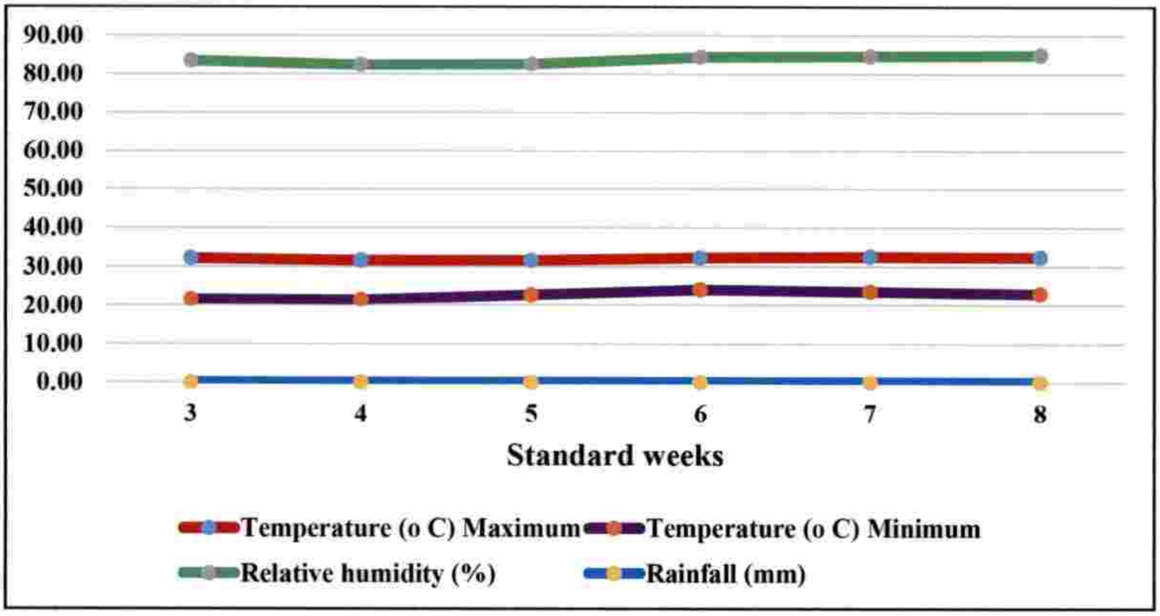


Fig. 3. Weather parameters during the field experiment No: II (15-01-2018 to 24-02-2018)

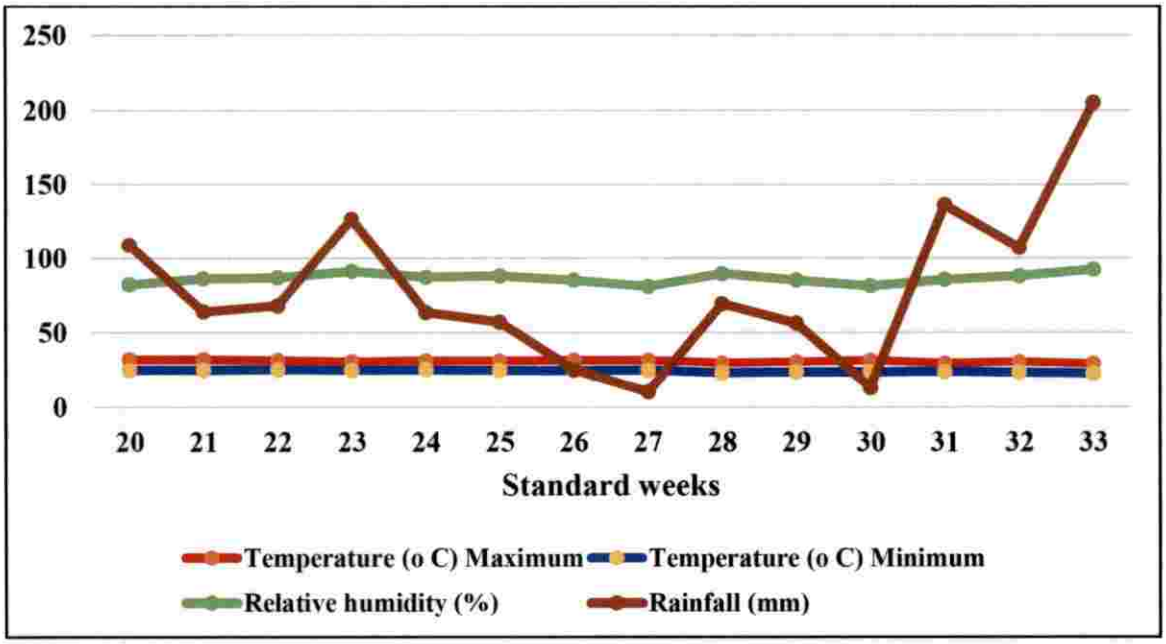


Fig. 4. Weather parameters during the field experiment No: III (15-05-2018 to 20-08-2018)

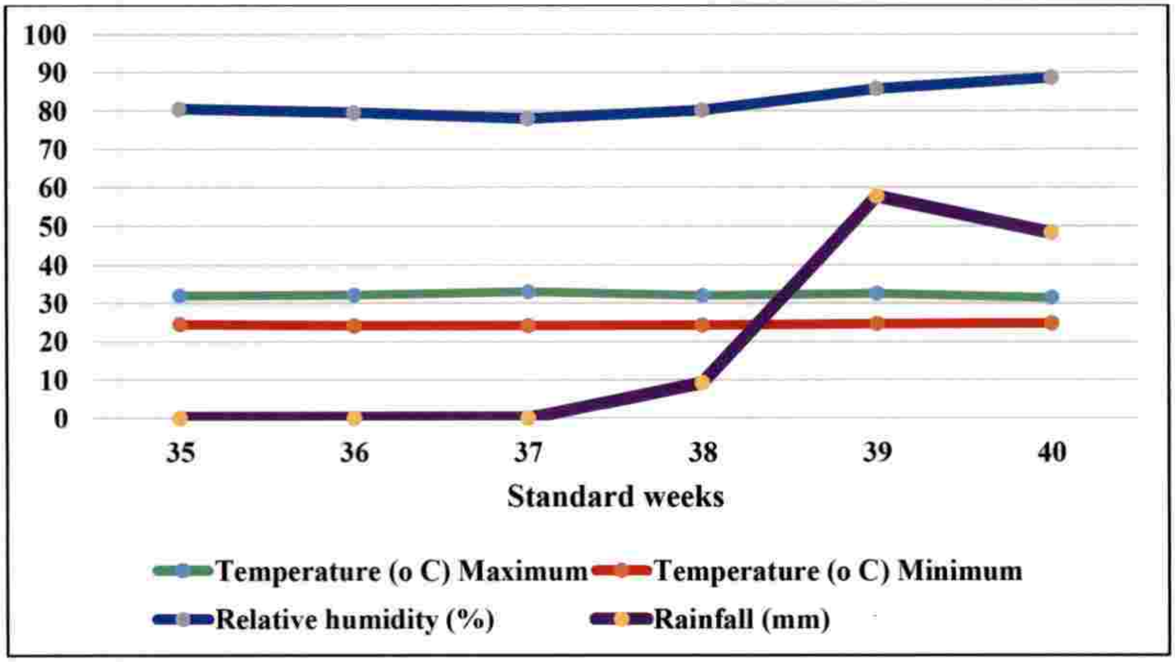


Fig. 5. Weather parameters during the field experiment No: IV (27-08-2018 to 04-10-2018)

3.4.2 Manures, fertilizers and organic nano NPK formulations

Farm yard manure, organic nano NPK formulations and chemical fertilizers *viz.*, urea, rock phosphate and muriate of potash were used as per treatments.

3.5 METHODS

The different methods used for the analysis of soil (Table 2), analysis of plant samples (Table 3) and layout of field experiment (Fig. 6) are presented in the following pages.

3.5.1 Details of field experiments I and III

Design : Lattice Design

Crop : Okra

Variety : Varsha Uphar

Spacing : 60 cm × 30 cm

Plot size : 3.6 m × 3.6 m

Replication : 3

Treatments : 16

The field experiments were conducted by adopting the following treatments.

T_1: Soil application of nano NPK (12.5 kg ha^{-1})

T_2: FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1})

T_3: Soil application of nano NPK (25 kg ha^{-1})

T_4: FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})

T_5: Soil application of nano NPK (50 kg ha^{-1})

T_6: FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1})

T_7: Foliar application of nano NPK (0.2%)

T_8: FYM (12 t ha^{-1}) + Foliar application of nano NPK (0.2%)

T_9: Foliar application of nano NPK (0.4%)

T_{10}: FYM (12 t ha^{-1}) + Foliar application of nano NPK (0.4%)

T_{11}: Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)

T_{12}: FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)

T_{13}: Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2%)

T_{14}: FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2%)

T_{15}: KAU POP (FYM 12 t ha^{-1} + NPK 110:35:70 kg ha^{-1})

T_{16}: Absolute control

Foliar applications were done at 15 days interval.

3.5.2 Preparatory cultivation for okra

The experimental area was ploughed, stubbles removed, clods broken and levelled. Field was laid out into blocks and plots of size 3.6 m × 3.6 m as per experimental design. Lime was incorporated at the rate of 350 kg ha^{-1} and the individual plots were levelled. FYM, organic nano NPK formulations and inorganic fertilizers were applied as per the schedule of treatments.

3.5.3 After Cultivation

Plant population was maintained uniformly by gap filling and thinning wherever necessary. Irrigation and weeding were done as and when required.

3.5.4 Plant protection

The crop was sprayed with the Nimbicidine and Neem garlic emulsion (2 %) as prophylactic measure against pest and disease.

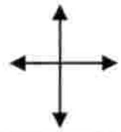
Table 2. Analytical procedures followed in soil analysis of the experiment

Sl. No.	Parameter	Method	Reference
1	Texture	International pipette method	Piper (1966)
2	Water holding capacity	Core method	Gupta and Dakshinamoorthi (1980)
3	Bulk density	Core method	Gupta and Dakshinamoorthi (1980)
4	pH	pH meter	Jackson (1958)
5	EC	Conductivity meter	Jackson(1958)
6	Cation exchange capacity	Neutral normal ammonium acetate extraction	Jackson (1973)
7	Organic carbon	Walkley and Black rapid titration method	Walkley and Black(1934)
8	Labile carbon	Potassium permanganate method	Blair *et al.*(1995)
9	Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
10	Available P	Bray No.1 extraction and estimation using spectrophotometer at 660 nm.	Bray and Kurtz (1945)
11	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
12	Exchangeable Ca and Mg	Versanate titration method	Hesse (1971)
13	Available S	$CaCl_2$ extraction and estimation using spectrophotometer	Massoumi and Cornfield (1963)
14	Available Micronutrients Fe, Mn, Zn and Cu	0.1 N HCl extraction and estimation using AAS	Sims and Jhonson (1991)
15	Dehydrogenase assay	Spectrophotometric method	Casida *et al.* (1964)
16	Urease assay	Spectrophotometric method	Broadbent *et al.*(1964)
17	Alkaline phosphatase assay	Spectrophotometric method	Tabatabai and Bremner (1969)
18	Acid phosphatase assay	Spectrophotometric method	Tabatabai and Bremner (1969)
19	Bacteria count	Nutrient Agar medium	Atlas and Parks (1993)
20	Fungi count	Martin's Rose Bengal Agar	Martin (1950)
21	Actinomycetes count	Ken knight's agar medium	Coppuccino and Sheman (1996)

Table 3. Analytical methods followed in plant analysis

Sl. No.	Parameter	Method	Reference
1	Nitrogen	Microkjedahl digestion and distillation	Jackson (1973)
2	Phosphorus	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using Vanado molybdate yellow colour method	Jackson (1973)
3	Potassium	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using flame photometer	Jackson(1973)
4	Calcium and Magnesium	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using Versanate titration method	Hesse (1971)
5	Sulphur	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and turbidimetry	Massoumi and Cornfield (1963)
6	Micronutrients: Fe, Mn, Zn and Cu	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using AAS	Jackson (1973)

N



R1				
B1	**T_3**	**T_2**	**T_4**	**T_1**
B2	**T_6**	**T_5**	**T_8**	**T_7**
B3	**T_{12}**	**T_{11}**	**T_9**	**T_{10}**
B4	**T_{13}**	**T_{15}**	**T_{14}**	**T_{16}**
R2				
B1	**T_1**	**T_5**	**T_9**	**T_{13}**
B2	**T_6**	**T_2**	**T_{10}**	**T_{14}**
B3	**T_{11}**	**T_7**	**T_{15}**	**T_3**
B4	**T_{12}**	**T_8**	**T_4**	**T_{16}**
R3				
B1	**T_1**	**T_8**	**T_{11}**	**T_{14}**
B2	**T_5**	**T_2**	**T_{12}**	**T_{15}**
B3	**T_3**	**T_9**	**T_6**	**T_{16}**
B4	**T_7**	**T_4**	**T_{10}**	**T_{13}**

Fig 6. Lay out of experiment field

3.6 Observations for direct test crop (okra)

Five plants were selected at random from the sampling area and tagged. The biometric observations were recorded from all the tagged plants. The observations on growth characters, physiological characters, yield and yield attributes were recorded from the tagged plants.

3.6.1 Growth Characters

3.6.1.1 Plant height

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

3.6.1.2 Number of branches per plant

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

3.6.1.3 Leaf area index (LAI)

LAI was computed using the formula suggested by Watson (1952) at first harvest.

$$LAI = \text{Leaf area} / \text{Land area}$$

3.6.1.4 Root volume

Five plants were selected at random and uprooted at harvest stage. Root volume was measured by water displacement method (Misra and Ahmed, 1989). The roots of the observational plants were washed free of adhering soil with water and immersed in a graduated cylinder containing water. The rise of water level was recorded. Displacement of volume of water was taken as the volume of the root and the average was expressed in cm^3.

3.6.1.5 Root length

The length of roots of the uprooted plants were measured from plant base to the tip of longest rootlet and recorded in cm, at the time of harvest stage.

3.6.1.6 Dry matter production of plant

The samples were shade dried initially and then dried in hot air oven at 70°C till attained constant weight. From the dried samples the dry matter production (DMP) was calculated and expressed in kg ha^{-1}.

3.6.2 Physiological characters

3.6.2.1 Estimation of chlorophyll content

Half gram of fresh leaf sample was taken and cut into small bits and kept overnight in 10 ml acetone (80%): DMSO mixture (1:1 v/v) and the coloured solution was used for reading in spectrophotometer. Absorbance was read at 663 nm and 645 nm. The chlorophyll content was calculated as mg g^{-1} by using the formula given below (Hiscox and Israelstam, 1979).

Chlorophyll a = $(12.7 \times A_{663} - 2.69 \times A_{645}) \times V/1000 \times 1/$ fresh weight

Chlorophyll b = $(22.9 \times A_{645} - 4.68 \times A_{663}) \times V/1000 \times 1/$ fresh weight

Total Chlorophyll content = $(8.02 \times A_{663} + 20.2 \times A_{645})\ V/1000 \times 1/$ fresh weight

3.6.3 Yield and yield attributes

3.6.3.1 Days to first flowering

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

3.6.3.2 Days to 50% flowering

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

3.6.3.3 Number of fruits per plant

Number of fruits harvested from all the tagged plants were counted and the average was worked out.

3.6.3.4 Length of fruit

The fruit length was measured from the base (stalk end) to the apex with the help of measuring scale and the mean was worked out and expressed in centimeter.

3.6.3.5 Girth of fruit

The circumference of the fruit at the broadest point was measured using a thread and scale. The mean was worked out and expressed in centimeter.

3.6.3.6 Crop period

Number of days from the date of sowing till the final harvest of the plant.

3.6.3.7 Average fruit weight

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

3.6.3.8 Total fruit yield

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

3.6.4 Quality parameters

3.6.4.1 Crude protein content

The total nitrogen content of fruits were determined and the values were multiplied by the factor 6.25 to obtain the crude protein content of fruits and the values were expressed in per cent (Simpson *et al.*, 1965).

3.6.4.2 Crude fibre content

Two grams of powdered dry fruit sample was treated with acid and alkali then allowed oxidative hydrolytic degradation of the native cellulose and considerable degradation of lignin. The residue left over after the last filtration was weighed, incinerated, cooled and weighed once again. The difference in both weights were determined and recorded as the crude fibre present in the sample (Sadasivam and Manickam, 1992).

3.6.4.3 Ascorbic acid content

The ascorbic acid content present in the fruit was estimated by titrimetric method (Sadasivam and Manickam, 1996) and expressed in mg 100 g^{-1}.

3.6.5 Incidence of pests and diseases

Incidence of semi loopers and fruit and shoot borers were seen initially. Nimbicidine 5 per cent was applied at fortnightly intervals and controlled these pests.

3.6.6 Soil samples collection and analysis

The initial soil samples (0-15 cm depth) were collected and analyzed as per standard procedures (Table 2). The post-harvest surface soil samples (0-15 cm) were collected from all the treatment plots. The soil samples thus collected were shade dried, gently ground with a wooden mallet and sieved through 2 mm sieve and stored in polyethylene bags. These samples were analysed for pH, EC, organic carbon and available nutrients *viz.*, N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu. The analytical methods followed for above analysis are given in Table 2.

3.6.6.1 Nutrient Use Efficiency

Nutrient use efficiency in terms of yield was calculated by using the formula.

$$\text{NUE (\%)} = \frac{\text{Yield of treatment with Organic nano NPK} - \text{Yield of treatment without Organic nano NPK (KAU POP)}}{\text{Yield of treatment without Organic nano NPK (KAU POP)}} \times 100$$

3.6.7 Plant analysis

After the final picking, a representative plant sample from each plot was taken for analyzing nutrient content. Representative fruit sample from each plot was also taken at each picking for analyzing the nutrient content in fruit. The samples thus collected were dried in hot air oven at 70° C for constant weight. The powdered samples were analyzed for N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu content and the analytical methods followed are given in Table 3.

3.6.7.1 Nutrient uptake

Total uptake by plant was worked out using the given formula.

$$\text{Nutrient uptake} = \frac{\text{Nutrient content (\%)} \times \text{DMP (kg ha}^{-1}\text{)}}{100}$$

3.6.8 ECONOMICS OF CULTIVATION

Economics of cultivation was worked out for the field experiment after taking into account the cost of cultivation and prevailing market price of okra. The B:C ratio was calculated as follows.

Benefit: Cost ratio = Gross income / Total expenditure

3.6.9 STATISTICAL ANALYSIS

Statistical analysis was done using SAS 9.3 proc glm.

3.7 FIELD EXPERIMENTS II and IV: RESIDUAL CROP - AMARANTHUS

The red amaranthus variety, Arun was used as the test crop for assessing the residual effect of organic nano NPK formulations. The variety was released from KAU. It is a high yielding, photo insensitive variety suited for homesteads of Southern Kerala.

3.7.1 Seeds

The seeds were collected from the Institutional Farm, College of Agriculture, Vellayani.

3.7.2 Details of residual field experiments II and IV

Design : Lattice Design

Crop : Amaranthus

Variety : Arun

Spacing : 30 cm x 20 cm

Plot size : 3.6 m × 3.6 m

Replication : 3

Treatments : 16

3.8 Observations for residual test crop (Amaranthus)

3.8.1 Plant height (cm)

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

3.8.2 Number of branches

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

3.8.3 Dry matter production

The fresh samples of shoots were initially shade dried and then oven dried at 70^0C till it attained the constant dry weight and was expressed in kg ha^{-1}.

3.8.4 Yield

Yield from the observation plants were recorded and expressed in kg ha^{-1}.

3.8.5 Ascorbic acid

Ascorbic acid content of amaranthus were estimated as per the standard procedure expressed in mg 100 g^{-1} (Sadasivam and Manickam, 1996).

3.8.6 β carotene

Estimation was done by the method proposed by Srivatsava and Kumar (1998). 10-15 ml acetone and few crystals of anhydrous sodium sulphate were used to crush 5 gram of fresh sample in pestle and mortar. Supernatant was stored in a beaker and the same process was repeated twice and transferred to a separating funnel. Added petroleum ether of 10-15 ml to that mixture which resulted in the formation of two layers. Discarded the lower layer and upper layer was collected in a 100 ml volumetric flask. Volume was made into 100 ml by adding petroleum ether and the optical density at 452 nm was recorded with petroleum ether as blank.

$$\beta \text{ carotene } (\mu g/\ 100g) = \frac{\text{Optical density} \times 13.9 \times 10^4 \times 100}{\text{Weight of sample} \times 560 \times 1000}$$

3.8.7 Oxalate content

Estimation of oxalate was done by method suggested by A.O.A.C (1984). Extracted one gram of dried powder with 0.25N HCl in a water bath twice for one hour. Centrifuged the sample and was collected in a conical flask then it was precipitated by the addition of 5 ml tungsto phosphoric acid, kept overnight and then again centrifuged. This was neutralized with dilute ammonia solution at 1:1 ratio. Precipitation was done using 5 ml acetate buffer with calcium chloride (pH 4.5). The precipitate is centrifuged and washed two times with 6 ml wash liquid. Precipitate was transferred into 100 ml conical flask by dissolving 10-15 ml 2N Sulphuric acid and titrated against 0.01N potassium permanganate solution at 60°C.

$$\text{Percentage Oxalate} = \frac{0.063}{1\text{g}} \times V$$

3.8.8 Nitrate content

Estimated by the procedure suggested by Middleton (1958). 9 ml silver sulphate was added to 0.1 g dried sample and swirled quickly. After filtration, 2 ml of filtrate and 2 ml of copper sulphate were added to 15ml centrifuge tube which was mixed thoroughly by the addition of 6 ml water. 0.5g of calcium hydroxide – magnesium carbonate mixture added was allowed to stand for 1hour and centrifuged for 5 minutes at 3000 rpm. 2 ml phenol-p-sulphuric acid was mixed into a boiling tube, directly to the bottom. Swirling was done by adding 2 ml of supernatant drop by drop from above directly into the reagent. After cooling, 25 ml ammonium hydroxide was added with stirring. Cooled mixture was read at 475 nm in a spectrophotometer with instrument set at zero using water as blank.

3.9 Soil and plant analysis

Important physical, chemical, biochemical and biological analysis of soil and plant uptake of the residual crop were done as per standard procedures (Table 2 and Table 3).

3.10 ECONOMICS OF CULTIVATION

Economics of cultivation was worked out for the field experiment after taking into account the cost of cultivation and prevailing market price of amaranthus. The B:C ratio was calculated as follows.

Benefit: Cost ratio = Gross income / Total expenditure

3.11 STATISTICAL ANALYSIS

Statistical analysis was done using SAS 9.3 proc glm.

Parameters for observations of the experiment No. I (direct test crop - okra) and experiment No. II (residual test crop - amaranthus) were recorded for experiment No. III (direct test crop - okra) and experiment No. IV (residual test crop - amaranthus) also.

Results

4. RESULTS

The present study entitled "Organic nano NPK formulations for enhancing soil health and productivity" was undertaken at College of Agriculture, Vellayani during the period from July 2017 to February 2019. Characterization of organic nano NPK formulations, incubation study to monitor the nutrient release pattern of granular organic nano NPK formulation under laboratory condition and field experiments to assess the effectiveness of soil and foliar applications of organic nano NPK formulations using okra as direct test crop and amaranthus as residual test crop were the objectives of the present investigation.

The investigation consisted of three parts. The first part of the study was characterization of organic nano NPK formulations to determine physical, physico-chemical, chemical and biochemical properties. The second part was laboratory incubation experiment to monitor the nutrient release pattern of granular nano NPK formulation. The third part of the investigation was field experiments in which okra was used as the direct test crop and amaranthus as the residual test crop to test the efficacy of organic nano NPK formulations on crop growth, yield, quality and soil health. The same field experiments using okra as direct test crop and amaranthus as residual test crop were conducted once again to get the confirmatory results. The results obtained during the course of investigation is presented in this chapter.

PART I

4.1 CHARACTERIZATION OF GRANULAR AND LIQUID ORGANIC NANO NPK FORMULATIONS

4.1.1 Physical properties

4.1.1.1 Particle size analysis

Granular organic nano NPK formulation had the particle size with an average single peak exhibited at 83.20 nm (Table 4 and Fig. 7). Similarly liquid nano NPK formulation had an average particle size of 71.79 nm (Table 4 and Fig. 8).

4.1.1.2 Zeta potential

Granular organic nano NPK formulation exhibited the zeta potential of -14.4 mV (Table 4 and Fig. 9).

4.1.1.3 Surface morphology

Surface morphology of granular organic nano NPK formulation were determined by scanning electron microscope and revealed that granular nano NPK formulation was having circular to irregular surface morphology (Table 4 and Fig. 10).

4.1.1.4 Surface area

Surface area of the granular nano NPK formulation used for the study as given in Table 4 and Fig. 11 was found to be 138.95 $m^2\ g^{-1}$.

4.1.2 Physico-chemical characters of granular and liquid organic nano NPK formulations

Perusal of data presented in table 4 shows the physico-chemical characters of granular and liquid organic nano NPK formulations.

Among the nano NPK formulations, the granular organic nano NPK formulation had the pH and EC of 7.68 and 0.141 dS m^{-1} respectively. Liquid nano

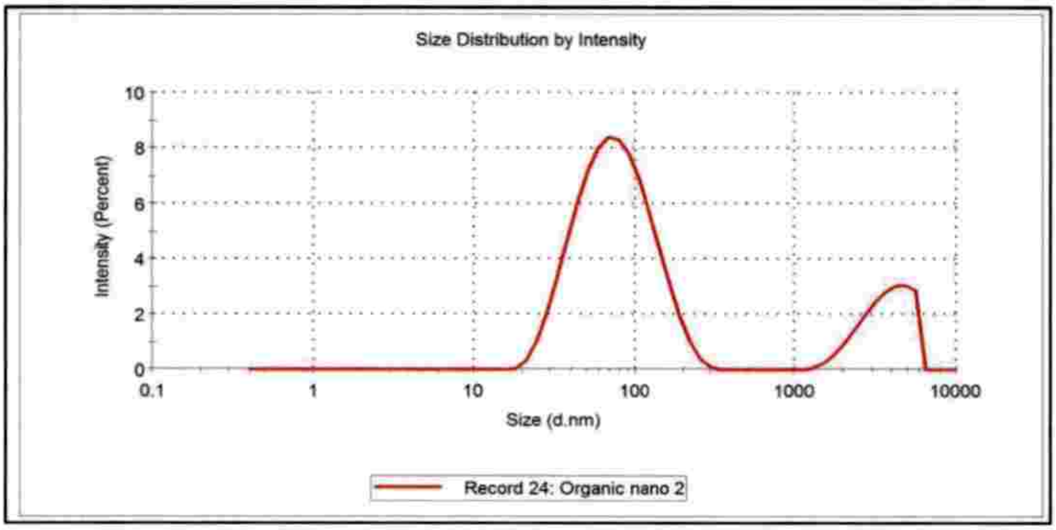


Fig. 7. Particle size of granular nano NPK formulation

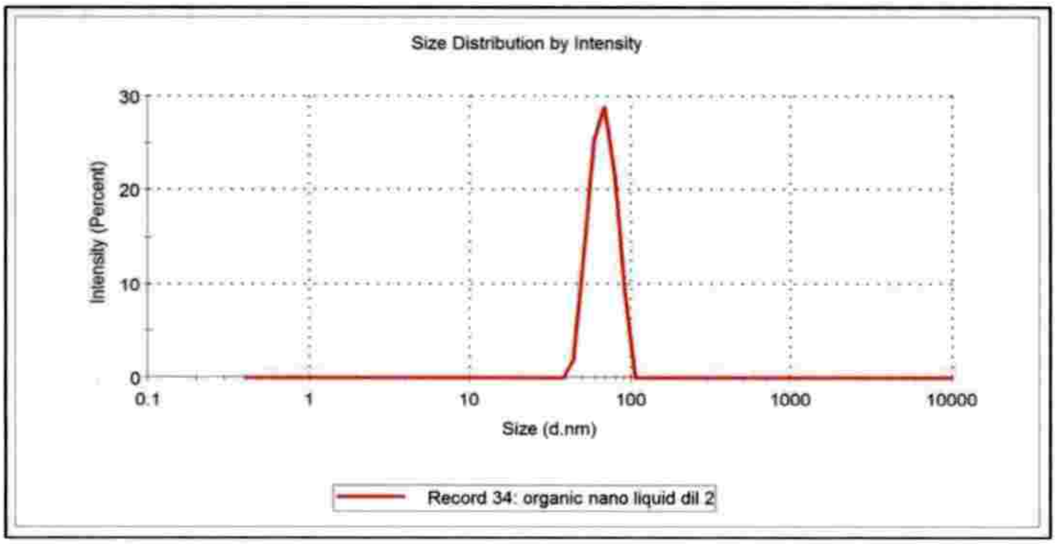


Fig.8. Particle size of liquid nano NPK formulation

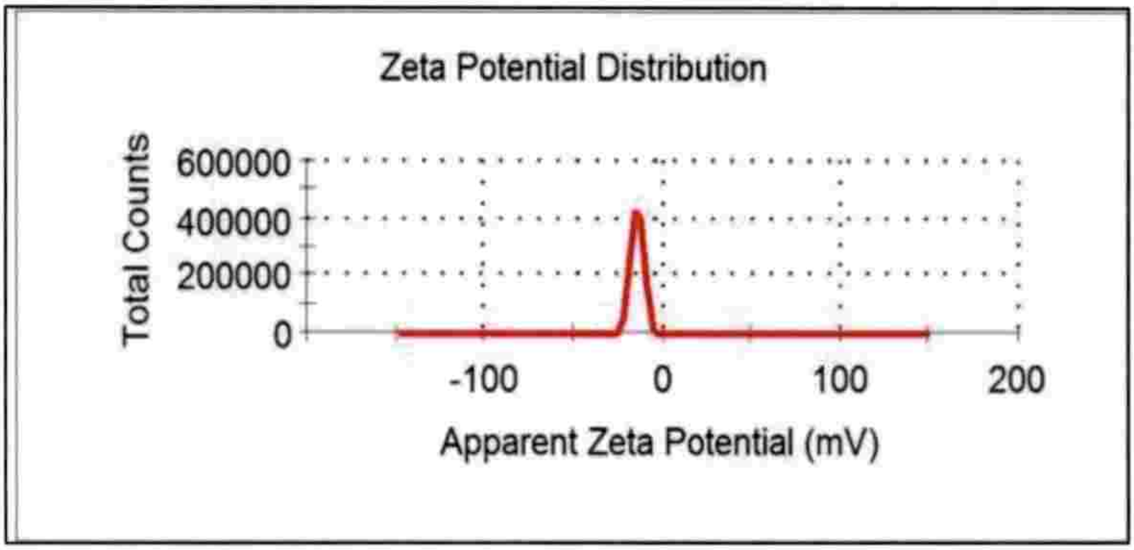


Fig. 9. Zeta potential of granular nano NPK formulation

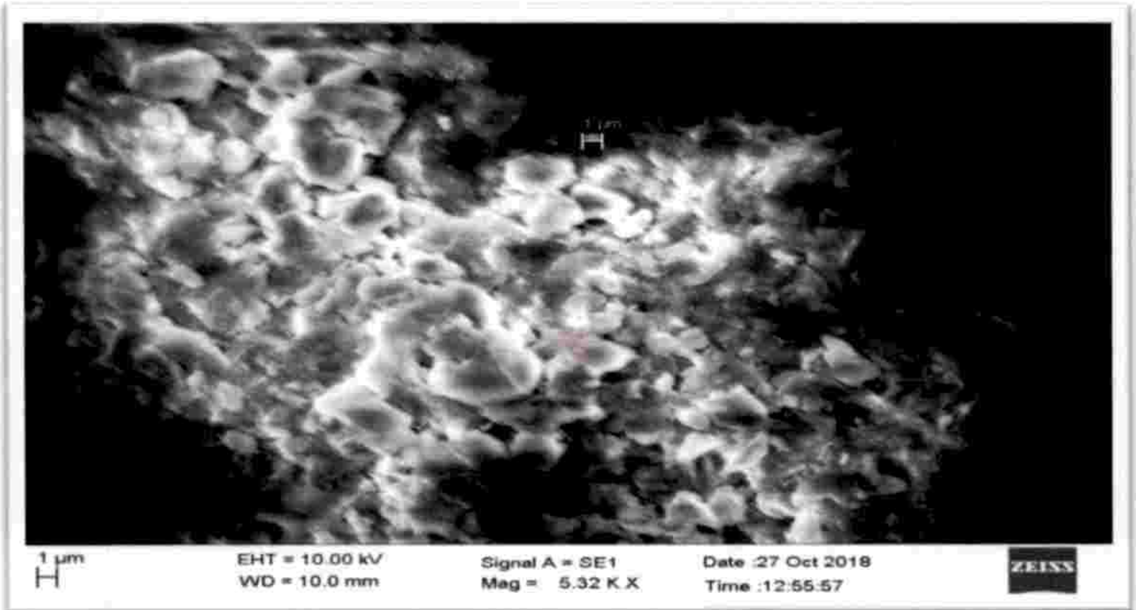


Fig. 10. SEM image of granular nano NPK formulation

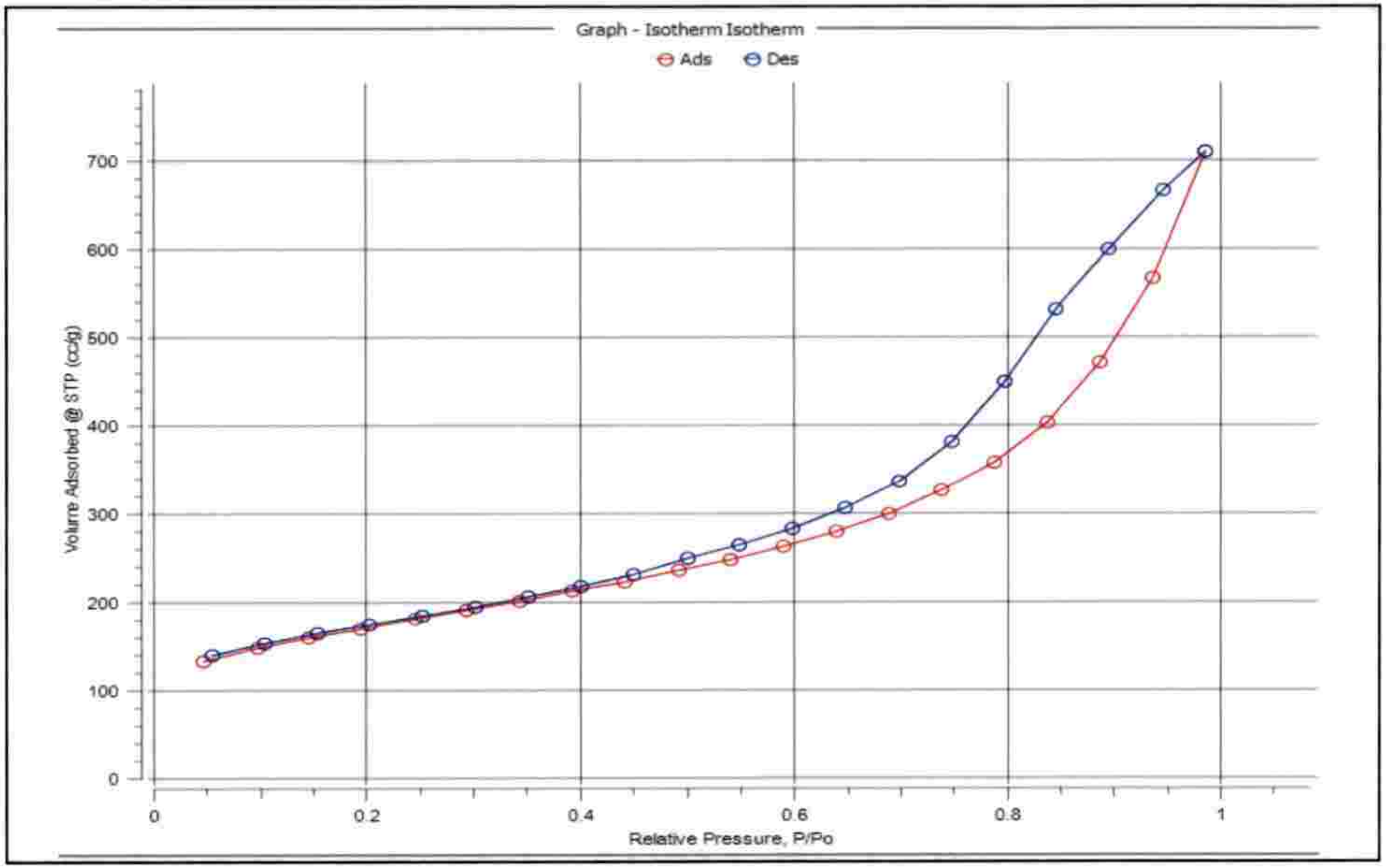


Fig. 11. Surface area of granular nano NPK formulation

Table 4. Characterization of granular and liquid organic nano NPK formulations

<table>
<tr><th>Sl. No</th><th colspan="2">Parameter</th><th>Granular nano NPK</th><th>Liquid nano NPK</th></tr>
<tr><td>1</td><td colspan="2">Particle size (nm)</td><td>83.20</td><td>71.79</td></tr>
<tr><td>2</td><td colspan="2">Zeta potential (mV)</td><td>-14.40</td><td>-</td></tr>
<tr><td>3</td><td colspan="2">Morphology</td><td>Circular to irregular</td><td>-</td></tr>
<tr><td>4</td><td colspan="2">Surface area ($m^2 g^{-1}$)</td><td>138.95</td><td>-</td></tr>
<tr><td>5</td><td colspan="2">pH (1:5)</td><td>7.68</td><td>6.55</td></tr>
<tr><td>6</td><td colspan="2">EC, dS m^{-1} (1:5)</td><td>0.141</td><td>0.184</td></tr>
<tr><td>7</td><td colspan="2">N (%)</td><td>1.96</td><td>1.82</td></tr>
<tr><td>8</td><td colspan="2">P (%)</td><td>1.76</td><td>1.89</td></tr>
<tr><td>9</td><td colspan="2">K (%)</td><td>2.75</td><td>3.53</td></tr>
<tr><td>10</td><td colspan="2">OC (%)</td><td>2.25</td><td>-</td></tr>
<tr><td>11</td><td colspan="2">Ca (%)</td><td>0.37</td><td>0.21</td></tr>
<tr><td>12</td><td colspan="2">Mg (%)</td><td>0.30</td><td>0.09</td></tr>
<tr><td>13</td><td colspan="2">S (%)</td><td>0.59</td><td>0.75</td></tr>
<tr><td>14</td><td colspan="2">Cu (mg kg^{-1})</td><td>104.0</td><td>3.10</td></tr>
<tr><td>15</td><td colspan="2">Fe (mg kg^{-1})</td><td>465.7</td><td>152.8</td></tr>
<tr><td>16</td><td colspan="2">Mn (mg kg^{-1})</td><td>662.5</td><td>41.77</td></tr>
<tr><td>17</td><td colspan="2">Zn (mg kg^{-1})</td><td>398.3</td><td>318.1</td></tr>
<tr><td>18</td><td colspan="2">B (mg kg^{-1})</td><td>47.54</td><td>9.37</td></tr>
<tr><td>19</td><td colspan="2">As (mg kg^{-1})</td><td>ND</td><td>ND</td></tr>
<tr><td>20</td><td colspan="2">Pb (mg kg^{-1})</td><td>ND</td><td>6.90</td></tr>
<tr><td>21</td><td colspan="2">Cd (mg kg^{-1})</td><td>ND</td><td>ND</td></tr>
<tr><td>22</td><td colspan="2">Ni (mg kg^{-1})</td><td>6.00</td><td>5.40</td></tr>
<tr><td>23</td><td colspan="2">Cr (mg kg^{-1})</td><td>9.67</td><td>3.43</td></tr>
<tr><td>24</td><td colspan="2">Total Amino acid (mg kg^{-1})</td><td>270</td><td>370</td></tr>
<tr><td rowspan="3">25</td><td rowspan="3">Organic matter fraction (%)</td><td>Fulvic acid</td><td>29.86</td><td>-</td></tr>
<tr><td>Humic acid</td><td>16.73</td><td>-</td></tr>
<tr><td>Humin</td><td>5.90</td><td>-</td></tr>
</table>

NPK formulation had the pH and EC of 6.55 and 0.184 dS m^{-1}. The organic carbon content of granular organic nano NPK formulation was 2.25 per cent.

4.1.3 Chemical properties

4.1.3.1 Nutrient contents of granular and liquid organic nano NPK formulations

Primary, secondary and micronutrient contents of granular and liquid organic nano NPK formulations were analyzed and the results are presented in Table 4.

Regarding primary nutrients, the granular organic nano NPK formulation had N, P and K content of 1.96 per cent, 1.76 per cent and 2.75 per cent, respectively whereas, the liquid nano NPK formulation had N, P and K content of 1.82 per cent, 1.89 per cent and 3.53 per cent, respectively.

The secondary nutrients *viz.,* Ca, Mg and S contained in the granular organic nano NPK formulation were 0.37 per cent, 0.30 per cent and 0.59 per cent, respectively. In the case of liquid nano NPK formulation, the secondary nutrients *viz.,* Ca, Mg and S contents were 0.21 per cent, 0.09 per cent and 0.75 per cent, respectively.

With respect to the micronutrient contents of organic nano NPK formulations, the granular nano NPK formulation recorded Cu content of 104.0 mg kg^{-1}, Fe content of 465.7 mg kg^{-1}, Mn content of 662.5 mg kg^{-1}, Zn content of 398.3 mg kg^{-1} and B content of 47.54 mg kg^{-1}, whereas, liquid nano NPK formulation had Cu, Fe, Mn, Zn and B content of 3.10 mg kg^{-1}, 152.8 mg kg^{-1}, 41.77 mg kg^{-1}, 318.1 mg kg^{-1} and 9.37 mg kg^{-1}, respectively.

4.1.3.2 Heavy metal contents of granular and liquid organic nano NPK formulations

Heavy metal contents of granular and liquid organic nano NPK formulations are presented in table 4. All the heavy metal contents of granular organic nano NPK formulations were under the permissible limit. As and Cd contents were not even detected. Granular organic nano NPK formulation contained Ni and Cr 6.00 mg kg^{-1} and 9.67 mg kg^{-1}, respectively.

Liquid nano NPK formulation was under the permissible limit with respect to heavy metal content. As and Cd contents were not even detected and Pb, Ni and Cr contents were 6.90 mg kg^{-1}, 5.40 mg kg^{-1} and 3.43 mg kg^{-1}, respectively.

4.1.4 Biochemical properties

Total amino acid present in the granular and liquid organic nano NPK formulations were found to be 270 mg kg^{-1} and 370 mg kg^{-1}, respectively (Table 4).

Organic matter fractions were determined in the granular nano NPK formulation and recorded fulvic acid content of 29.86 per cent, humic acid content of 16.73 per cent and humin content of 5.90 per cent (Table 4).

PART II

4.2 LABORATORY INCUBATION STUDY

An incubation experiment was conducted to evaluate the nutrient release pattern of granular nano NPK formulation in the laboratory conditions. The various soil parameters *viz.,* pH, EC, organic carbon, primary, secondary and micro nutrients were estimated on 0^{th}, 7^{th}, 15^{th}, 30^{th}, 45^{th}, 60^{th} and 75^{th} day of incubation and the results are presented in Table 5-17.

4.2.1 pH

From the result (Table 5) it was found that pH showed significant variation due to the influence of various treatments. In general, increased pH values were observed in all the treatments received different rates of organic nano NPK formulation compared to that of control throughout the incubation period. It was also noticed that

Table 5. pH of the soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	5.11	5.37	5.54	5.41	5.52	5.20	5.36
T_2: Soil + FYM (12 t ha^{-1})	5.26	5.50	5.68	5.55	5.60	5.35	5.81
T_3: Soil + nano NPK (12.5 kg ha^{-1})	5.26	5.58	5.55	5.53	5.67	5.42	5.77
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	5.30	5.65	5.76	5.62	5.69	5.91	5.91
T_5: Soil + nano NPK (25 kg ha^{-1})	5.26	5.53	5.70	5.58	5.67	5.35	5.79
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	5.33	5.67	5.79	5.82	5.83	5.93	5.93
T_7: Soil + nano NPK (50 kg ha^{-1})	5.27	5.59	5.73	5.60	5.68	5.45	5.87
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	5.36	5.66	5.77	5.71	5.75	5.91	5.91
SEm (±)	0.02	0.02	0.03	0.02	0.03	0.02	0.02
CD (0.05)	0.05	0.04	0.05	0.05	0.05	0.04	0.03

treatments that received a combination of FYM and granular nano formulation recorded higher pH values than treatments with granular nano NPK formulation alone throughout the incubation period.

Soil reaction was found to be increased gradually during the incubation period from 0th day to 75th day of incubation in all treatments. A maximum pH value of 5.93 was recorded by T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) on 60th and 75th days of incubation. The lowest values were recorded by T_1 (Soil alone treatment) throughout the incubation periods. On 0th day T_8 (Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})) recorded the highest value of 5.36 which was found to be on par with T_6. On 7th day, the highest mean value of 5.67 was recorded in T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) and was on par with T_8 (5.66) and T_4 (5.65). T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) recorded the highest value (5.79) on 15th day of incubation which found to be on par with T_8 (5.77), T_4 (5.76) and T_7 (5.73). On 30th and 45th the highest soil reaction values 5.82 and 5.83 was observed, respectively by T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) was significantly superior to all other treatments. On the 60th day of incubation, T_6 recorded higher soil pH of 5.93 and was comparable with T8 (5.91) and T4 (5.91). The highest value of 5.93 was also recorded by T_6 on 75th day of incubation.

4.2.2 EC

The treatments showed significant variation in the electrical conductivity during incubation (Table 6). In general there was an increasing trend with respect to electrical conductivity on advancement of the incubation period in all treatments. Treatments that received combination of FYM and organic nano NPK formulation recorded higher EC values than treatments that received organic nano NPK formulation alone.

Table 6. EC (dS m^{-1}) of the soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	0.089	0.140	0.153	0.184	0.201	0.224	0.277
T_2: Soil + FYM (12 t ha^{-1})	0.163	0.205	0.217	0.266	0.285	0.384	0.310
T_3: Soil + nano NPK (12.5 kg ha^{-1})	0.095	0.162	0.158	0.188	0.211	0.249	0.379
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	0.157	0.167	0.250	0.277	0.356	0.306	0.369
T_5: Soil + nano NPK (25 kg ha^{-1})	0.106	0.143	0.161	0.201	0.214	0.243	0.305
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	0.168	0.204	0.233	0.240	0.234	0.291	0.365
T_7: Soil + nano NPK (50 kg ha^{-1})	0.112	0.160	0.191	0.198	0.255	0.274	0.415
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	0.183	0.223	0.258	0.258	0.285	0.390	0.439
SEm (±)	0.008	0.007	0.007	0.007	0.009	0.006	0.008
CD (0.05)	0.017	0.016	0.016	0.016	0.021	0.014	0.018

The treatment T_8 (Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})) observed the highest value (0.183 dS m^{-1}) of electrical conductivity on 0^{th} day of incubation and was also on par with T_6 (0.168 dS m^{-1}). The treatment T_8 (Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})) registered the highest value of electrical conductivity on 7^{th} day (0.223 dS m^{-1}). On 15^{th} day of incubation treatment T_8 (Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})) observed the highest value (0.258 dS m^{-1}) electrical conductivity which was also on par with T_4 (0.250 dS m^{-1}). T_1 (Soil alone) recorded the lowest EC throughout the incubation period. On 30^{th} day of incubation, T_4 (0.277 dS m^{-1}) was on par with T_2 (0.266 dS m^{-1}). T_4 (0.356 dS m^{-1}) was found to be significantly superior than all other treatments on 45^{th} day of incubation. On 60^{th} day of incubation T_8 recorded the highest value (0.390 dS m^{-1}) of electrical conductivity which was on par with T_2 (0.384 dS m^{-1}). The treatment T_8 recorded the highest electrical conductivity (0.439 dS m^{-1}) on 75^{th} day of incubation.

4.2.3 Organic carbon

Organic carbon content had shown significant changes among treatments and it is presented in table 7. Organic carbon ranged from 0.40 per cent to 0.96 per cent during the period of the incubation study. In general treatments that received combination of FYM and organic nano NPK formulation recorded higher organic carbon content than treatments that received organic nano NPK formulation alone.

The highest mean value of organic carbon content (0.53 %), (0.69 %) and (0.96 %) were registered in T_8 (Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})) on 0^{th}, 30^{th} and 75^{th} day of incubation and was superior than all the other treatments. On 7^{th} day of incubation, T_6 recorded the highest mean value (0.64 %) of organic carbon and was comparable with T_4 (0.59 %), T_7 (0.58 %) and T_2 (0.57 %). The highest mean value of organic carbon content was registered by T_8 (0.74 %) and was on par with T_4 (0.71 %) on the 15^{th} day of incubation. The highest mean value (0.59 %) was observed by T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) on 45^{th} day of incubation and

Table 7. Organic carbon content (%) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	0.40	0.54	0.57	0.54	0.49	0.57	0.73
T_2: Soil + FYM (12 t ha^{-1})	0.42	0.57	0.67	0.64	0.56	0.82	0.83
T_3: Soil + nano NPK (12.5 kg ha^{-1})	0.44	0.55	0.68	0.65	0.51	0.75	0.75
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	0.48	0.59	0.71	0.64	0.57	0.79	0.94
T_5: Soil + nano NPK (25 kg ha^{-1})	0.41	0.55	0.63	0.57	0.52	0.75	0.77
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	0.44	0.64	0.63	0.64	0.59	0.77	0.84
T_7: Soil + nano NPK (50 kg ha^{-1})	0.45	0.58	0.62	0.66	0.51	0.83	0.86
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	0.53	0.56	0.74	0.69	0.58	0.85	0.96
SEm (±)	0.009	0.03	0.01	0.01	0.02	0.01	0.01
CD (0.05)	0.02	0.08	0.03	0.02	0.04	0.02	0.02

was comparable with T_8 (0.58 %), T_4 (0.57 %) and T_2 (0.56 %). On 60th day of incubation, T_8 (0.85 %) recorded the highest mean value of organic carbon content and was comparable with T_7 (0.83 %). The least organic carbon content was recorded in the T_1 (Soil alone treatment) throughout the incubation period.

4.2.4 Available nitrogen

Nitrogen is considered as the most important plant nutrient so data on the available N need a thorough study throughout the incubation period. Mean values of soil available nitrogen content during the incubation period are presented in table 8. Treatments showed significant difference in available N content during the period of incubation study.

The highest value (177.0 kg ha^{-1}) was observed by T_4 (Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})) which was found to be on par with T_6 (173.3 kg ha^{-1}), T_2 (169.2 kg ha^{-1}) and T_8 (168.0 kg ha^{-1}) on 0th day of incubation. On 7th day of incubation T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) recorded the highest mean value (225.8 kg ha^{-1}) followed by T_4 (221.6 kg ha^{-1}), T_8 (217.5 kg ha^{-1}) and T_3 (215.0 kg ha^{-1}). On 15th day of incubation T_6 recorded the highest available N status (252.2 kg ha^{-1}) which was on par with T_2, T_3 and T_4. On 30th and 45th day of incubation T_6 recorded the highest mean value of 294.3 kg ha^{-1} and 339.3 kg ha^{-1} respectively and was superior to all the other treatments. The highest mean value of 290.2 kg ha^{-1} was recorded by T_8 (Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})) on 60th day of incubation and was on par with T_4 (285.7 kg ha^{-1}). On 75th day of incubation, the highest mean value (294.8 kg ha^{-1}) recorded by T_7, which was found to be on par with T_5 (288.1 kg ha^{-1}) and T_3 (285.9 kg ha^{-1}).

The release of available nitrogen was found to be increased upto 45th day of incubation and thereafter started declining. The maximum release (339.3 kg ha^{-1}) was recorded by T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) on 45th day of

Table 8. Available N status (kg ha^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	145.3	175.3	198.6	210.7	186.5	192.3	192.3
T_2: Soil + FYM (12 t ha^{-1})	169.2	191.1	244.4	221.7	263.8	255.5	204.5
T_3: Soil + nano NPK (12.5 kg ha^{-1})	158.7	215.0	242.6	223.4	296.9	263.6	285.9
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	177.0	221.6	242.4	267.4	305.5	285.7	262.7
T_5: Soil + nano NPK (25 kg ha^{-1})	154.9	200.0	233.8	263.4	272.6	263.4	288.1
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	173.3	225.8	252.2	294.3	339.3	265.0	266.7
T_7: Soil + nano NPK (50 kg ha^{-1})	163.1	193.4	222.2	259.7	277.2	272.9	294.8
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	168.0	217.5	229.3	274.8	294.0	290.2	276.0
SEm (±)	6.23	5.39	5.43	5.15	4.62	4.94	5.72
CD (0.05)	13.16	11.38	11.47	10.87	9.75	10.44	12.07

incubation. T_1 (Soil alone treatment) recorded the lowest values of available N throughout the period of incubation.

4.2.5 Available phosphorus

Available phosphorous content of the soil was found to be increased with the advancement of the incubation period (Table 9). The least available P content was recorded in T_1 (Soil alone treatment). In general, P content of the incubated soil was found to be increased upto 45^{th} day of incubation and thereafter showed a declining tendency.

The highest mean value of 48.72 kg ha^{-1} was recorded by T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) which was comparable with T_4 (48.64 kg ha^{-1}) on 0^{th} day of incubation. On 7^{th} day of incubation, T_4 (Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})) recorded the highest mean value of 58.43 kg ha^{-1} and which was on par with T_8 (58.39 kg ha^{-1}). On 15^{th} day of incubation the highest mean value of 63.48 kg ha^{-1} was recorded byT_4 which was significantly higher than all other treatments. The highest available P was recorded by T_6 on 30^{th}, 45^{th} and 60^{th} day with mean values of 68.67 kg ha^{-1}, 103.6 kg ha^{-1} and 93.51 kg ha^{-1}, respectively. On 75^{th} day of incubation highest available P was observed on T_6 (58.38 kg ha^{-1}) and was on par with T_4 (58.23 kg ha^{-1}).

4.2.6 Available potassium

The NH_4OAc-K content of soil was influenced by different levels of granular organic nano NPK formulation with and without FYM and is presented in table 10. In general, available K content of the soil increased gradually upto 60^{th} day of incubation and thereafter declined.

On 0^{th} day of incubation, T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1}) recorded the highest available potassium status (264.2 kg ha^{-1}) which was superior

Table 9. Available P status (kg ha^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	27.99	41.09	50.25	53.89	84.82	78.11	42.67
T_2: Soil + FYM (12 t ha^{-1})	45.33	50.75	53.71	65.50	96.15	84.11	55.35
T_3: Soil + nano NPK (12.5 kg ha^{-1})	34.36	44.09	54.00	58.35	94.04	84.84	48.30
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	48.64	58.43	63.48	67.91	102.00	92.14	58.23
T_5: Soil + nano NPK (25 kg ha^{-1})	35.10	43.61	53.74	58.30	93.26	82.88	51.75
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	48.72	56.65	62.09	68.67	103.59	93.51	58.38
T_7: Soil + nano NPK (50 kg ha^{-1})	33.23	43.68	54.72	60.35	93.97	88.55	48.69
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	45.39	58.39	61.69	67.01	101.50	91.84	55.77
SEm (±)	0.48	0.27	0.40	0.23	0.21	0.31	0.42
CD (0.05)	1.03	0.57	0.85	0.50	0.45	0.67	0.89

Table 10. Available K content (kg ha^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	96.41	93.95	76.96	80.33	84.02	94.64	93.33
T_2: Soil + FYM (12 t ha^{-1})	160.5	160.5	194.2	179.5	197.9	218.2	197.9
T_3: Soil + nano NPK (12.5 kg ha^{-1})	115.7	115.1	134.0	150.3	118.4	134.1	126.6
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	223.4	254.2	242.4	213.7	257.6	280.2	260.5
T_5: Soil + nano NPK (25 kg ha^{-1})	109.3	129.4	163.4	162.0	137.5	137.5	156.5
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	264.2	229.5	261.0	246.0	260.1	287.5	265.1
T_7: Soil + nano NPK (50 kg ha^{-1})	123.2	123.6	128.8	109.5	124.9	133.8	127.5
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	207.4	216.0	240.6	252.0	302.4	304.6	249.4
SEm (±)	4.81	5.54	6.30	5.12	5.06	5.53	4.77
CD (0.05)	10.15	11.71	13.31	10.82	10.69	11.67	10.07

to all the other treatments. The highest mean value was recorded by T_4 (254.2 kg ha^{-1}) on 7th day of incubation. On 15th day of incubation, T_6 (261.0 kg ha^{-1}) registered the highest available K content in the soil and was superior to all other treatments. The highest available K was observed by T_8 (252.0 kg ha^{-1}) and which was also on par with T_6 (246.0 kg ha^{-1}) on 30th day of incubation. On 45th and 60th day of incubation, T_8 recorded the highest value with mean value of 302.4 kg ha^{-1} and 304.6 kg ha^{-1} respectively. The highest mean value was registered by T_6 (265.1 kg ha^{-1}) and was on par with T_4 (260.5 kg ha^{-1}) on 75th day of incubation. T_1 (Soil alone treatment) was found to be inferior to all other treatments throughout the incubation experiment.

4.2.7 Exchangeable calcium

The results of the exchangeable calcium as influenced by different treatments is presented in table 11. The exchangeable Ca increased with increase in duration of the incubation upto 45th day of incubation and after 60th day showed a drastic decrease in exchangeable calcium content. The highest mean values of exchangeable Ca content was registered by T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) on 15th, 30th, 45th and 60th day of incubation experiment.

On 0th day of incubation, T_5 (Soil + nano NPK (25 kg ha^{-1})) recorded the highest mean value of exchangeable Ca (202.9 mg kg^{-1}) which was comparable with T_8 (200.7 mg kg^{-1}). The highest mean value was observed by T_2 (Soil + FYM (12 t ha^{-1})) on 7th day of incubation (246.6 mg kg^{-1}) and was on par with T_3 (245.8 mg kg^{-1}), T_8 (243.3 mg kg^{-1}), T_6 (236.2 mg kg^{-1}) and T_4 (235.7 mg kg^{-1}). On 15th day of incubation, T_6 (612.9 mg kg^{-1}) recorded the highest mean value of exchangeable Ca and which was comparable with T_3 (593.7 mg kg^{-1}), T_2 (592.2 mg kg^{-1}) and T_5 (582.9 mg kg^{-1}). On 30th, 45th and 60th day of incubation, T_6 recorded the highest mean value of 626.7 mg kg^{-1}, 723.3 mg kg^{-1} and 623.3 mg kg^{-1}, respectively and was superior to all other treatments. The highest mean value of exchangeable Ca was recorded by T_8 (253.3 mg kg^{-1}) and which was on par with T_4 (231.9 mg kg^{-1}) and T_6

Table 11. Exchangeable Ca content (mg kg^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	150.4	228.3	500.0	526.7	403.3	503.3	206.7
T_2: Soil + FYM (12 t ha^{-1})	186.7	246.6	592.2	579.3	422.4	585.3	222.1
T_3: Soil + nano NPK (12.5 kg ha^{-1})	178.0	245.8	593.7	613.3	460.0	523.3	227.6
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	176.7	235.7	576.3	538.1	623.3	586.7	231.9
T_5: Soil + nano NPK (25 kg ha^{-1})	202.9	232.7	582.9	610.0	610.0	590.0	212.8
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	186.7	236.2	612.9	626.7	723.3	623.3	229.2
T_7: Soil + nano NPK (50 kg ha^{-1})	173.0	230.0	566.7	566.7	560.0	595.3	216.4
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	200.7	243.3	540.0	556.7	603.3	511.8	253.3
SEm (±)	6.73	6.34	15.51	5.03	6.18	6.47	11.64
CD (0.05)	14.21	13.39	32.73	10.62	13.06	13.67	24.58

(229.2 mg kg^{-1}) on 75th day of incubation. The lowest exchangeable Ca was registered by T_1 (Soil alone treatment) throughout the incubation period.

4.2.8 Exchangeable magnesium

The availability of magnesium due to the influence of different treatments were presented in table 12. All the treatments showed significant difference in exchangeable Mg content due to the effect of treatments.

On 0th day of incubation, the soil that was treated with nano NPK (25 kg ha^{-1}) (T_5) resulted in highest mean value of 85.55 mg kg^{-1} and which was superior than all the other treatments. The highest mean value of exchangeable Mg content (61.75 mg kg^{-1}) was registered in T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) on 7th day of incubation and was comparable with T_8 (51.59 mg kg^{-1}). On 15th day of incubation, T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) recorded the highest mean value (73.40 mg kg^{-1}) and which was on par with T_2 (65.21 mg kg^{-1}), T_5 (58.94 mg kg^{-1}) and T_7 (58.74 mg kg^{-1}). The highest mean value (60.23 mg kg^{-1}) registered in T_6 and was comparable with T_8 (56.25 mg kg^{-1}) and T_3 (54.34 mg kg^{-1}) on 30th day of incubation period. On 45th day of incubation, T_8 (78.00 mg kg^{-1}) recorded the highest mean value and which was on par with T_4 (74.65 mg kg^{-1}), T_2 (69.20 mg kg^{-1}), T_7 (65.41 mg kg^{-1}) and T_6 (61.68 mg kg^{-1}). The highest mean value was observed on T_8 (58.64 mg kg^{-1}) on 60th day of incubation and was superior than all the other treatments. On 75th day of incubation, T_6 recorded the highest mean value (55.53 mg kg^{-1}) and which was comparable with T_5 (55.30 mg kg^{-1}) and T_8 (52.59 mg kg^{-1}). T_1 recorded the lowest exchangeable magnesium throughout the incubation study.

Table 12. Exchangeable Mg content (mg kg^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	24.00	20.00	40.51	14.69	40.36	22.66	33.25
T_2: Soil + FYM (12 t ha^{-1})	51.31	34.00	65.21	28.17	69.20	26.68	42.90
T_3: Soil + nano NPK (12.5 kg ha^{-1})	48.06	35.22	50.99	54.34	52.00	26.58	47.08
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	56.00	42.00	48.69	24.71	74.65	39.78	48.25
T_5: Soil + nano NPK (25 kg ha^{-1})	85.55	34.24	58.94	43.58	42.48	30.00	55.30
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	46.00	61.75	73.40	60.23	61.68	40.54	55.53
T_7: Soil + nano NPK (50 kg ha^{-1})	54.00	44.19	58.74	31.08	65.41	35.94	41.22
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	26.00	51.59	52.90	56.25	78.00	58.64	52.59
SEm (±)	4.07	6.87	9.69	6.37	10.05	6.25	2.71
CD (0.05)	8.60	14.51	20.46	13.45	21.22	13.19	5.72

4.2.9 Available sulphur

Available sulphur content of soil was influenced by different levels of organic nano NPK formulations and is presented in table 13. The availability of sulphur content was gradually increased upto 45th day of incubation and thereafter the content was decreased. In general, treatments that received combination of FYM and organic nano NPK formulation recorded higher available S than treatments that received organic nano NPK formulation alone.

On 0th day of incubation, T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) recorded the highest mean value (6.38 mg kg^{-1}) and was comparable with T_8 (6.30 mg kg^{-1}). The highest mean value was registered by T_6 (8.11 mg kg^{-1}) and was on par with T_4 (7.64 mg kg^{-1}) on 7th day of incubation study. On 15th day of incubation, T_6 observed the highest mean value of 13.61 mg kg^{-1} followed by T_8 (13.23 mg kg^{-1}), T_3 (13.20 mg kg^{-1}) and T_7 (13.04 mg kg^{-1}). On 30th and 60th day of incubation, T_8 recorded the highest mean value of 13.88 mg kg^{-1} and 15.83 mg kg^{-1} respectively and was superior than all other treatments. On 45th day of incubation, T_6 recorded the highest mean value (37.50 mg kg^{-1}) and was also superior to other treatments. The highest mean value was registered with T_6 (5.28 mg kg^{-1}) on 75th day of incubation and was comparable with T_8 (4.89 mg kg^{-1}). T_1 (soil alone treatment) registered the lowest mean value throughout the incubation period.

4.2.10 Available iron

Data on available iron content due to different treatment effects during the whole incubation is presented in table 14. Available Fe content showed significant difference among the various treatments. In general, the available Fe content of the soil increased upto 45th day of incubation and thereafter decreased.

On 0th day of incubation, T_2 (Soil + FYM (12 t ha^{-1})) registered the highest mean value (8.34 mg kg^{-1}) and was comparable with T_4 (8.21 mg kg^{-1}),

Table 13. Available S content (mg kg^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	2.56	1.85	9.67	2.96	9.40	5.50	1.59
T_2: Soil + FYM (12 t ha^{-1})	5.25	4.24	11.86	9.15	15.29	11.57	2.98
T_3: Soil + nano NPK (12.5 kg ha^{-1})	4.15	5.46	13.20	10.08	9.79	8.17	2.95
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	4.54	7.64	11.21	12.25	23.17	14.00	3.67
T_5: Soil + nano NPK (25 kg ha^{-1})	4.39	4.98	11.52	12.48	19.63	14.88	3.83
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	6.38	8.11	13.61	6.55	37.50	6.34	5.28
T_7: Soil + nano NPK (50 kg ha^{-1})	4.50	4.25	13.04	12.54	29.58	11.57	3.53
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	6.30	6.49	13.23	13.88	29.72	15.83	4.89
SEm (±)	0.36	0.34	0.38	0.46	0.50	0.29	0.22
CD (0.05)	0.77	0.72	0.81	0.98	1.06	0.63	0.48

Table 14. Available Fe content (mg kg^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	6.89	6.66	9.55	11.32	16.99	10.29	8.25
T_2: Soil + FYM (12 t ha^{-1})	8.34	10.37	9.83	11.86	17.07	10.91	9.50
T_3: Soil + nano NPK (12.5 kg ha^{-1})	8.19	10.72	10.23	11.81	17.11	10.58	8.69
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	8.21	11.77	10.78	11.88	18.25	10.61	9.78
T_5: Soil + nano NPK (25 kg ha^{-1})	7.73	10.26	11.02	12.25	17.04	12.06	9.36
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	8.19	11.86	11.24	12.17	19.13	15.55	9.98
T_7: Soil + nano NPK (50 kg ha^{-1})	7.66	11.79	11.45	11.73	17.80	10.33	8.48
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	7.47	11.79	11.66	13.57	17.09	11.75	9.64
SEm (±)	0.14	0.02	0.05	0.15	0.04	0.02	0.13
CD (0.05)	0.30	0.05	0.10	0.31	0.08	0.04	0.28

T_3 (8.19 mg kg^{-1}) and T_6 (8.19 mg kg^{-1}). On 7th, 45th and 60th day of incubation T_6 recorded the highest mean values of 11.86 mg kg^{-1}, 19.13 mg kg^{-1} and 15.55 mg kg^{-1} respectively and was superior than all other treatments. The highest mean values of available iron content of 11.66 mg kg^{-1} and 13.57 mg kg^{-1} were registered by T_8 on 15th and 30th day of incubation, respectively and was superior than other treatments. On 75th day of incubation, T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) recorded the highest mean value of available iron (9.98 mg kg^{-1}) and on par with T_4 (9.78 mg kg^{-1}). The treatment T_1 (soil alone treatment) registered the least values throughout the incubation experiment.

4.2.11 Available manganese

Available manganese content of the incubation experiment is presented in table 15 and was evident that different treatments significantly influenced the available Mn content of the soil. In general, available Mn content increased upto 45th day of incubation and thereafter declined. It was revealed from the data that treatments that received combination of FYM and organic nano NPK formulation recorded higher available Mn than treatments that received organic nano NPK formulation alone.

On the 0th day of incubation, T_4 (Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})) registered the highest mean value of 15.27 mg kg^{-1} available Mn content of the soil and was significantly higher than all other treatments. The highest mean values of available Mn content of 11.07 mg kg^{-1}, 16.64 mg kg^{-1}, 20.61 mg kg^{-1} and 13.21 mg kg^{-1} were registered in T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) on 7th, 30th, 45th and 60th day of incubation, respectively and was superior to all other treatments. On 15th day of incubation, T_8 recorded the highest mean value (11.56 mg kg^{-1}) and was followed by T_6 (11.55 mg kg^{-1}). The highest mean value of 11.94 mg kg^{-1} observed on 75th day of incubation in T_6 and was comparable with T_4 (11.68 mg kg^{-1}). The treatment T_1 (Soil alone treatment) recorded the lowest available Mn values throughout incubation study.

Table 15. Available Mn content (mg kg^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	11.70	8.17	9.64	13.07	17.39	8.61	8.23
T_2: Soil + FYM (12 t ha^{-1})	14.91	9.84	10.54	13.74	20.27	10.03	11.39
T_3: Soil + nano NPK (12.5 kg ha^{-1})	11.47	7.94	9.74	13.55	17.86	9.65	10.19
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	15.27	8.20	11.21	14.89	19.71	9.88	11.68
T_5: Soil + nano NPK (25 kg ha^{-1})	12.81	8.30	10.58	15.75	19.96	8.79	9.15
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	13.86	11.07	11.55	16.64	20.61	13.21	11.94
T_7: Soil + nano NPK (50 kg ha^{-1})	12.06	8.24	9.73	13.92	17.89	9.28	9.63
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	12.98	10.13	11.56	14.84	19.75	10.65	10.08
SEm (±)	0.15	0.14	0.14	0.14	0.15	0.14	0.13
CD (0.05)	0.31	0.30	0.30	0.29	0.32	0.30	0.28

4.2.12 Available zinc

Mean values of available zinc content of the soil during incubation study is presented in table 16. Treatments showed significant difference among themselves with respect to available Zn content during the incubation study. In general, treatments that received combination of FYM and organic nano NPK formulation recorded higher available Zn than treatments that received organic nano NPK formulation alone.

On 0^{th} day of incubation, T_8 (Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})) recorded the highest available Zn content (4.29 mg kg^{-1}) and which was significant to all other treatments. The highest mean value of Zn content was registered by T_7 (4.64 mg kg^{-1}) on the 7^{th} day of incubation. The highest mean value of available Zn content of 4.68 mg kg^{-1} and 4.87 mg kg^{-1} were registered by T_4 on 15^{th} and 30^{th} day of incubation, respectively and was superior than all other treatments. On 45^{th}, 60^{th} and 75^{th} day of incubation T_6 recorded the highest mean values of 5.68 mg kg^{-1}, 4.90 mg kg^{-1} and 5.55 mg kg^{-1}, respectively and was superior than all other treatments. Soil without any treatment (T_1) was recorded the lowest mean values throughout the incubation period.

4.2.13 Available Copper

Mean values of available copper content of differently treated soil is presented in table 17. In general available Cu content was increased upto 45^{th} day of incubation and thereafter showed a declining tendency.

On 0^{th} day of incubation, T_7 (Soil + nano NPK (50 kg ha^{-1})) recorded the highest mean value of 1.56 mg kg^{-1} and which was comparable with T_5 (1.52 mg kg^{-1}), T_2 (1.52 mg kg^{-1}), T_4 (1.50 mg kg^{-1}) and T_3 (1.49 mg kg^{-1}). On 7^{th}, 15^{th} and 45^{th} day of incubation T_6 recorded the highest mean values of 1.60 mg kg^{-1}, 1.70 mg kg^{-1} and 2.24 mg kg^{-1}, respectively and was superior than all other treatments. The highest mean value was registered with T_6 (1.70 mg kg^{-1}) and was on par with

Table 16. Available Zn content (mg kg^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	4.10	4.10	4.10	4.40	4.17	4.09	4.18
T_2: Soil + FYM (12 t ha^{-1})	4.15	4.56	4.53	4.65	4.30	4.75	4.63
T_3: Soil + nano NPK (12.5 kg ha^{-1})	4.20	4.11	4.38	4.51	4.35	4.11	4.65
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	4.16	4.39	4.68	4.87	5.17	4.25	4.64
T_5: Soil + nano NPK (25 kg ha^{-1})	4.25	4.40	4.30	4.67	4.84	4.41	4.44
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	4.19	4.48	4.63	4.50	5.68	4.90	5.55
T_7: Soil + nano NPK (50 kg ha^{-1})	4.17	4.64	4.12	4.47	4.42	4.43	4.66
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	4.29	4.45	4.42	4.79	4.85	4.41	4.68
SEm (±)	0.01	0.02	0.02	0.02	0.02	0.02	0.02
CD (0.05)	0.03	0.05	0.04	0.05	0.04	0.05	0.05

Table 17. Available Cu content (mg kg^{-1}) of soil during the days of incubation period

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	75^{th}
T_1: Soil alone	1.36	1.33	1.44	1.52	1.63	1.46	1.55
T_2: Soil + FYM (12 t ha^{-1})	1.52	1.39	1.58	1.65	1.85	1.51	1.74
T_3: Soil + nano NPK (12.5 kg ha^{-1})	1.49	1.44	1.49	1.69	2.03	1.68	1.74
T_4: Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1})	1.50	1.35	1.60	1.68	1.93	1.70	1.85
T_5: Soil + nano NPK (25 kg ha^{-1})	1.52	1.35	1.63	1.65	1.93	1.75	1.73
T_6: Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})	1.46	1.60	1.70	1.70	2.24	1.64	1.90
T_7: Soil + nano NPK (50 kg ha^{-1})	1.56	1.38	1.51	1.60	1.84	1.59	1.70
T_8: Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1})	1.43	1.51	1.61	1.62	1.90	1.82	1.80
SEm (±)	0.05	0.04	0.04	0.03	0.02	0.04	0.04
CD (0.05)	0.10	0.08	0.08	0.06	0.03	0.08	0.08

T_3 (1.69 mg kg^{-1}), T_4 (1.68 mg kg^{-1}), T_2 (1.65 mg kg^{-1}) and T_5 (1.65 mg kg^{-1}) on 30th day of incubation. The highest mean value of 1.82 mg kg^{-1} available copper content was registered in T_8 on 60th day of incubation and was on par with T_5 (1.75 mg kg^{-1}). On 75th day of incubation, T_6 (Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1})) recorded the highest mean value of 1.90 mg kg^{-1} and which was comparable with T_4 (1.85 mg kg^{-1}). Among all the treatments, T_1 (soil alone treatment) registered the lowest available copper content in all intervals of sampling.

PART III

4.3 FIELD EXPERIMENT

The field investigation on the effect of organic nano NPK formulations on soil health and productivity was carried out using okra as the direct test crop and amaranthus as the residual test crop and the observations recorded were compiled, analysed and tabulated. The results achieved from the observations recorded during the course of investigation is presented in this chapter.

4.3.1 Initial soil characteristics

The field experiment was conducted at Model Organic Farm under the Department of Soil Science and Agricultural chemistry, College of Agriculture Vellayani. The soil used for the field experiment was sandy clay loam belonging to the taxonomic class Loamy Kaolinitic Isohyperthermic Typic Kandiustult. Initial soil analysis revealed that the soil selected for the field experimental site was acidic in reaction (pH=5.48) with an EC of 0.095 dS m^{-1}. The cation exchange capacity (CEC) was 3.36 cmol (p^+) kg^{-1}. The organic carbon content was 0.97 per cent. The primary, secondary and micronutrient status indicated that the soil possessed low N (175.6 kg ha^{-1}), high P (60.25 kg ha^{-1}), low K (100.8 kg ha^{-1}), sufficient Ca (350.6 mg kg^{-1}), deficient Mg (77.81 mg kg^{-1}), sufficient S (22.95 mg kg^{-1}) and sufficient micronutrients with respect to available nutrient status. Properties of the soil in the experimental field is furnished in table 18.

4.3.2 Field experiment No: I and III using okra as direct test crop

4.3.2.1 Effect of treatments on growth characteristics of okra

Various biometric observations of the experiment No. I and III with the direct test crop of okra are presented in the tables 19 to 22. Various growth attributes of crop *viz.,* height of plants, number of branches per plant, Leaf Area Index, dry matter production, root length and root volume were recorded and presented.

4.3.2.1.1 Plant height

The results of the statistical analysis of the plant height at first harvest and final harvest as influenced by the different treatments during the direct test crop of first and third field experiments were furnished in table 19.

During the field experiment No I, the plant height of okra at first harvest ranged from 29.03 cm to 73.38 cm. The highest plant height at the first harvest was observed in T_9 (Foliar application of nano NPK (0.4 %)) which was comparable with T_{15} (KAU POP). Plant height at final harvest ranged from 57.97 cm to 110.4 cm. The highest plant height at final harvest was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was on par with T_{11} (104.9 cm). The lowest plant heights were found in the absolute control treatment at first and final harvest.

The response of treatments with respect to plant height during the third field experiment as inferred from the table 19 at first harvest ranged from 26.25 cm to 67.07 cm. The highest plant height (67.07 cm) at the first harvest was observed in T_{15} (KAU POP (FYM 12 t ha^{-1} NPK 110:35:70 kg ha^{-1})). Plant height at final harvest

Table 18. Properties of soil in the experimental field

Sl. No.	Parameter	Value
	Physical Properties	
1	Mechanical composition	
	Sand (%) Silt (%) Clay (%)	74.24 4.00 21.76
2	Texture	Sandy clay loam
3	Water holding capacity (%)	20.04
4	Bulk density ($Mg\ m^{-3}$)	1.543
	Physico-Chemical Properties	
5	pH (1:2.5)	5.48
6	EC (1:2.5) $dS\ m^{-1}$	0.095
7	CEC ($cmol\ kg^{-1}$)	3.36
	Chemical Properties	
8	Organic carbon (%)	0.97
9	Available N ($kg\ ha^{-1}$)	175.6
10	Available P ($kg\ ha^{-1}$)	60.25
11	Available K ($kg\ ha^{-1}$)	100.8
12	Exchangeable Ca ($mg\ kg^{-1}$)	350.6
13	Exchangeable Mg ($mg\ kg^{-1}$)	77.81
14	Available S ($mg\ kg^{-1}$)	22.95
15	Micronutrients ($mg\ kg^{-1}$) Fe Mn Zn Cu	 17.29 21.02 4.66 2.10
	Biochemical Properties	
16	Dehydrogenase (μg of $TPF g^{-1}$ soil $24h^{-1}$)	15.02
17	Acid phosphatase (μg of p-nitrophenol g^{-1} soil h^{-1})	13.05
18	Alkaline phosphatase (μg of p-nitrophenol g^{-1} soil h^{-1})	1.49
19	Urease (ppm of urea g^{-1} soil h^{-1})	6.13
	Biological properties	
20	Bacteria (log cfu g^{-1} soil)	6.39
21	Fungi (log cfu g^{-1} soil)	3.88
22	Actinomycetes (log cfu g^{-1} soil)	3.62

Table 19. Effect of organic nano NPK formulations on plant height of okra, cm

Treatment	First direct test crop (Expt No. I)		Second direct test crop (Expt No. III)	
	First harvest	Final harvest	First harvest	Final harvest
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	53.40	95.95	47.58	102.9
T_2: FYM (12 t ha^{-1}) + T_1	56.44	86.70	48.70	91.36
T_3: Soil application of nano NPK (25 kg ha^{-1})	43.25	76.46	50.93	86.35
T_4: FYM (12 t ha^{-1}) + T_3	63.44	89.97	58.66	91.53
T_5: Soil application of nano NPK (50 kg ha^{-1})	53.30	82.60	47.77	88.66
T_6: FYM (12 t ha^{-1}) + T_5	60.57	91.09	53.21	95.35
T_7: Foliar application of nano NPK (0.2%)	51.13	82.87	49.93	87.04
T_8: FYM (12 t ha^{-1}) + T_7	54.17	93.11	52.68	98.49
T_9: Foliar application of nano NPK (0.4%)	73.38	102.6	57.54	109.7
T_{10}: FYM (12 t ha^{-1}) + T_9	60.64	88.44	54.28	92.30
T_{11}: T_1 + T_9	64.95	104.9	51.21	110.3
T_{12}: T_2 + T_9	62.26	110.4	60.20	111.8
T_{13}: T_3 +T_7	56.62	102.2	53.65	109.3
T_{14}: T_4 + T_7	57.65	99.29	55.30	107.6
T_{15}: KAU POP	69.17	93.58	67.07	93.94
T_{16}: Absolute control	29.03	57.97	26.25	47.71
SEm (±)	5.85	12.84	6.21	6.24
CD (0.05): for any two treatments in the same block	4.60	6.80	4.73	4.74
CD (0.05): for any two treatments in different blocks	4.81	7.13	4.96	4.97

ranged from 47.71 cm to 111.8 cm. The maximum plant height (111.8 cm) at the final harvest was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was comparable with the effects of T_{11}, T_9, T_{13} and T_{14}. The lowest plant height was found in the absolute control treatment.

4.3.2.1.2 Number of branches per plant

The number of branches per plant recorded at final harvest of direct test crop of field experiments No. I and III are presented in table 20. The treatments imposed exhibited significant influence on number of branches per plant. The number of branches per plant ranged from 1.24 to 3.55. The maximum number of branches per plant (3.55) was recorded by the treatment T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})) which was comparable with T_9 (3.41) and T_{12} (3.39), T_6 (3.16), whereas, the treatment T_{16} (Absolute control) recorded the lowest number of branches per plant.

During the third field experiment, number of branches per plant ranged from 0.93 to 3.78. The result showed that T_4, FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) resulted in significantly higher number of branches per plant (3.78) and was on par with the effect of T_9, which produced 3.59 number of branches per plant.

4.3.2.1.3 Leaf Area Index (LAI)

The different treatments imposed significantly influenced the leaf area index of two direct test crops and the results are presented in table 21.

The mean value of LAI analysed at the time of first harvest ranged from 0.220 to 1.583. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest LAI and was significantly

Table 20. Effect of organic nano NPK formulations on number of branches per plant of okra

Treatment	First direct test crop (Expt No. I)	Second direct test crop (Expt No. III)
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	2.55	2.79
T_2: FYM (12 t ha^{-1}) + T_1	2.73	2.91
T_3: Soil application of nano NPK (25 kg ha^{-1})	2.62	2.88
T_4: FYM (12 t ha^{-1}) + T_3	3.55	3.78
T_5: Soil application of nano NPK (50 kg ha^{-1})	2.38	2.38
T_6: FYM (12 t ha^{-1}) + T_5	3.16	2.98
T_7: Foliar application of nano NPK (0.2%)	2.96	2.94
T_8: FYM (12 t ha^{-1}) + T_7	2.90	2.66
T_9: Foliar application of nano NPK (0.4%)	3.41	3.59
T_{10}: FYM (12 t ha^{-1}) + T_9	2.38	2.21
T_{11}: T_1 + T_9	2.42	2.38
T_{12}: T_2 + T_9	3.39	3.19
T_{13}: T_3 +T_7	2.54	2.65
T_{14}: T_4 + T_7	2.95	2.85
T_{15}: KAU POP	2.03	2.15
T_{16}: Absolute control	1.24	0.93
SEm (±)	0.05	0.04
CD (0.05): for any two treatments in the same block	0.42	0.40
CD (0.05): for any two treatments in different blocks	0.44	0.42

superior than all other treatments and T_{16} (Absolute control) recorded the lowest LAI (0.220).

Similarly in the case of second okra crop, leaf area index was significantly varied with the effect of different treatments. The result indicated that significantly higher leaf area index (1.676) was resulted with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) compared with other treatments. Lowest mean value for Leaf area index (0.297) was recorded by absolute control treatment.

4.3.2.1.4 Dry matter production (DMP)

Treatments imparted exhibited significant influence on plant dry matter production (DMP). The results of plant dry matter production as influenced by the different treatments are presented in table 21.

The DMP of the first field experiment ranged from 980.4 kg ha^{-1} to 3790 kg ha^{-1}. The highest DMP was registered in treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was significantly superior to all other treatments. The lowest DMP (980.4 kg ha^{-1}) was recorded in the absolute control treatment.

Dry matter production were significantly varied with the effect of different treatments during third field experiment using okra as direct test crop. The result indicated that the highest dry matter production (3780 kg ha^{-1}) was resulted with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was significantly superior to other treatments. Lowest value for dry matter production (1011 kg ha^{-1}) was recorded for absolute control treatment.

Table 21. Influence of organic nano NPK formulations on leaf area index and dry matter production in okra

Treatment	First direct test crop (Expt No. I)		Second direct test crop (Expt No. I)	
	LAI	DMP (kg ha^{-1})	LAI	DMP (kg ha^{-1})
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	0.517	1837	0.590	1876
T_2: FYM (12 t ha^{-1}) + T_1	0.913	2270	0.990	2257
T_3: Soil application of nano NPK (25 kg ha^{-1})	0.567	2042	0.651	2057
T_4: FYM (12 t ha^{-1}) + T_3	0.600	2419	0.669	2300
T_5: Soil application of nano NPK (50 kg ha^{-1})	0.713	2334	0.793	2353
T_6: FYM (12 t ha^{-1}) + T_5	1.408	2612	1.483	2908
T_7: Foliar application of nano NPK (0.2%)	0.567	1660	0.634	1716
T_8: FYM (12 t ha^{-1}) + T_7	0.817	2433	0.892	2306
T_9: Foliar application of nano NPK (0.4%)	0.570	1958	0.659	2123
T_{10}: FYM (12 t ha^{-1}) + T_9	1.013	2667	1.083	2789
T_{11}: T_1 + T_9	0.780	2701	0.866	2890
T_{12}: T_2 + T_9	1.583	3790	1.676	3780
T_{13}: T_3 +T_7	0.975	2937	1.054	2987
T_{14}: T_4 + T_7	1.350	3209	1.433	3558
T_{15}: KAU POP	0.767	2355	0.865	2127
T_{16}: Absolute control	0.220	98	0.297	1011
SEm (±)	0.001	804.5	0.005	1739.7
CD (0.05): for any two treatments in the same block	0.060	53.89	0.410	79.24
CD (0.05): for any two treatments in different blocks	0.070	56.44	0.430	83.00

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4.3.2.1.5 Root length and root volume

The average root length of the first direct test crop ranged from 20.94 cm to 26.36 cm and is presented in table 22. T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})) recorded the highest root length (26.36 cm) and was comparable with T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with a mean value of 26.28 cm. The minimum root length (20.94 cm) was reported in T_{16} (Absolute control).

Result from the table 22 indicated that root length of confirmatory okra crop ranged from 20.79 cm to 34.03 cm. Significantly higher root length was recorded with T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})) and was on par with the effects of T_{14}, T_6 and T_9 which produced root length of 33.95 cm, 33.17 cm and 31.69 cm respectively.

In the first field experiment, treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest root volume (50.92 cm^3) and was on par with T_{13} (49.83 cm^3) and T_9 (48.96 cm^3). The lowest root volume (21.13 cm^3) was recorded by T_{16} (Absolute control).

Root volume of second okra crop was significantly influenced by different treatments and it was found that root volume was significantly higher (55.81 cm^3) with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was on par with the effect of T_{14} (54.27 cm^3). The lowest root volume (18.49 cm^3) was recorded by absolute control treatment.

4.3.3 Physiological characters

The analytical data on various physiological characters of both okra crop were presented in table 23. The mean data on chlorophyll 'a', chlorophyll 'b' and total

Table 22. Effect of organic nano NPK formulations on root length and root volume of okra

Treatment	First direct test crop (Expt No. I)		Second direct test crop (Expt No. III)	
	Root length (cm)	Root volume (cm^3)	Root length (cm)	Root volume (cm^3)
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	24.53	46.00	27.22	35.22
T_2: FYM (12 t ha^{-1}) + T_1	24.33	41.92	27.13	40.81
T_3: Soil application of nano NPK (25 kg ha^{-1})	24.18	49.13	25.32	36.06
T_4: FYM (12 t ha^{-1}) + T_3	26.36	41.21	34.03	50.47
T_5: Soil application of nano NPK (50 kg ha^{-1})	24.08	45.08	24.29	32.60
T_6: FYM (12 t ha^{-1}) + T_5	25.94	40.67	33.17	42.34
T_7: Foliar application of nano NPK (0.2%)	23.60	41.25	22.37	30.07
T_8: FYM (12 t ha^{-1}) + T_7	24.39	47.75	27.69	32.43
T_9: Foliar application of nano NPK (0.4%)	26.13	48.96	31.69	41.81
T_{10}: FYM (12 t ha^{-1}) + T_9	24.76	47.58	28.68	50.70
T_{11}: T_1 + T_9	23.90	46.29	22.31	47.40
T_{12}: T_2 + T_9	24.59	50.92	27.04	55.81
T_{13}: T_3 +T_7	24.85	49.83	29.93	38.08
T_{14}: T_4 + T_7	26.28	45.21	33.95	54.27
T_{15}: KAU POP	24.34	36.08	27.08	39.69
T_{16}: Absolute control	20.94	21.13	20.79	18.49
SEm (±)	0.003	1.37	2.32	2.51
CD (0.05): for any two treatments in the same block	0.10	2.22	2.90	3.01
CD (0.05): for any two treatments in different blocks	0.10	2.33	3.03	3.15

chlorophyll content were recorded at first harvest of the crop. Treatments showed the significant influence on the chlorophyll content of okra.

In the case first direct test crop, the highest chlorophyll a content (0.600 mg g^{-1}) was recorded in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was on par with T_{13}, T_{10}, T_6, T_2, T_{15}, T_4, T_{11}, T_3, T_9, T_7, T_5 and T_1. The lowest chlorophyll a content was observed in T_{16} (0.542 mg g^{-1}). The highest chlorophyll b content was registered in T_{12} (0.952 mg g^{-1}) and was comparable with T_6, T_8, T_5, T_2 and T_{15}. T_{16} (Absolute control) registered the lowest chlorophyll b content of 0.700 mg g^{-1}. Total chlorophyll content of okra ranged from 1.242 mg g^{-1} to 1.551 mg g^{-1}. Among the treatments, T_{12} recorded the highest total chlorophyll content (1.551 mg g^{-1}) followed by T_6 (1.503 mg g^{-1}), T_2 (1.485 mg g^{-1}), T_8 (1.482 mg g^{-1}), T_5 (1.476 mg g^{-1}) and T_{15} (1.473 mg g^{-1}). T_{16} registered the lowest chlorophyll content of 1.242 mg g^{-1}.

In the case of confirmatory direct test crop, treatments shows significant influence on chlorophyll content. Among the treatments significantly higher chlorophyll a content (0.468 mg g^{-1}) was found with T_{13} (Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was comparable with the chlorophyll a content of T_6, T_{15}, T_3, T_5, T_7, T_8, T_{14} and T_2. The chlorophyll b content ranged from 0.248 mg g^{-1} to 0.563 mg g^{-1} and total chlorophyll content ranged from 0.702 mg g^{-1} to 1.027 mg g^{-1}. Significantly superior chlorophyll b and total chlorophyll content were recorded with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was on par with T_{10} and T_{11}, where T_{10} recorded chlorophyll b content of 0.559 mg g^{-1} and total chlorophyll content of 1.023 mg g^{-1} and T_{11} recorded a chlorophyll b content of 0.557 mg g^{-1} and total chlorophyll content of 1.019 mg g^{-1}.

Table 23. Effect of organic nano NPK formulations on chlorophyll a, chlorophyll b and total chlorophyll content of okra leaves, mg g^{-1}

Treatments	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Chlorophyll a	Chlorophyll b	Total Chlorophyll	Chlorophyll a	Chlorophyll b	Total Chlorophyll
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	0.569	0.760	1.328	0.463	0.511	0.974
T_2: FYM (12 t ha^{-1}) + T_1	0.581	0.904	1.485	0.465	0.547	1.012
T_3: Soil application of nano NPK (25 kg ha^{-1})	0.575	0.826	1.400	0.466	0.474	0.940
T_4: FYM (12 t ha^{-1}) + T_3	0.577	0.754	1.330	0.465	0.514	0.978
T_5: Soil application of nano NPK (50 kg ha^{-1})	0.570	0.906	1.476	0.466	0.462	0.929
T_6: FYM (12 t ha^{-1}) + T_5	0.582	0.922	1.503	0.467	0.546	1.014
T_7: Foliar application of nano NPK (0.2%)	0.570	0.850	1.419	0.466	0.460	0.925
T_8: FYM (12 t ha^{-1}) + T_7	0.564	0.918	1.482	0.466	0.484	0.950
T_9: Foliar application of nano NPK (0.4%)	0.574	0.801	1.374	0.461	0.547	1.008
T_{10}: FYM (12 t ha^{-1}) + T_9	0.593	0.737	1.330	0.465	0.559	1.023
T_{11}: T_1 + T_9	0.575	0.841	1.416	0.462	0.557	1.019
T_{12}: T_2 + T_9	0.600	0.952	1.551	0.464	0.563	1.027
T_{13}: T_3 +T_7	0.595	0.729	1.324	0.468	0.421	0.889
T_{14}: T_4 + T_7	0.551	0.759	1.310	0.466	0.545	1.010
T_{15}: KAU POP	0.579	0.895	1.473	0.467	0.444	0.911
T_{16}: Absolute control	0.542	0.700	1.242	0.455	0.248	0.702
SEm (±)	0.003	0.002	0.02	0.001	0.0002	0.0001
CD (0.05): for any two treatments in the same block	0.030	0.050	0.092	0.003	0.009	0.008
CD (0.05): for any two treatments in different blocks	0.030	0.100	0.100	0.003	0.010	0.009

4.3.4 Effect of treatments on yield and yield attributes of okra

Yield attributes such as number of fruits per plant, individual fruit weight, fruit length and fruit girth were found to be significantly influenced by different treatments with respect to two okra crops (Table 24-26).

4.3.4.1 Days to first flowering

In case of the first direct test crop, the data in table 24 revealed that treatments significantly influenced the days to first flowering. The least time taken for the plant to flowering from the day of sowing was the treatment, T_9 (Foliar application of nano NPK (0.4 %)) with the mean value of 39.21 days and was on par with T_3, T_5, T_{14}, T_{12}, T_2, T_{15}, T_6 and T_7. Absolute control (T_{16}) treatment took the highest number of days (44.13) to flowering.

For the second direct test crop, treatments significantly influenced the days to flowering. The least time taken for the plant to flowering from the day of sowing was the treatment, T_6 that received FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1}) with a mean value of 40.79 days and was comparable with T_3, T_{10}, T_9, T_{12}, T_8, T_5, T_4, T_{13}, T_1, T_{14} and T_{11}. Absolute control treatment (T_{16}) took the highest number of days (47.54) for flowering.

4.3.4.2 Days to 50 % flowering

Perusal of data in table 24 revealed that for the first direct test crop the least number of days required to attain 50 per cent flowering was by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 43.71 days and was on par with T_{14}, T_9, T_6, T_2, T_3, T_{13}, T_{11} and T_1. Treatment, T_{16} took 48.92 days for 50 per cent flowering.

In the case of second direct test crop, the least number of days required by the treatment to take 50 per cent flowering was by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 43.42 days and was on par with T_3, T_4, T_{14}, T_5, T_{13}, T_8, T_{10} and T_6. Treatment T_{16} took 51.29 days for 50 per cent flowering in the case of second direct test crop.

4.3.4.3 Crop period

It was observed from the data (Table 24) that crop period was significantly influenced by the treatments at the final harvest stage of both okra crops. In the first okra crop, among the treatments, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest crop period (94.42 days) and was on par with T_{14} (93.17 days). Lowest crop period (84.46 days) was noticed in T_{16} (Absolute control).

In the case of second direct test crop, the crop period was significantly influenced by the treatments at the final harvest stage (Table 24). Among the treatments, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest crop period (98.71 days) and was on par with T_{14} (97.83 days). Lowest crop period (85.21 days) was noticed in T_{16} (Absolute control).

4.3.4.4 Fruit length

All the treatments exhibited significant influence on fruit length of both direct test crops and is presented in table 25.

The fruit length for the first okra crop ranged from 12.38 cm to 14.43 cm. The longer fruits were recorded in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was comparable with T_{14}

Table 24. Effect of organic nano NPK formulations on days to first flowering, days to 50 % flowering and crop period of okra

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Days to first flowering	Days to 50% flowering	Crop period	Days to first flowering	Days to 50% flowering	Crop period
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	41.13	44.83	86.92	42.00	45.75	88.92
T_2: FYM (12 t ha^{-1}) + T_1	40.29	44.63	87.96	42.79	45.92	89.79
T_3: Soil application of nano NPK (25 kg ha^{-1})	39.38	44.75	86.13	41.21	44.08	88.04
T_4: FYM (12 t ha^{-1}) + T_3	41.54	45.38	88.25	41.71	44.17	90.63
T_5: Soil application of nano NPK (50 kg ha^{-1})	39.50	45.13	87.71	41.42	44.33	90.75
T_6: FYM (12 t ha^{-1}) + T_5	40.38	44.58	89.50	40.79	44.71	93.25
T_7: Foliar application of nano NPK (0.2%)	40.50	46.42	89.92	43.13	45.21	93.67
T_8: FYM (12 t ha^{-1}) + T_7	40.96	44.96	91.63	41.38	44.67	94.21
T_9: Foliar application of nano NPK (0.4%)	39.21	44.21	91.92	41.29	44.96	94.88
T_{10}: FYM (12 t ha^{-1}) + T_9	41.79	45.38	92.63	41.25	44.67	95.88
T_{11}: T_1 + T_9	40.88	44.79	92.29	42.33	44.88	95.92
T_{12}: T_2 + T_9	39.96	43.71	94.42	41.33	43.42	98.71
T_{13}: T_3 +T_7	40.75	44.79	90.21	41.75	44.50	94.21
T_{14}: T_4 + T_7	39.63	43.88	93.17	42.13	44.25	97.83
T_{15}: KAU POP	40.33	46.00	87.92	44.29	46.88	90.13
T_{16}: Absolute control	44.13	48.92	84.46	47.54	51.29	85.21
SEm (±)	0.55	0.39	0.65	0.97	0.58	0.34
CD (0.05): for any two treatments in the same block	1.41	1.19	1.53	1.87	1.44	1.10
CD (0.05): for any two treatments in different blocks	1.47	1.25	1.60	1.96	1.51	1.16

(14.37 cm) and T_6 (14.36 cm). The absolute control treatment registered the lowest fruit length of 12.38 cm.

As evident from the data in table 25, treatments had significant effects on the fruit length of okra in the third field experiment. Significantly higher fruit length (15.51 cm) was obtained with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was on par with the effect of T_{14} which recorded fruit length of 15.47 cm. The lowest value (12.03 cm) was registered by T_{16} (Absolute control).

4.3.4.5 Girth of fruit

The different treatments imposed had significantly influenced the fruit girth of both the okra crops and the results are presented in table 25.

The mean value of fruit girth varied between 5.66 cm to 6.79 cm in the first direct test crop. The highest fruit girth was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) followed by T_{13} (6.45 cm), T_9 (6.26 cm), T_5 (6.26 cm), T_{14} (6.24 cm), T_8 (6.24 cm) and T_{11} (6.23 cm). The lower fruit girth of 5.66 cm was noticed in absolute control treatment.

In the case of second direct test crop, fruit girth of okra was significantly higher (7.02 cm) in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)). Absolute control treatment recorded significantly lower fruit girth of 5.49 cm.

Table 25. Effect of organic nano NPK formulations on fruit length and fruit girth of okra, cm

Treatment	First direct test crop (Expt No. I)		Second direct test crop (Expt No. III)	
	Fruit length	Fruit girth	Fruit length	Fruit girth
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	13.83	6.10	13.38	6.53
T_2: FYM (12 t ha^{-1}) + T_1	13.91	5.86	14.58	6.00
T_3: Soil application of nano NPK (25 kg ha^{-1})	13.49	5.82	14.19	6.29
T_4: FYM (12 t ha^{-1}) + T_3	13.79	5.79	14.17	6.35
T_5: Soil application of nano NPK (50 kg ha^{-1})	14.10	6.26	14.79	6.52
T_6: FYM (12 t ha^{-1}) + T_5	14.36	6.08	15.36	6.60
T_7: Foliar application of nano NPK (0.2%)	13.70	5.81	13.52	6.32
T_8: FYM (12 t ha^{-1}) + T_7	14.09	6.24	14.59	6.59
T_9: Foliar application of nano NPK (0.4%)	13.76	6.26	14.00	6.85
T_{10}: FYM (12 t ha^{-1}) + T_9	13.88	5.92	14.45	6.48
T_{11}: T_1 + T_9	14.30	6.23	13.60	6.62
T_{12}: T_2 + T_9	14.43	6.79	15.51	7.02
T_{13}: T_3 +T_7	14.16	6.45	13.74	6.81
T_{14}: T_4 + T_7	14.37	6.24	15.47	6.49
T_{15}: KAU POP	13.80	5.97	14.25	6.06
T_{16}: Absolute control	12.38	5.66	12.03	5.49
SEm (±)	0.003	0.093	0.03	0.004
CD (0.05): for any two treatments in the same block	0.10	0.58	0.31	0.12
CD (0.05): for any two treatments in different blocks	0.10	0.61	0.32	0.12

4.3.4.6 Number of fruits plant^{-1}

Perusal of the data in table 26 revealed that there was significant difference between the treatments with respect to number of fruits per plant for both direct test crops.

The highest number of fruits per plant (20.10) was recorded in the treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was significantly superior than other treatments. The least number of fruits per plant was registered by T_{16} (12.79) in the first experiment.

Similarly, in the case of second direct test crop the highest number of fruits per plant (19.83) was recorded in the treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was significantly superior to other treatments. The least number of fruits per plant was registered in T_{16} (13.30).

4.3.4.7 Average fruit weight

The average fruit weight for both direct test crops were recorded and are presented in table 26. Treatments showed significant influence on the average fruit weight. The mean value of fruit weight ranged from 9.14 g to 21.20 g. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) registered the highest fruit weight (21.20 g). T_{16} (Absolute control) recorded the lowest fruit weight (9.14 g) and was significantly inferior to all other treatments.

The data indicated that different treatments had significant influence on average fruit weight of okra in the second direct test crop. The average fruit weight of okra ranged from 10.35 g to 19.47 g. Among the different treatments, significantly higher average fruit weight was produced by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano

NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and average fruit weight was lowest with absolute control treatment.

4.3.4.8 Total fruit yield

The total fruit yield of okra was significantly influenced due to the imposition of different treatments in the first and third experiment using okra as the direct test crop and the result are presented in table 26.

Treatment that received FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) recorded the highest fruit yield (13.97 t ha^{-1}) and was significantly superior than all other treatments in the first experiment. The lowest fruit yield (3.86 t ha^{-1}) was observed in the absolute control treatment.

Total fruit yield of second direct test crop ranged from 3.52 t ha^{-1} to 13.90 t ha^{-1}. The result indicated that the treatment, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) resulted in significantly higher total fruit yield compared to other treatments. The least fruit yield was registered by absolute control treatment (T_{16}).

4.3.5 Quality parameters of fruit

The analytical data on the quality parameters *viz.,* crude protein, crude fibre and ascorbic acid content of fruits of both direct test crops are presented in table 27.

4.3.5.1 Crude protein content

In the first and third field experiments all the treatments exhibited significant influence on crude protein content. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) registered the highest

Table 26. Effect of organic nano NPK formulations on number of fruits per plant, average fruit weight and total fruit yield of okra

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Number of fruits $plant^{-1}$	Average fruit weight (g)	Total fruit yield ($t\ ha^{-1}$)	Number of fruits $plant^{-1}$	Average fruit weight (g)	Total fruit yield ($t\ ha^{-1}$)
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	17.97	17.87	9.27	16.22	14.73	9.77
T_2: FYM (12 t ha^{-1}) + T_1	18.18	16.97	12.20	17.78	14.97	12.75
T_3: Soil application of nano NPK (25 kg ha^{-1})	18.40	16.82	10.43	18.57	14.85	10.42
T_4: FYM (12 t ha^{-1}) + T_3	19.06	17.23	11.19	19.24	16.17	11.11
T_5: Soil application of nano NPK (50 kg ha^{-1})	17.18	18.37	11.59	16.98	17.62	11.98
T_6: FYM (12 t ha^{-1}) + T_5	17.41	19.25	12.59	16.98	17.68	13.65
T_7: Foliar application of nano NPK (0.2%)	17.96	14.81	9.32	17.53	14.32	9.68
T_8: FYM (12 t ha^{-1}) + T_7	16.66	15.33	10.61	17.48	17.61	10.92
T_9: Foliar application of nano NPK (0.4%)	17.45	17.04	11.09	18.13	16.48	11.32
T_{10}: FYM (12 t ha^{-1}) + T_9	15.86	20.53	11.91	16.10	18.68	12.32
T_{11}: T_1 + T_9	16.68	17.80	12.14	16.95	17.07	12.82
T_{12}: T_2 + T_9	20.10	21.20	13.97	19.83	19.47	13.90
T_{13}: T_3 +T_7	17.48	18.24	11.44	17.17	17.62	11.78
T_{14}: T_4 + T_7	18.62	20.17	12.30	18.48	18.64	13.31
T_{15}: KAU POP	18.34	17.72	10.68	17.25	16.15	10.58
T_{16}: Absolute control	12.79	9.14	3.86	13.30	10.35	3.52
SEm (±)	0.08	0.009	0.013	0.08	0.001	0.004
CD (0.05): for any two treatments in the same block	0.53	0.18	0.22	0.54	0.07	0.12
CD (0.05): for any two treatments in different blocks	0.56	0.19	0.23	0.56	0.07	0.12

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crude protein content (24.30 %) which was on par with T_{13}, T_7 and T_3. The treatment, T_{16} (Absolute control) registered the lowest crude protein content (17.50 %).

The results revealed that crude protein content of second direct test crop ranged between 17.21 per cent to 22.18 per cent and significantly higher content of crude protein was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was comparable with the effects of T_{13}, T_{10}, T_7 and T_3. The lowest crude protein content (17.21 %) was noticed with the treatment, T_{16} (Absolute control).

4.3.5.2 Crude fibre content

The crude fibre content of okra fruit is presented in the table 27. The treatment imposed significantly influenced the crude fibre content of okra fruit in both the experiments. The lowest crude fibre content was noticed in T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with 8.17 per cent. The highest value of crude fibre content was found in T_{16} (24.12 %).

The crude fibre content ranged between 10.35 per cent to 23.87 per cent and significantly higher content of crude fibre was observed with absolute control treatment in second direct test crop also. The treatment, T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) recorded the lowest value of 10.35 per cent. The trends were same in both the experiments.

4.3.5.3 Ascorbic acid content

The results of the ascorbic acid content in okra fruit as influenced by the different treatments in both experiments are presented in table 27. The mean values of ascorbic acid content in okra fruit ranged from 10.02 mg 100 g^{-1} to 14.25 mg 100 g^{-1}. The highest ascorbic acid content (14.25 mg 100 g^{-1}) in okra fruit was registered in T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of

Table 27. Effect of organic nano NPK formulations on the quality parameters of okra

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Crude protein (%)	Crude fibre (%)	Ascorbic acid (mg $100g^{-1}$)	Crude protein (%)	Crude fibre (%)	Ascorbic acid (mg $100g^{-1}$)
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	20.06	18.11	12.02	20.27	14.98	12.25
T_2: FYM (12 t ha^{-1}) + T_1	20.18	15.96	11.86	20.48	12.78	12.48
T_3: Soil application of nano NPK (25 kg ha^{-1})	20.41	13.98	12.13	20.96	12.06	12.80
T_4: FYM (12 t ha^{-1}) + T_3	19.36	14.93	12.03	19.00	12.42	12.63
T_5: Soil application of nano NPK (50 kg ha^{-1})	19.48	17.30	11.81	19.70	15.04	12.58
T_6: FYM (12 t ha^{-1}) + T_5	19.48	12.95	13.85	19.73	12.11	13.47
T_7: Foliar application of nano NPK (0.2%)	20.88	21.07	11.84	21.23	19.12	12.20
T_8: FYM (12 t ha^{-1}) + T_7	19.48	16.06	12.54	19.69	14.36	12.93
T_9: Foliar application of nano NPK (0.4%)	18.55	19.98	11.78	18.87	17.28	12.39
T_{10}: FYM (12 t ha^{-1}) + T_9	20.11	16.77	13.67	21.32	14.07	13.25
T_{11}: T_1 + T_9	18.55	17.99	12.87	17.63	15.36	13.11
T_{12}: T_2 + T_9	24.30	11.90	13.70	22.18	10.84	14.08
T_{13}: T_3 +T_7	21.11	14.27	13.58	22.04	12.22	13.35
T_{14}: T_4 + T_7	20.30	8.17	14.25	20.93	10.35	13.81
T_{15}: KAU POP	18.13	19.27	11.53	18.78	15.87	12.45
T_{16}: Absolute control	17.50	24.12	10.02	17.21	23.87	10.80
SEm (±)	4.28	0.10	0.56	0.38	0.69	0.22
CD (0.05): for any two treatments in the same block	3.93	0.60	1.42	1.18	1.58	0.89
CD (0.05): for any two treatments in different blocks	4.12	0.63	1.50	1.23	1.65	0.93

nano NPK (0.2 %)) and was found to be on par with T_6 (13.85 mg 100 g^{-1}), T_{12} (13.70 mg 100 g^{-1}), T_{10} (13.67 mg 100 g^{-1}), T_{13} (13.58 mg 100 g^{-1}) and T_{11} (12.87 mg 100 g^{-1}). The lowest ascorbic acid content (10.02 mg 100 g^{-1}) was noticed in T_{16} (Absolute control).

The above trend was observed in the case of second direct test crop also. Ascorbic acid content in okra fruit was also significantly influenced by different treatments. Ascorbic acid content value ranged between 10.80 mg 100 g^{-1} to 14.08 mg 100 g^{-1}. Significantly higher content of ascorbic acid was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was on par with the effects of T_{14} (13.81 mg 100 g^{-1}), T_6 (13.47 mg 100 g^{-1}), T_{13} (13.35 mg 100 g^{-1}) and T_{10} (13.25 mg 100 g^{-1}). The lowest ascorbic acid content (10.80 mg 100 g^{-1}) was registered by T_{16} (Absolute control).

4.3.6 Incidence of pest and diseases

Incidence of pest and disease was observed rarely during the crop growth stage of both direct test crops. Incidence of semi loopers, fruit and shoot borers were noticed and was controlled by spraying with 5 per cent nimbicidine at fortnightly intervals. Yellow vein mosaic virus was noticed, the affected plants were removed from the plot and sprayed 2 per cent neem garlic emulsion to control vectors. Similar incidence was noticed in next okra crop also.

4.3.7 Post harvest analysis of soil

Soil physical, chemical, biological and biochemical parameters after the harvest of the direct test crops are presented in table 28-32.

4.3.7.1 Bulk density

Table 28 revealed that the bulk density of the post harvest soil of both experiment I and III were not significantly influenced by different treatments.

4.3.7.2 Water holding capacity

It is noticed from the data (Table 28) that the water holding capacity of the soil was significantly influenced by the treatments in the post harvest soil of both direct test crops. After the first field experiment the highest WHC value of 29.35 per cent was recorded in the treatment T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})) and was found to be on par with T_{11}, T_1, T_{15}, T_{14}, T_8, T_{12}, T_5, T_7, T_6, T_{13}, T_3 and T_2. The lowest value of 21.75 per cent was recorded by T_{10} and was on par with T_9 and T_{16}.

The water holding capacity of soil ranged between 17.85 per cent to 23.30 per cent after the second direct crop and significantly higher water holding capacity of soil was observed with T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})). It was comparable with the effect of T_9, T_{15}, T_{13}, T_{10} and T_6, which recorded water holding capacity of 23.22 per cent, 22.08 per cent, 21.86 per cent, 21.61 per cent and 21.38 per cent, respectively.

4.3.7.3 pH

A significant influence of treatments in the soil pH was evident in the post harvest soil of two direct test crops and are presented in table 29. The analysis of post harvest soil after the first direct test crop showed an increase in soil pH from the initial pH value of 5.48 in all the treatments. The mean values of soil pH after the first field experiment ranged between 5.60 to 6.75. The treatment, T_{12} that was received FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) was found to have a pH value of 6.75, which was on par with T_5, T_3, T_7,

Table 28. Effect of organic nano NPK formulations on physical properties of soil after harvest of okra

Treatment	First direct test crop (Expt No. I)		Second direct test crop (Expt No. I)	
	Bulk density (Mg m^{-3})	Water Holding Capacity (%)	Bulk density (Mg m^{-3})	Water Holding Capacity (%)
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	1.404	27.01	1.660	19.95
T_2: FYM (12 t ha^{-1}) + T_1	1.470	24.83	1.621	20.56
T_3: Soil application of nano NPK (25 kg ha^{-1})	1.430	25.22	1.602	19.46
T_4: FYM (12 t ha^{-1}) + T_3	1.380	29.35	1.643	23.30
T_5: Soil application of nano NPK (50 kg ha^{-1})	1.452	26.25	1.627	20.17
T_6: FYM (12 t ha^{-1}) + T_5	1.350	25.38	1.631	21.38
T_7: Foliar application of nano NPK (0.2%)	1.464	26.10	1.718	18.89
T_8: FYM (12 t ha^{-1}) + T_7	1.434	26.40	1.674	20.87
T_9: Foliar application of nano NPK (0.4%)	1.483	22.98	1.642	23.22
T_{10}: FYM (12 t ha^{-1}) + T_9	1.537	21.75	1.555	21.61
T_{11}: T_1 + T_9	1.364	27.07	1.604	20.95
T_{12}: T_2 + T_9	1.417	26.35	1.753	21.18
T_{13}: T_3 +T_7	1.470	25.30	1.588	21.86
T_{14}: T_4 + T_7	1.383	26.41	1.743	17.85
T_{15}: KAU POP	1.418	26.48	1.579	22.08
T_{16}: Absolute control	1.468	23.79	1.669	20.56
SEm (±)		8.75		1.10
CD (0.05): for any two treatments in the same block	NS	5.61	NS	2.00
CD (0.05): for any two treatments in different blocks	NS	5.88	NS	2.09

T_{10}, T_6, T_2, T_{13} and T_{14}. The lowest soil pH (5.60) was registered by the absolute control treatment (T_{16}).

After the confirmatory test crop (*ie.* Second direct test crop), pH of the soil ranged from 5.40 to 6.64 and significantly higher pH was recorded with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was on par with T_{10}, T_{14}, T_2, T_3, T_5, T_{13} and T_6. The lowest soil pH (5.40) was registered by absolute control treatment.

4.3.7.4 Electrical conductivity

The electrical conductivity of the post harvest soil registered significant difference between the treatments in two experiments with okra as direct test crops and are presented in table 29.

The electrical conductivity of the post harvest soil of first direct test crop ranged from 0.089 dS m^{-1} to 0.124 dS m^{-1}. The results indicated that highest EC registered in T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})) and was significantly superior than all other treatments. The lowest EC (0.089 dS m^{-1}) was registered by T_{16} (Absolute control).

EC of the post harvest soil of second direct test crop ranged between 0.068 dS m^{-1} to 0.165 dS m^{-1} and significantly higher EC of 0.165 dS m^{-1} was recorded with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and T_4 (0.165 dS m^{-1}). The lowest EC of 0.068 dS m^{-1} was registered in T_{16} (Absolute control).

4.3.7.5 Organic carbon

Perusal of data (Table 29) revealed that there was significant influence of the treatments in the post harvest soil of two direct test crop with respect to organic carbon content in the soil.

The mean values of organic carbon content in the post harvest soil of first direct test crop ranged from 0.91 per cent to 1.59 per cent. The highest organic carbon content was noticed in T_{12} FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was found to be on par with T_{10} and T_4. T_{16} (Absolute control) recorded the lowest organic carbon content (0.91 %) after the experiment.

The perusal of data revealed that the organic carbon content of the second direct test crop of the soil ranged from 0.69 per cent to 1.28 per cent. Significantly higher content of organic carbon (1.28 %) was recorded with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was on par with T_4 (1.25 %) and T_{10} (1.18 %). The lowest organic carbon content of 0.69 per cent was registered by T_{16} (Absolute control).

4.3.7.6 Labile carbon

Critical appraisal of the data (Table 29) showed that the treatments had influenced the labile carbon content of soil after the harvest of the crop in two direct test crops.

The result showed that treatment, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest labile carbon content of 1109 mg kg^{-1} after the first direct test crop and was found to be on par with T_{13} (1095 mg kg^{-1}) and T_4 (1082 mg kg^{-1}). The lowest value of

Table 29. Effect of organic nano NPK formulations on physico-chemical properties and carbon content of the soil after harvest of okra

Treatment	First direct test crop (Expt No. I)				Second direct test crop (Expt No. III)			
	pH	EC (dS m^{-1})	Organic carbon (%)	Labile carbon (mg kg^{-1})	pH	EC (dS m^{-1})	Organic carbon (%)	Labile carbon (mg kg^{-1})
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	6.19	0.101	1.35	893.7	5.88	0.132	1.07	981.70
T_2: FYM (12 t ha^{-1}) + T_1	6.56	0.107	1.28	1003	6.57	0.117	1.16	1097
T_3: Soil application of nano NPK (25 kg ha^{-1})	6.63	0.096	1.30	868.4	6.55	0.135	1.10	986.8
T_4: FYM (12 t ha^{-1}) + T_3	6.33	0.124	1.50	1082	6.06	0.165	1.25	1148
T_5: Soil application of nano NPK (50 kg ha^{-1})	6.64	0.106	1.38	845.0	6.53	0.101	1.11	965.3
T_6: FYM (12 t ha^{-1}) + T_5	6.56	0.109	1.41	981.6	6.41	0.118	1.16	1068
T_7: Foliar application of nano NPK (0.2%)	6.59	0.094	1.27	822.6	6.21	0.127	0.89	807.8
T_8: FYM (12 t ha^{-1}) + T_7	6.39	0.100	1.14	831.7	6.08	0.150	1.12	920.8
T_9: Foliar application of nano NPK (0.4%)	6.31	0.108	1.37	1037	6.18	0.152	1.00	1153
T_{10}: FYM (12 t ha^{-1}) + T_9	6.58	0.111	1.53	1013	6.62	0.148	1.18	1102
T_{11}: T_1 + T_9	6.30	0.105	1.38	854.8	6.09	0.155	1.02	966.4
T_{12}: T_2 + T_9	6.75	0.114	1.59	1109	6.64	0.165	1.28	1219
T_{13}: T_3 +T_7	6.51	0.107	1.35	1095	6.45	0.126	1.06	1175
T_{14}: T_4 + T_7	6.48	0.113	1.33	1039	6.59	0.144	1.20	1145
T_{15}: KAU POP	6.05	0.110	0.98	989.0	5.58	0.154	1.05	1070
T_{16}: Absolute control	5.60	0.089	0.91	732.0	5.40	0.068	0.69	677.0
SEm (±)	0.020	0.0001	0.002	307.6	0.014	0.0001	0.007	274.4
CD (0.05): for any two treatments in the same block	0.26	0.007	0.087	33.32	0.23	0.006	0.05	31.48
CD (0.05): for any two treatments in different blocks	0.28	0.007	0.090	34.90	0.24	0.007	0.05	32.97

732.0 mg kg^{-1} was noticed in T_{16} (Absolute control) and was found to be significantly inferior to all other treatments.

During the confirmatory experiment (third experiment) using okra as direct test crop, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded significantly highest content of labile carbon (1219 mg kg^{-1}). The lowest labile carbon content of 677.0 mg kg^{-1} was observed with absolute control treatment (T_{16}).

4.3.7.7 Available Nitrogen

It is concluded from the table 30 that the mean values of available nitrogen in soil after the first field experiment using okra as direct test crop ranged between 140.6 kg ha^{-1} to 188.2 kg ha^{-1}. Treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) registered the highest mean value of 188.2 kg ha^{-1} which was on par with T_4 (186.1 kg ha^{-1}), T_{13} (186.1 kg ha^{-1}), T_{10} (181.9 kg ha^{-1}), T_3 (178.8 kg ha^{-1}), T_5 (178.2 kg ha^{-1}), T_9 (177.2 kg ha^{-1}) and T_{14} (174.0 kg ha^{-1}). The absolute control treatment registered the lowest available soil N status (140.6 kg ha^{-1}).

The data from the table 30 revealed that available nitrogen status after the third experiment of soil had significantly influenced by different treatments after the harvest of second direct test crop. The available nitrogen content of the soil varied from 136.4 kg ha^{-1} to 234.1 kg ha^{-1}. Among the treatments, significantly higher nitrogen content of soil was recorded with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was on par with T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})). The lowest mean value was noticed in absolute control treatment.

4.3.7.8 Available Phosphorous

From the results it is revealed that there was a significant effect on the applied treatments and is presented in table 30. Available phosphorous after the harvest of first direct test crop ranged from 58.96 kg ha^{-1} to 112.0 kg ha^{-1}. Treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) registered the highest available phosphorous and was significantly superior than all other treatments. The lowest mean value was noticed in T_{16} (Absolute control).

Available phosphorous in the soil after the second direct test crop ranged between 56.24 kg ha^{-1} to 99.64 kg ha^{-1} and significantly higher phosphorus content of soil was recorded with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was on par with the effect of T_{10} with available soil phosphorus of 98.59 kg ha^{-1}. T_{16} registered the lowest available soil phosphorous.

4.3.7.9 Available Potassium

It is inferred from the table 30 that available potassium in the post harvest soil of the first direct test crop ranged from 122.3 kg ha^{-1} to 231.5 kg ha^{-1}. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) registered the highest available K content after the harvest of the crop and was followed by T_{14} (230.1 kg ha^{-1}). The lowest available soil K status was recorded treatment, T_{16} which did not receive any input.

Highest available potassium of soil was recorded by T_{12} after the second direct test crop and the available potassium of the soil ranged between 87.27 kg ha^{-1} to 167.1 kg ha^{-1}. The treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded potassium content

Table 30. Available N P K status (kg ha^{-1}) of soil as influenced by organic nano NPK formulations after the direct test crops of okra

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Available Nitrogen	Available Phosphorus	Available Potassium	Available Nitrogen	Available Phosphorus	Available Potassium
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	146.8	76.42	138.6	178.2	82.92	120.9
T_2: FYM (12 t ha^{-1}) + T_1	167.3	91.04	170.3	189.8	94.18	122.7
T_3: Soil application of nano NPK (25 kg ha^{-1})	178.8	86.90	177.3	196.5	85.56	133.5
T_4: FYM (12 t ha^{-1}) + T_3	186.1	83.14	181.5	223.2	85.03	139.1
T_5: Soil application of nano NPK (50 kg ha^{-1})	178.2	85.95	189.9	177.2	86.96	132.5
T_6: FYM (12 t ha^{-1}) + T_5	164.1	88.32	175.0	188.7	90.55	138.1
T_7: Foliar application of nano NPK (0.2%)	150.5	86.07	127.4	175.1	86.35	108.3
T_8: FYM (12 t ha^{-1}) + T_7	160.0	82.81	147.5	184.0	67.59	120.4
T_9: Foliar application of nano NPK (0.4%)	177.2	86.17	165.2	197.1	87.15	122.3
T_{10}: FYM (12 t ha^{-1}) + T_9	181.9	101.1	177.8	195.5	98.59	139.5
T_{11}: T_1 + T_9	168.3	75.29	168.5	186.1	84.49	119.9
T_{12}: T_2 + T_9	188.2	112.0	231.5	234.1	99.64	167.1
T_{13}: T_3 +T_7	186.1	98.54	206.7	205.4	95.78	151.2
T_{14}: T_4 + T_7	174.0	82.53	230.1	195.5	89.92	153.5
T_{15}: KAU POP	158.4	88.55	168.0	181.4	87.78	130.7
T_{16}: Absolute control	140.6	58.96	122.3	136.4	56.24	87.27
SEm (±)	62.30	6.89	115.6	35.80	2.33	63.34
CD (0.05): for any two treatments in the same block	15.00	4.99	20.43	11.37	2.90	15.12
CD (0.05): for any two treatments in different blocks	15.71	5.22	21.40	11.90	3.03	15.83

of 167.1 kg ha^{-1} and was found to be comparable with the effect of T_{14}. The lowest available potassium status was registered by T_{16} (Absolute control).

4.3.7.10 Exchangeable Calcium

From the result it is revealed that various treatment application showed a significant effect on the exchangeable calcium content of the soil and is presented in table 31. The exchangeable Ca content after the harvest of the first direct test crop ranged from 220.0 mg kg^{-1} to 417.1 mg kg^{-1}. The maximum exchangeable Ca was found in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was found to be on par with T_2, T_{10}, T_4, T_5, T_{14}, T_6, T_7 and T_3. The lowest mean value was recorded by T_{16} (220.0 mg kg^{-1}).

The exchangeable calcium of the post harvest soil after the second direct test crop ranged from 281.3 mg kg^{-1} to 418.5 mg kg^{-1}. Among the treatments, significantly higher calcium content of soil was recorded with T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was superior over other treatment effects. The lowest mean value was recorded by T_{16} (281.3 mg kg^{-1}).

4.3.7.11 Exchangeable Magnesium

Various treatments have significantly influenced the exchangeable Mg status of the soil after the first direct test crop (Table 31). From the result it was revealed that T_2 (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1})) recorded the highest mean value of 134.0 mg kg^{-1} and was on par with T_7 (117.0 mg kg^{-1}), T_5 (117.0 mg kg^{-1}), T_{12} (116.8 mg kg^{-1}) and T_{14} (115.8 mg kg^{-1}). The lowest mean value of 72.00 mg kg^{-1} was registered by T_{16} (Absolute control).

After the confirmatory direct test crop, the data on exchangeable magnesium of soil showed that, it ranged from 34.50 mg kg^{-1} to 120.3 mg kg^{-1}. The treatment, T_2

(FYM (12 t ha^{-1}) + Soil application of nano NPK(12.5 kg ha^{-1})) was significantly superior over other treatment effects and was on par with the effects of T_7 and T_5 recorded higher magnesium content of 108.8 mg kg^{-1} and 104.3 mg kg^{-1} respectively.

4.3.7.12 Available Sulphur

The data on the available sulphur of the soil is presented in table 31. The treatments revealed significant effect on the available S status in the soil after the harvest first direct test crop. The mean available S content in the soil ranged from 5.17 mg kg^{-1} to 31.34 mg kg^{-1}. The highest available S was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) which was significantly superior than all other treatments. The lowest mean value (5.17 mg kg^{-1}) was registered by T_{16} (Absolute control).

Available sulphur of the post harvest soil after the second direct test crop ranged from 3.40 mg kg^{-1} to 12.29 mg kg^{-1}. Highest available sulphur of soil was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was on par with the effects of T_{13}, T_{12} and T_{10}.

4.3.7.13 Available Iron

Perusal of the data revealed that application of organic nano NPK formulations showed a significant influence on the available Fe status in soil after the harvest of the first and second direct test crop and are presented in table 32. Treatment T_2 (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1})) recorded the highest available Fe content (18.43 mg kg^{-1}) and was significantly superior than all other treatments. The lowest available Fe content (12.34 mg kg^{-1}) registered by T_{16} (Absolute control).

The result showed that the highest available Fe at the post harvest soil of second direct test crop ranged from 12.07 mg kg^{-1} to 16.86 mg kg^{-1} and T_2 (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1})) recorded the highest content of Fe in soil.

Table 31. Effect of organic nano NPK formulations on soil available secondary nutrients after the test crop of okra, mg kg^{-1}

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Calcium	Magnesium	Sulphur	Calcium	Magnesium	Sulphur
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	328.3	90.00	6.81	310.2	81.00	5.63
T_2: FYM (12 t ha^{-1}) + T_1	415.8	134.0	10.21	395.4	120.3	8.85
T_3: Soil application of nano NPK (25 kg ha^{-1})	360.8	87.50	20.12	321.5	79.25	9.25
T_4: FYM (12 t ha^{-1}) + T_3	405.8	98.75	6.07	340.6	84.50	5.60
T_5: Soil application of nano NPK (50 kg ha^{-1})	392.5	117.0	10.40	352.2	104.3	5.83
T_6: FYM (12 t ha^{-1}) + T_5	381.3	96.00	11.03	331.5	80.00	6.06
T_7: Foliar application of nano NPK (0.2%)	379.2	117.0	5.97	328.7	108.8	4.10
T_8: FYM (12 t ha^{-1}) + T_7	347.9	95.25	10.93	310.2	75.00	6.83
T_9: Foliar application of nano NPK (0.4%)	346.3	91.50	7.56	332.5	85.00	4.81
T_{10}: FYM (12 t ha^{-1}) + T_9	414.6	86.00	21.29	385.3	78.50	10.69
T_{11}: T_1 + T_9	342.9	88.00	9.68	314.7	82.25	8.77
T_{12}: T_2 + T_9	417.1	116.8	19.85	418.5	101.3	10.31
T_{13}: T_3 +T_7	338.8	84.25	25.61	314.0	76.00	10.88
T_{14}: T_4 + T_7	384.2	115.8	31.34	353.5	100.5	12.29
T_{15}: KAU POP	317.9	84.25	6.27	308.9	73.00	5.02
T_{16}: Absolute control	220.0	72.00	5.17	281.3	34.50	3.40
SEm (±)	997.2	274.8	7.22	122.1	74.39	1.34
CD (0.05): for any two treatments in the same block	60.00	31.50	5.10	20.99	16.39	2.20
CD (0.05): for any two treatments in different blocks	62.84	32.99	5.35	21.99	17.16	2.31

4.3.7.14 Available Manganese

It is inferred from the table 32 that mean value of available Mn status of the soil after the first direct test crop ranged from 16.16 mg kg^{-1} to 28.95 mg kg^{-1}. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest available Mn and was on par with T_5 (26.92 mg kg^{-1}). The lowest mean value (16.16 mg kg^{-1}) was noticed in T_{16} (Absolute control).

After the second direct test crop available Mn status of the post harvest soil ranged between 10.38 mg kg^{-1} to 18.00 mg kg^{-1} and the effect of T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) was superior over other treatments. The lowest mean value (10.38 mg kg^{-1}) was noticed in T_{16} (Absolute control).

4.3.7.15 Available Zinc

Table 32 showed that available Zn status of the soil was found to be significantly influenced by the treatments after the direct test crops in first and third experiment. The highest mean value of 8.21 mg kg^{-1} was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was found to be significantly superior than all other treatments. The lowest mean value of 4.58 mg kg^{-1} was registered by T_{16} (Absolute control).

After the second direct test crop, the available Zn status (7.60 mg kg^{-1}) of soil was also found to be higher with the treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was found to be superior than all other treatments and the Zn status of soil ranged from 4.10 mg kg^{-1} to 7.60 mg kg^{-1}.

4.3.7.16 Available Copper

The analytical results of available Cu is presented in table 32. The mean value of available Cu ranged between 1.58 mg kg^{-1} to 2.99 mg kg^{-1}. The highest available Cu in the soil was observed in T_5 (Soil application of nano NPK (50 kg ha^{-1})). T_{16} registered the lowest mean value of 1.58 mg kg^{-1} and was significantly inferior to all other treatments after the first field experiment using okra as the test crop.

From the results obtained after the second direct test crop, it was found that available Cu in the soil ranged from 1.29 mg kg^{-1} to 8.05 mg kg^{-1}. The treatment T_5 (Soil application of nano NPK (50 kg ha^{-1})) recorded significantly higher Cu content of soil. The lowest mean value of 1.29 mg kg^{-1} was registered by T_{16} (Absolute control).

4.3.7.17 Nutrient use efficiency

The result of nutrient use efficiency is presented in table 33. The highest nutrient use efficiency of 30.81 per cent was recorded in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) followed by T_6 (FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1})) with a value of 17.88 per cent in the first direct test crop.

With respect to the nutrient use efficiency of the second direct test crop which is presented in table 33, the highest nutrient use efficiency of 31.38 per cent was recorded in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) followed by T_6 (FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1})) with a value of 29.02 per cent.

4.3.7.18 Dehydrogenase activity

The effect of different treatments on the dehydrogenase activity in the soil after the harvest of both direct test crop are presented in table 34 a. The highest

Table 32. Available Fe, Mn, Zn and Cu in the post harvest soil of first and second direct test crops of okra, mg kg^{-1}

Treatment	First direct test crop (Expt No. I)				Second direct test crop (Expt No. III)			
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	13.63	26.11	6.08	1.65	12.39	16.54	5.48	4.76
T_2: FYM (12 t ha^{-1}) + T_1	18.43	23.71	7.38	2.83	16.86	15.37	6.52	6.91
T_3: Soil application of nano NPK (25 kg ha^{-1})	15.50	25.25	6.11	1.62	13.69	16.45	5.54	2.78
T_4: FYM (12 t ha^{-1}) + T_3	14.26	24.30	7.11	1.62	13.52	16.43	6.47	5.12
T_5: Soil application of nano NPK (50 kg ha^{-1})	16.14	26.92	7.75	2.99	14.36	16.01	6.24	8.05
T_6: FYM (12 t ha^{-1}) + T_5	15.80	23.58	6.80	2.22	14.22	16.89	6.76	6.52
T_7: Foliar application of nano NPK (0.2%)	15.98	23.60	5.97	2.22	14.29	15.40	5.37	6.42
T_8: FYM (12 t ha^{-1}) + T_7	16.45	20.74	7.75	2.10	15.76	15.15	7.34	6.38
T_9: Foliar application of nano NPK (0.4%)	14.66	21.39	5.94	1.98	13.49	15.21	5.18	6.01
T_{10}: FYM (12 t ha^{-1}) + T_9	17.40	25.07	7.08	1.94	15.96	16.46	6.44	6.23
T_{11}: T_1 + T_9	14.23	20.93	6.68	1.78	13.10	14.69	5.84	5.38
T_{12}: T_2 + T_9	15.43	28.95	8.21	1.94	15.17	18.00	7.60	6.84
T_{13}: T_3 +T_7	16.18	24.00	6.55	2.56	13.54	16.21	5.78	5.39
T_{14}: T_4 + T_7	16.33	23.99	6.45	2.46	15.42	16.83	5.90	6.51
T_{15}: KAU POP	13.09	23.06	5.80	1.80	12.95	12.77	4.87	5.23
T_{16}: Absolute control	12.34	16.16	4.58	1.58	12.07	10.38	4.10	1.29
SEm (±)	0.014	1.79	0.002	0.003	0.003	0.005	0.004	0.006
CD (0.05): for any two treatments in the same block	0.23	2.54	0.09	0.10	0.10	0.14	0.13	0.15
CD (0.05): for any two treatments in different blocks	0.24	2.66	0.09	0.11	0.11	0.14	0.13	0.15

Table 33. Effect of organic nano NPK formulations on nutrient use efficiency (NUE) of the first and second direct test crops of okra, %

Treatments	First direct test crop (Expt No. I)	Second direct test crop (Expt No. III)
	Nutrient Use Efficiency (%)	Nutrient Use Efficiency (%)
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	0.00	0.00
T_2: FYM (12 t ha^{-1}) + T_1	14.23	20.51
T_3: Soil application of nano NPK (25 kg ha^{-1})	0.00	0.00
T_4: FYM (12 t ha^{-1}) + T_3	4.78	5.01
T_5: Soil application of nano NPK (50 kg ha^{-1})	8.52	13.23
T_6: FYM (12 t ha^{-1}) + T_5	17.88	29.02
T_7: Foliar application of nano NPK (0.2%)	0.00	0.00
T_8: FYM (12 t ha^{-1}) + T_7	0.00	3.21
T_9: Foliar application of nano NPK (0.4%)	3.84	6.99
T_{10}: FYM (12 t ha^{-1}) + T_9	11.52	16.45
T_{11}: T_1 + T_9	13.67	21.17
T_{12}: T_2 + T_9	30.81	31.38
T_{13}: T_3 +T_7	7.12	11.34
T_{14}: T_4 + T_7	15.17	25.80
T_{15}: KAU POP	0.00	0.00
T_{16}: Absolute control	0.00	0.00

dehydrogenase activity in the soil was obtained in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 29.08 μg of TPF g^{-1} soil 24 h^{-1} and was comparable with T_9 and T_{14}. The lowest dehydrogenase activity was noticed in the absolute control treatment (T_{16}) with a mean value of 4.90 μg of TPF g^{-1} soil 24 h^{-1}.

Highest dehydrogenase activity was recorded by T_{12}, FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) with a mean value 27.93 μg of TPFg^{-1} soil 24 h^{-1} after the second direct test crop and was found to be superior than all other treatments. The lowest dehydrogenase was found in the absolute control treatment with a mean value of 11.32 μg of TPFg^{-1} soil 24 h^{-1}.

4.3.7.19 Urease activity

Data presented in table 34 a revealed that different treatments significantly influenced the urease activity of the post harvest soil after the direct test crops. The mean values of the various treatments on urease activity ranged from 29.76 ppm urea g^{-1} soil h^{-1} to 33.90 ppm urea g^{-1} soil h^{-1}. Among the treatments observed after the first direct test crop, the highest urease activity was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with a mean value of 33.90 ppm urea g^{-1} soil h^{-1} and was on par with T_{14}, T_6, T_7 and T_{13}. The treatment, T_{16} had the lowest mean value (29.76 ppm urea g^{-1} soil h^{-1}).

Data presented in table 34 a revealed that different treatments significantly influenced the urease activity of the soil after the second direct test crop. The mean values of the various treatments on urease activity ranged from 29.30 ppm urea g^{-1} soil h^{-1} to 35.66 ppm urea g^{-1} soil h^{-1}. Among 16 treatments, T_{12} FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) recorded the highest urease activity with a mean value of 35.66 ppm urea g^{-1}soil h^{-1} which was on par with T_{14} (35.58 ppm urea g^{-1} soil h^{-1}), T_{13} (35.04 ppm urea g^{-1}

Table 34 a. Effect of organic nano NPK formulations on dehydrogenase and urease activities after the direct test crops of okra

Treatment	First direct test crop (Expt No. I)		Second direct test crop (Expt No. III)	
	Dehydrogenase (µg of TPF g^{-1} soil 24 h^{-1})	Urease (ppm urea g^{-1} soil h^{-1})	Dehydrogenase (µg of TPF g^{-1} soil 24 h^{-1})	Urease (ppm urea g^{-1} soil h^{-1})
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	11.70	31.60	16.35	30.93
T_2: FYM (12 t ha^{-1}) + T_1	14.86	31.68	21.08	34.52
T_3: Soil application of nano NPK (25 kg ha^{-1})	14.51	30.44	17.55	31.82
T_4: FYM (12 t ha^{-1}) + T_3	17.70	32.26	22.16	34.52
T_5: Soil application of nano NPK (50 kg ha^{-1})	14.93	31.80	21.13	33.20
T_6: FYM (12 t ha^{-1}) + T_5	16.25	33.62	22.70	35.01
T_7: Foliar application of nano NPK (0.2%)	17.83	33.32	21.08	32.64
T_8: FYM (12 t ha^{-1}) + T_7	17.62	32.28	22.88	32.11
T_9: Foliar application of nano NPK (0.4%)	26.02	32.56	24.24	32.37
T_{10}: FYM (12 t ha^{-1}) + T_9	15.18	32.09	21.13	33.33
T_{11}: T_1 + T_9	15.20	32.04	21.88	33.85
T_{12}: T_2 + T_9	29.08	33.90	27.93	35.66
T_{13}: T_3 +T_7	22.06	32.93	23.42	35.04
T_{14}: T_4 + T_7	25.70	33.89	25.43	35.58
T_{15}: KAU POP	11.42	31.94	19.18	32.52
T_{16}: Absolute control	4.90	29.76	11.32	29.30
SEm (±)	11.64	0.43	0.95	0.66
CD (0.05): for any two treatments in the same block	6.48	1.24	1.85	1.55
CD (0.05): for any two treatments in different blocks	6.79	1.30	1.94	1.62

soil h^{-1}), T_6 (35.01 ppm urea g^{-1} soil h^{-1}), T_4 (34.52 ppm urea g^{-1} soil h^{-1}) and T_2 (34.52 ppm urea g^{-1} soil h^{-1}). The lowest urease activity (29.30 ppm urea g^{-1} soil h^{-1}) was found in the absolute control treatment.

4.3.7.19 Acid phosphatase

Activity of acid phosphatase enzyme of the soil varied significantly with different treatments (Table 34 b). The mean values ranged from 45.20 μg of p-nitrophenol g^{-1} soil h^{-1} to 91.16 μg of p-nitrophenol g^{-1} soil h^{-1} of various treatments after the first direct test crop. The highest value reported in the treatment that was received FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) and was found to be on par with T_{14} (90.61 μg of p-nitrophenol g^{-1} soil h^{-1}), T_6 (88.60 μg of p-nitrophenol g^{-1} soil h^{-1}) and T_4 (82.45 μg of p-nitrophenol g^{-1} soil h^{-1}). The lowest acid phosphatase activity (45.20 μg of p-nitrophenol g^{-1} soil h^{-1}) on the soil was reported by T_{16} (Absolute control).

Acid phosphatase activity in the post harvest soil ranged from 12.32 μg of p-nitrophenol g^{-1} soil h^{-1} to 28.93 μg of p- nitrophenol g^{-1} soil h^{-1} after the second direct test crop. The highest mean value was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) after the second direct test crop and was found to be significantly superior to all other treatments. The lowest acid phosphatase activity (12.32 μg of p-nitrophenol g^{-1} soil h^{-1}) was found in the control treatment.

4.3.7.20 Alkaline phosphatase

Table 34 b revealed that the alkaline phosphatase activity showed the significant influence among the treatments. The highest mean value of 4.14 μg of p - nitrophenol g^{-1} soil h^{-1} was reported in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was comparable with T_2 (4.13 μg of p - nitrophenol g^{-1} soil h^{-1}), T_4 (4.10 μg of p - nitrophenol g^{-1} soil h^{-1}) and

Table 34 b. Effect of organic nano NPK formulations on acid and alkaline phosphatase after the direct test crops of okra

Treatment	First direct test crop (Expt No. I)		Second direct test crop (Expt No. III)	
	Acid phosphatase (μg of p-nitrophenol g^{-1} soil h^{-1})	Alkaline phosphatase (μg of p-nitrophenol g^{-1}soil h^{-1})	Acid phosphatase (μg of p-nitrophenol g^{-1} soil h^{-1})	Alkaline phosphatase (μg of p-nitrophenol g^{-1}soil h^{-1})
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	48.12	3.23	17.35	5.32
T_2: FYM (12 t ha^{-1}) + T_1	69.93	4.13	22.08	4.22
T_3: Soil application of nano NPK (25 kg ha^{-1})	50.38	3.42	18.55	5.39
T_4: FYM (12 t ha^{-1}) + T_3	82.45	4.10	23.16	5.75
T_5: Soil application of nano NPK (50 kg ha^{-1})	57.16	3.53	22.13	5.57
T_6: FYM (12 t ha^{-1}) + T_5	88.60	3.55	23.70	5.65
T_7: Foliar application of nano NPK (0.2%)	58.33	3.70	22.08	5.45
T_8: FYM (12 t ha^{-1}) + T_7	54.92	2.92	23.88	6.30
T_9: Foliar application of nano NPK (0.4%)	51.38	2.48	25.24	4.92
T_{10}: FYM (12 t ha^{-1}) + T_9	51.88	2.79	22.13	5.74
T_{11}: T_1 + T_9	54.93	2.17	22.88	4.95
T_{12}: T_2 + T_9	91.16	4.14	28.93	6.79
T_{13}: T_3 +T_7	70.26	2.41	24.42	4.71
T_{14}: T_4 + T_7	90.61	1.80	26.43	6.12
T_{15}: KAU POP	51.59	2.81	20.18	4.96
T_{16}: Absolute control	45.20	1.66	12.32	3.12
SEm (±)	80.15	0.07	0.95	0.03
CD (0.05): for any two treatments in the same block	17.00	0.49	1.85	0.34
CD (0.05): for any two treatments in different blocks	17.81	0.51	1.94	0.36

T_7 (3.70 μg of p - nitrophenol g^{-1} soil h^{-1}). The lowest mean value was noticed in T_{16} (Absolute control) with a mean value of 1.66 μg of p - nitrophenol g^{-1}soil h^{-1}.

The result presented in the table 34 b revealed that the alkaline phosphatase activity showed significant influence among the treatments after the second direct test crop. Alkaline phosphatase was significantly varied among the treatments with a range value of 3.12 μg of p - nitrophenol g^{-1} soil h^{-1} to 6.79 μg of p-nitrophenol g^{-1} soil h^{-1}. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest value of 6.79 μg of p- nitrophenol g^{-1} soil h^{-1}. The lowest alkaline phosphate activity was found in the absolute control treatment (T_{16}).

4.3.7.22 Bacteria

Different treatments with organic nano NPK formulations showed significant influence on the soil microbial population and are presented in table 35. The mean value of bacterial count of the post harvest soil after the first direct test crop ranged from 6.03 log cfu g^{-1} soil to 7.31 log cfu g^{-1} soil. T_6 (FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1})) recorded the highest bacterial count and was comparable with T_{12} (7.29 log cfu g^{-1} soil). The lowest bacterial count was reported by T_{16} (Absolute control).

Bacterial count varied among treatments with a range of 6.26 log cfu g^{-1} soil to 7.27 log cfu g^{-1} soil. The highest count recorded in T_6 (FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1}) and was found to be significantly superior than other treatments in the post harvest soil of second direct test crop. The lowest bacterial count was found in the absolute control treatment.

4.3.7.23 Fungi

From the analytical data (Table 35), it was inferred that different treatments showed significant effect on the fungal population after the crop and the mean values ranged from 3.94 log cfu g^{-1} soil to 4.68 log cfu g^{-1} soil. The highest mean value was recorded by T_6 (FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1})) and was on par with T_{14} (4.66 log cfu g^{-1} soil), T_8 (4.53 log cfu g^{-1} soil), T_{11} (4.51 log cfu g^{-1} soil) and T_3 (4.51 log cfu g^{-1} soil). The treatment, T_{16} (Absolute control) recorded the lowest fungal population.

After the confirmatory crop, fungal counts varied from 3.81 log cfu g^{-1} soil to 4.32 log cfu g^{-1} soil. The highest fungal count was observed in T_6 (FYM (12 t ha^{-1}) + soil application of nano NPK (50 kg ha^{-1})) and was on par with T_{14} (4.28 log cfu g^{-1} soil), T_4 (4.26 log cfu g^{-1} soil), T_{11} (4.24 log cfu g^{-1} soil), T_8 (4.23 log cfu g^{-1} soil) and T_{13} (4.14 log cfu g^{-1} soil). The lowest Fungal count was recorded in T_{16} (Absolute control) with a mean value of 3.81 log cfu g^{-1} soil.

4.3.7.24 Actinomycetes

A perusal of the data (Table 35) reported that different treatments have a significant effect on the actinomycetes count in the soil after the direct test crops. After the first direct test crop, the highest mean value (4.39 log cfu g^{-1} soil) of actinomyctes was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was significantly superior than all other treatments. T_{16} (Absolute control) recorded the lowest actinomycetes count of 4.07 log cfu g^{-1} soil.

Among 16 treatments, T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) exhibited high actinomycetes count (4.09 log cfu g^{-1} soil) which was on par with T_2 (3.98 log cfu g^{-1} soil) after the

Table 35. Influence of organic nano NPK formulations on soil microbial population of post harvest soil after the direct test crops of okra, log cfu g^{-1} soil

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	6.43	4.46	4.12	6.60	4.05	3.57
T_2: FYM (12 t ha^{-1}) + T_1	6.80	4.30	4.34	7.03	3.87	3.98
T_3: Soil application of nano NPK (25 kg ha^{-1})	7.17	4.51	4.23	6.72	3.92	3.87
T_4: FYM (12 t ha^{-1}) + T_3	6.10	4.41	4.17	7.10	4.26	3.63
T_5: Soil application of nano NPK (50 kg ha^{-1})	6.16	4.38	4.19	6.75	4.13	3.76
T_6: FYM (12 t ha^{-1}) + T_5	7.31	4.68	4.33	7.27	4.32	3.94
T_7: Foliar application of nano NPK (0.2%)	7.03	4.41	4.16	6.30	3.96	3.73
T_8: FYM (12 t ha^{-1}) + T_7	6.67	4.53	4.15	6.84	4.23	3.74
T_9: Foliar application of nano NPK (0.4%)	6.31	4.35	4.20	6.40	4.03	3.82
T_{10}: FYM (12 t ha^{-1}) + T_9	6.98	4.23	4.22	6.51	3.92	3.94
T_{11}: T_1 + T_9	6.24	4.51	4.19	6.65	4.24	3.40
T_{12}: T_2 + T_9	7.29	4.05	4.16	7.13	4.04	3.96
T_{13}: T_3 +T_7	6.55	4.35	4.31	6.85	4.14	3.63
T_{14}: T_4 + T_7	6.09	4.66	4.39	7.16	4.28	4.09
T_{15}: KAU POP	6.35	4.05	4.14	6.83	3.89	3.66
T_{16}: Absolute control	6.03	3.94	4.07	6.26	3.81	3.25
SEm (±)	0.001	0.072	0.006	0.001	0.004	0.003
CD (0.05): for any two treatments in the same block	0.025	0.21	0.047	0.071	0.12	0.11
CD (0.05): for any two treatments in different blocks	0.026	0.22	0.048	0.075	0.13	0.11

second direct test crop. The lowest mean value of 3.25 log cfu g^{-1} soil was found in T_{16} (Absolute control).

4.3.8 Plant uptake

All the treatments imposed significantly influenced nutrient uptake by okra plants in both the field experiments I and III and the results are presented in table 36-38.

4.3.8.1 Nitrogen uptake

All the treatments imposed significantly influenced the N uptake by the okra plant and result is presented in table 36. The mean value of nitrogen uptake by plant ranged from 19.11 kg ha^{-1} to 87.19 kg ha^{-1}. The highest N uptake by plant was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)) in the first direct test crop and was significantly superior than all other treatments. The lowest value of 19.11 kg ha^{-1} was observed in T_{16} (Absolute control).

Nitrogen uptake was significantly varied among the treatments with a range value of 20.31 kg ha^{-1} to 119.8 kg ha^{-1}. The highest nitrogen uptake was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)) which was on par with T_{14} (118.5 kg ha^{-1}) in the second direct test crop. The lowest nitrogen uptake was found in the control treatment.

4.3.8.2 Phosphorous uptake

The results of P uptake by the plant as influenced by the different treatments in okra is presented in table 36. The maximum P uptake by okra plants was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)) with a mean value of 16.53 kg ha^{-1} and was found to be significantly superior than all other treatments. The lowest P uptake was registered by the treatment (T_{16}) which received no input.

Phosphorous uptake by second direct test crop varied in a range of 3.42 kg ha^{-1} to 25.48 kg ha^{-1}. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)) recorded the highest value. The lowest phosphorous uptake was found in the absolute control treatment.

4.3.8.3 Potassium uptake

Potassium uptake by okra crop as influenced by different treatments and is presented in table 36. All the treatments imposed significantly influenced K uptake by the plant. The highest K uptake highest value (127.5 kg ha^{-1}) was observed in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)) and was superior to all other treatments. The absolute control treatment (T_{16}) recorded the lowest K uptake by the plant.

In the case of second direct test crop, potassium uptake exhibited high magnitude of variation among the treatments with a range of 19.12 kg ha^{-1} to 124.4 kg ha^{-1}. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)) registered the highest potassium uptake. The lowest potassium uptake was found in the absolute control treatment.

4.3.8.4 Calcium uptake

Significant variations in calcium uptake between the treatments recorded and is presented in table 37. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)) recorded the highest uptake of calcium with a mean value of 42.86 kg ha^{-1}. Absolute control (T_{16}) registered the lowest value of 4.93 kg ha^{-1} with respect to calcium uptake in the first direct test crop.

Table 36. Effect of organic nano NPK formulations on N, P and K uptake by okra plant, kg ha^{-1}

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Nitrogen	Phosphorous	Potassium	Nitrogen	Phosphorous	Potassium
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	44.85	7.22	56.66	50.91	8.83	54.38
T_2: FYM (12 t ha^{-1}) + T_1	54.83	10.53	72.74	60.87	12.81	69.58
T_3: Soil application of nano NPK (25 kg ha^{-1})	50.34	8.55	58.04	54.45	9.91	58.72
T_4: FYM (12 t ha^{-1}) + T_3	56.23	9.43	75.98	67.29	11.91	70.02
T_5: Soil application of nano NPK (50 kg ha^{-1})	57.58	10.29	70.81	65.08	12.99	71.38
T_6: FYM (12 t ha^{-1}) + T_5	63.21	11.99	87.02	87.73	18.71	94.19
T_7: Foliar application of nano NPK (0.2%)	40.44	7.72	44.54	45.36	8.25	41.32
T_8: FYM (12 t ha^{-1}) + T_7	51.93	8.69	60.77	66.76	12.00	63.90
T_9: Foliar application of nano NPK (0.4%)	54.20	8.37	66.90	56.67	11.47	60.49
T_{10}: FYM (12 t ha^{-1}) + T_9	62.48	11.83	80.26	77.82	16.68	83.50
T_{11}: T_1 + T_9	59.00	9.60	76.89	75.12	14.77	86.44
T_{12}: T_2 + T_9	87.19	16.53	127.5	119.8	25.48	124.4
T_{13}: T_3 +T_7	69.27	12.54	96.29	92.90	17.96	91.21
T_{14}: T_4 + T_7	74.77	13.65	113.3	118.5	22.70	114.0
T_{15}: KAU POP	45.77	8.82	61.28	57.26	10.33	65.38
T_{16}: Absolute control	19.11	2.31	17.65	20.31	3.42	19.12
SEm (±)	12.76	0.25	18.48	5.18	0.53	12.06
CD (0.05): for any two treatments in the same block	6.79	0.95	8.17	4.32	1.39	6.60
CD (0.05): for any two treatments in different blocks	7.11	1.00	8.56	4.53	1.45	6.91

The data presented in table 37 revealed that calcium uptake significantly influenced by the treatments in the second direct test crop. Calcium uptake recorded higher value of 50.95 kg ha^{-1} in T_{12} which was on par with T_{14} (47.80 kg ha^{-1}). The lowest value for calcium uptake was noticed in absolute control treatment with a mean value of 6.47 kg ha^{-1}.

4.3.8.5 Magnesium uptake

All the treatments exhibited significant influence on magnesium uptake by both the okra crops and result are presented in table 37. The highest Mg uptake by the first direct test crop was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 29.26 kg ha^{-1} and was on par with T_{14} (24.72 kg ha^{-1}) and T_3 (23.26 kg ha^{-1}). Absolute control treatment recorded the lowest mean value of 4.79 kg ha^{-1}.

Magnesium uptake by the plants varied from 7.02 kg ha^{-1} to 29.77 kg ha^{-1} in the second direct test crop. The highest magnesium uptake was reported in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + foliar application of nano NPK (0.4 %)) and was on par with T_{13} (28.97 kg ha^{-1}), T_8 (26.76 kg ha^{-1}) and T_{14} (24.58 kg ha^{-1}). The lowest magnesium uptake value (7.02 kg ha^{-1}) was found in the absolute control treatment.

4.3.8.6 Sulphur uptake

The sulphur uptake by okra plants are presented in table 37. The different treatments imposed significantly influenced the S uptake by both okra crops. Among the different treatments, S uptake was maximum in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with the mean value of 18.25 kg ha^{-1}. The lowest S uptake was reported in T_{16} (Absolute control) with mean value of 3.16 kg ha^{-1}.

Table 37. Effect of organic nano NPK formulations on uptake of secondary nutrients by the direct test crops of okra, kg ha^{-1}

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Calcium	Magnesium	Sulphur	Calcium	Magnesium	Sulphur
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	15.72	12.89	6.92	19.07	15.57	7.48
T_2: FYM (12 t ha^{-1}) + T_1	20.14	20.91	9.48	25.92	23.09	9.58
T_3: Soil application of nano NPK (25 kg ha^{-1})	17.64	23.26	8.53	22.57	20.52	8.20
T_4: FYM (12 t ha^{-1}) + T_3	23.83	18.88	10.33	28.54	20.79	9.43
T_5: Soil application of nano NPK (50 kg ha^{-1})	18.49	18.50	9.49	27.12	21.89	9.88
T_6: FYM (12 t ha^{-1}) + T_5	30.48	20.04	11.44	37.34	21.53	13.22
T_7: Foliar application of nano NPK (0.2%)	11.94	14.92	6.74	15.97	10.74	5.94
T_8: FYM (12 t ha^{-1}) + T_7	22.01	15.60	10.45	28.84	26.76	8.72
T_9: Foliar application of nano NPK (0.4%)	17.52	13.91	7.38	21.57	21.03	8.91
T_{10}: FYM (12 t ha^{-1}) + T_9	23.88	21.17	11.72	32.20	23.23	12.09
T_{11}: T_1 + T_9	26.32	15.64	12.88	34.52	23.47	13.02
T_{12}: T_2 + T_9	42.86	29.26	18.25	50.95	29.77	18.25
T_{13}: T_3 +T_7	30.64	20.74	14.20	40.70	28.97	13.65
T_{14}: T_4 + T_7	31.18	24.72	15.56	47.80	24.58	16.87
T_{15}: KAU POP	17.58	17.57	7.72	22.76	15.30	8.13
T_{16}: Absolute control	4.93	4.79	3.16	6.47	7.02	3.44
SEm (±)	4.04	11.97	0.11	6.99	10.00	0.18
CD (0.05): for any two treatments in the same block	3.82	6.57	0.62	5.02	6.00	0.80
CD (0.05): for any two treatments in different blocks	4.00	6.89	0.65	5.26	6.30	0.84

In the case of second direct test crop, sulphur exhibited high variation among the treatments with range value of 3.44 kg ha^{-1} to 18.25 kg ha^{-1}. Among the different treatments T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest value. The lowest sulphur uptake was found in the absolute control treatment (3.44 kg ha^{-1}).

4.3.8.7 Iron uptake

The analytical reports from the table 38 showed that Fe uptake by plants had a significant difference among the treatments. The mean value of Fe uptake by first direct test crop ranged from 0.19 kg ha^{-1} to 1.94 kg ha^{-1}. The highest Fe uptake by okra plant was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was significantly superior than all other treatments. T_{16} recorded the lowest Fe uptake by the plants.

In the confirmatory crop, iron uptake recorded highest value of 1.96 kg ha^{-1} in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was on par with T_{14} (1.95 kg ha^{-1}). The lowest iron uptake value of 0.20 kg ha^{-1} was found in the absolute control treatment.

4.3.8.8 Manganese uptake

The uptake of manganese by okra was significantly influenced by the application of different treatments and result is presented in table 38. Maximum uptake of Mn was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was superior to all other treatments in the first direct test crop.

The results pertaining to the uptake of manganese by the second direct test crop is presented in table 38. The highest manganese uptake of 0.30 kg ha^{-1} was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)). The lowest value of 0.03 kg ha^{-1} was found in the absolute control treatment.

4.3.8.9 Zinc uptake

The results of the statistical analysis of the uptake of zinc as influenced by different combination of treatments are presented in table 38. The result showed that for the first direct test crop, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) resulted in significantly higher uptake of Zn compared to other treatments with a mean value of 0.35 kg ha^{-1}. Absolute Control treatment recorded significantly lower uptake with a mean value of 0.06 kg ha^{-1}.

With respect to the second direct test crop, among the treatments (Table 38), zinc uptake varied in a range of 0.06 kg ha^{-1} to 0.33 kg ha^{-1}. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) exhibited higher uptake of zinc and was significantly superior than all other treatments. The lowest zinc uptake was found in absolute control treatment.

4.3.8.10 Copper uptake

The perusal of the data (Table 38) revealed that the uptake of Cu by okra plants ranged between 0.15 kg ha^{-1} to 1.98 kg ha^{-1}. Significantly higher Cu uptake was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 1.98 kg ha^{-1}. T_{16} (Absolute control) treatment registered the lowest Cu uptake.

The results summarized in table 38 revealed that copper uptake of second direct test crop ranged from 0.15 kg ha^{-1} to 2.28 kg ha^{-1}. Among the treatments, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano

Table 38. Uptake of micronutrients as influenced by organic nano NPK formulations in direct test crops of okra, kg ha^{-1}

Treatment	First direct test crop (Expt No. I)				Second direct test crop (Expt No. III)			
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	0.42	0.06	0.16	0.45	0.43	0.07	0.13	0.49
T_2: FYM (12 t ha^{-1}) + T_1	0.61	0.08	0.17	0.86	0.61	0.09	0.17	0.98
T_3: Soil application of nano NPK (25 kg ha^{-1})	0.54	0.07	0.14	0.53	0.55	0.07	0.15	0.58
T_4: FYM (12 t ha^{-1}) + T_3	0.68	0.09	0.18	1.13	0.65	0.09	0.17	1.15
T_5: Soil application of nano NPK (50 kg ha^{-1})	0.50	0.08	0.17	0.74	0.50	0.09	0.18	0.82
T_6: FYM (12 t ha^{-1}) + T_5	0.84	0.12	0.20	1.61	0.95	0.13	0.22	1.88
T_7: Foliar application of nano NPK (0.2%)	0.33	0.05	0.11	0.30	0.33	0.06	0.11	0.35
T_8: FYM (12 t ha^{-1}) + T_7	0.58	0.08	0.17	0.58	0.55	0.09	0.17	0.59
T_9: Foliar application of nano NPK (0.4%)	0.39	0.06	0.14	0.41	0.42	0.07	0.15	0.49
T_{10}: FYM (12 t ha^{-1}) + T_9	0.69	0.11	0.20	0.66	0.72	0.12	0.21	0.79
T_{11}: T_1 + T_9	0.82	0.11	0.21	1.22	0.88	0.14	0.22	1.35
T_{12}: T_2 + T_9	1.94	0.31	0.35	1.98	1.96	0.30	0.33	2.28
T_{13}: T_3 +T_7	1.09	0.16	0.23	1.70	1.10	0.15	0.23	1.77
T_{14}: T_4 + T_7	1.75	0.25	0.26	1.69	1.95	0.25	0.29	2.15
T_{15}: KAU POP	0.53	0.08	0.13	0.49	0.47	0.06	0.14	0.48
T_{16}: Absolute control	0.19	0.03	0.06	0.15	0.20	0.03	0.06	0.15
SEm (±)	0.001	0.005	0.004	0.005	0.001	0.004	0.005	0.002
CD (0.05): for any two treatments in the same block	0.036	0.010	0.038	0.13	0.06	0.039	0.030	0.090
CD (0.05): for any two treatments in different blocks	0.037	0.011	0.040	0.13	0.063	0.040	0.034	0.092

NPK (0.4 %)) registered the highest copper uptake. The lowest mean value of 0.15 kg ha^{-1} was found in absolute control treatment.

4.3.9 Correlation analysis

4.3.9.1 Correlation analysis of yield with biometric characters and yield attributes of okra

Correlation between yield and biometric parameters of first direct test crop are presented in table 39. From the result it was revealed that yield was significantly and positively correlated with all other parameters except with days to first flowering (DFF). But days to first flowering was negatively and significantly correlated with all parameters except DMP which was insignificant.

Correlation of yield with biometric characters and yield attributes of okra during the second direct crop are presented in table 40. The result showed that yield was significantly and positively correlated with all characters except with days to first flowering. Similarly, days to first flowering was negatively correlated with all parameters.

4.3.9.2 Correlation analysis of yield with soil nutrients

Correlation study between yield and physico-chemical and chemical properties of soil are presented in tables 41 and 42. The results revealed that yield was positively correlated with all except EC during the first direct test crop. And EC was negatively correlated with all parameters except with available nitrogen where it was positively correlated and with available copper negatively correlated.

Similarly with respect to the second direct test crop yield was positively correlated with all the parameters.

Table 39. Correlation analysis of yield with biometric characters and yield attributes of the first direct test crop of okra (n=11)

	Yield	DFF	Fruit length	Fruit girth	DMP	Number of fruits per plant	Number of branches	Plant height	Root length	Root volume	LAI
Yield	1.000										
DFF	-0.657**	1.000									
Fruit length	0.889**	-0.582**	1.000								
Fruit girth	0.474**	-0.342*	0.496**	1.000							
DMP	0.668**	-0.282^{NS}	0.659**	0.575**	1.000						
Number of fruits per plant	0.687**	-0.705**	0.642**	0.376**	0.548**	1.000					
Number of branches	0.564**	-0.580**	0.544**	0.451**	0.357*	0.804**	1.000				
Plant height	0.757**	-0.495**	0.787**	0.576**	0.675**	0.607**	0.575**	1.000			
Root length	0.676**	-0.586**	0.691**	0.297*	0.384**	0.701**	0.763**	0.656**	1.000		
Root volume	0.747**	-0.409**	0.646**	0.390**	0.713**	0.604**	0.536**	0.742**	0.700**	1.000	
LAI	0.776**	-0.350*	0.751**	0.483**	0.847**	0.513**	0.415**	0.616**	0.519**	0.649**	1.000

** = Significant at 1% level * = Significant at 5% level NS = Non-significant

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Table 40. Correlation analysis of yield with biometric characters and yield attributes of the second direct test crop of okra (n=11)

	Yield	DFF	Fruit length	Fruit girth	DMP	Number of fruits per plant	Number of branches	Plant height	Root length	Root volume	LAI
Yield	1.000										
DFF	-0.689**	1.000									
Fruit length	0.801**	-0.629**	1.000								
Fruit girth	0.706**	-0.665**	0.531**	1.000							
DMP	0.837**	-0.524**	0.774**	0.713**	1.000						
Number of fruits per plant	0.660**	-0.652**	0.680**	0.536**	0.572**	1.000					
Number of branches	0.587**	-0.644**	0.527**	0.620**	0.397**	0.797**	1.000				
Plant height	0.756**	-0.548**	0.477**	0.852**	0.738**	0.564**	0.560**	1.000			
Root length	0.507**	-0.445**	0.542**	0.399**	0.478**	0.500**	0.571**	0.476**	1.000		
Root volume	0.800**	-0.507**	0.660**	0.547**	0.826**	0.667**	0.521**	0.674**	0.612**	1.000	
LAI	0.781**	-0.451**	0.842**	0.580**	0.912**	0.485**	0.342*	0.569**	0.439**	0.696**	1.000

** = Significant at 1% level   * = Significant at 5% level   NS = Non-significant

Table 41. Correlation analysis between yield and available soil nutrients of first direct test crop of okra (n=13)

	Yield	pH	EC	Available N	Available P	Available K	Available Ca	Available Mg	Available S	Available cu	Available Fe	Available Zn	Available Mn
Yield	1.000												
pH	0.720**	1.000											
EC	0.271^{NS}	0.052^{NS}	1.000										
Available N	0.583**	0.580**	0.441**	1.000									
Available P	0.712**	0.710**	0.192^{NS}	0.616**	1.000								
Available K	0.648**	0.552**	0.180^{NS}	0.617**	0.586**	1.000							
Available Ca	0.751**	0.767**	0.281^{NS}	0.542**	0.611**	0.470**	1.000						
Available Mg	0.452**	0.545**	0.084^{NS}	0.140^{NS}	0.300*	0.244^{NS}	0.782**	1.000					
Available S	0.446**	0.541**	-0.056^{NS}	0.489**	0.492**	0.748**	0.374**	0.163	1.000				
Available cu	0.360*	0.479**	-0.331*	0.236^{NS}	0.309*	0.391**	0.367*	0.477**	0.267^{NS}	1.000			
Available Fe	0.490**	0.697**	-0.173^{NS}	0.475**	0.549**	0.339*	0.600**	0.461**	0.468**	0.727**	1.000		
Available Zn	0.701**	0.632**	0.277^{NS}	0.552**	0.636**	0.395**	0.609**	0.392**	0.269^{NS}	0.478**	0.636**	1.000	
Available Mn	0.728**	0.701**	0.197^{NS}	0.480**	0.670**	0.440**	0.677**	0.454**	0.407**	0.273^{NS}	0.398**	0.600**	1.000

** = Significant at 1% level * = Significant at 5% level NS = Non-significant

Table 42. Correlation analysis between yield and available soil nutrients of second direct test crop of okra (n=13)

	Yield	pH	EC	Available N	Available P	Available K	Available Ca	Available Mg	Available S	Available cu	Available Fe	Available Zn	Available Mn
Yield	1.000												
pH	0.696**	1.000											
EC	0.602**	0.230^{NS}	1.000										
Available N	0.625**	0.551**	0.705**	1.000									
Available P	0.844**	0.705**	0.504**	0.687**	1.000								
Available K	0.749**	0.685**	0.488**	0.676**	0.733**	1.000							
Available Ca	0.606**	0.669**	0.300*	0.583**	0.693**	0.400**	1.000						
Available Mg	0.610**	0.597**	0.316*	0.323*	0.642**	0.355*	0.577**	1.000					
Available S	0.604**	0.691**	0.350*	0.527**	0.586**	0.674**	0.516**	0.333*	1.000				
Available cu	0.790**	0.589**	0.413**	0.406**	0.615**	0.508**	0.569**	0.732**	0.301*	1.000			
Available Fe	0.513**	0.683**	0.228^{NS}	0.416**	0.423**	0.341*	0.766**	0.583**	0.522**	0.650**	1.000		
Available Zn	0.655**	0.612**	0.452**	0.483**	0.423**	0.481**	0.558**	0.431**	0.453**	0.654**	0.708**	1.000	
Available Mn	0.799**	0.784**	0.517**	0.637**	0.731**	0.707**	0.559**	0.594**	0.556**	0.626**	0.474**	0.715**	1.000

** = Significant at 1% level * = Significant at 5% level NS = Non-significant

4.3.10 Economic analysis

Details regarding the economic analysis of okra is presented in table 43. It was recorded that benefit cost ratio was found to be the highest (2.27) in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) followed by T_{11} (2.14). The lowest B:C (0.80) was recorded by T_{16} (Absolute control).

The economic analysis of second okra crop is presented in table 43. It was recorded that benefit cost ratio was found to be the highest for T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a value of 2.27 followed by T_{11}. The lowest B:C (0.73) was recorded by T_{16} (Absolute control).

4.4 FIELD EXPERIMENTS NO: II and IV

4.4.1 Residual test crop: Amaranthus

Amaranthus was grown as the residual test crop in experiments No II and IV to study the residual effect of organic nano NPK formulations after the direct test crop okra.

4.4.1.1 Biometric characteristics of amaranthus

Various observations of both residual crops are presented in tables 44 to 45. Various growth attributes of crop *viz.,* height of plants, number of branches per plant, dry matter production and yield were recorded and presented.

4.4.1.1.1 Plant height

The plant height ranged from 17.19 cm to 41.95 cm (Table 44). The maximum plant height of 41.95 cm was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of

Table 43. Effect of organic nano NPK formulations on gross income, net returns and B:C ratio of the direct test crops of okra

Treatment	First direct test crop (Expt No. I)			Second direct test crop (Expt No. III)		
	Gross income (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio	Gross income (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	278100	111623	1.67	293100	126623	1.76
T_2: FYM (12 t ha^{-1}) + T_1	364200	181976	2.00	381000	198776	2.09
T_3: Soil application of nano NPK (25 kg ha^{-1})	312600	144748	1.86	312900	145048	1.86
T_4: FYM (12 t ha^{-1}) + T_3	336900	153301	1.83	333600	150001	1.82
T_5: Soil application of nano NPK (50 kg ha^{-1})	346200	175598	2.03	359400	188798	2.11
T_6: FYM (12 t ha^{-1}) + T_5	376650	190301	2.02	409200	222851	2.20
T_7: Foliar application of nano NPK (0.2%)	279600	118304	1.73	291000	129704	1.80
T_8: FYM (12 t ha^{-1}) + T_7	318600	143780	1.82	329400	154580	1.88
T_9: Foliar application of nano NPK (0.4%)	332700	170764	2.05	339600	177664	2.10
T_{10}: FYM (12 t ha^{-1}) + T_9	356700	181240	2.03	369000	193540	2.10
T_{11}: T_1 + T_9	365100	194379	2.14	385500	214779	2.25
T_{12}: T_2 + T_9	418200	233955	2.27	419100	234855	2.27
T_{13}: T_3 +T_7	343800	172344	2.01	352800	181344	2.06
T_{14}: T_4 + T_7	369900	184920	2.00	398700	213720	2.16
T_{15}: KAU POP	319800	137051	1.75	317100	134351	1.74
T_{16}: Absolute control	116700	-29323	0.80	106500	-39523	0.73

nano NPK (12 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) for the first residual crop. The second highest plant height was observed in T_8 (38.03 cm) and was on par with T_7 (37.07 cm), T_5 (37.03 cm), T_6 (36.98 cm), T_{13} (36.63 cm) and T_{14} (36.41 cm) whereas, the treatment which did not receive any treatments registered the lowest plant height (17.19 cm).

Residual effect of different nano NPK formulations had significant influence on plant height of second residual crop (Table 44). It ranged from 18.12 cm to 44.07 cm. The highest plant height was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)). Absolute control treatment recorded the lowest plant height.

4.4.1.1.2 Number of branches per plant

The treatment which received foliar application of nano NPK (0.4 %) during the first direct test crop registered the highest number of branches per plant (8.84) in the first residual test crop and was on par with T_2 (8.71) and T_3 (8.28) (Table 44). As in the case of direct test crop the lowest number of branches per plant was registered by T_{16} due to residual effect.

Number of branches per plant were significantly influenced by the treatment combinations (Table 44). With respect to the second residual crop, the highest number of branches per plant (10.74) was recorded in T_9 (Foliar application of nano NPK (0.4 %)) and was on par with T_3 (10.21). The lowest number of branches per plant was recorded by T_{16} in residual crop also..

4.4.1.1.3 Dry matter production

The dry matter production recorded under various treatments is furnished in table 45 and the mean values ranged from 471.8 kg ha^{-1} to 1298 kg ha^{-1}.

Table 44. Residual effect of organic nano NPK formulations on plant height and number of branches per plant of amaranthus

Treatment	First residual test crop (Expt No. II)		Second residual test crop (Expt No. IV)	
	Plant height (cm)	Number of branches per plant	Plant height (cm)	Number of branches per plant
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	25.37	5.85	25.40	3.39
T_2: FYM (12 t ha^{-1}) + T_1	29.71	8.71	29.50	9.61
T_3: Soil application of nano NPK (25 kg ha^{-1})	29.50	8.28	29.37	10.21
T_4: FYM (12 t ha^{-1}) + T_3	30.03	6.43	30.44	7.12
T_5: Soil application of nano NPK (50 kg ha^{-1})	37.03	6.76	37.41	7.05
T_6: FYM (12 t ha^{-1}) + T_5	36.98	7.66	37.24	9.14
T_7: Foliar application of nano NPK (0.2%)	37.07	6.56	37.65	5.95
T_8: FYM (12 t ha^{-1}) + T_7	38.03	7.89	39.29	9.68
T_9: Foliar application of nano NPK (0.4%)	34.98	8.84	36.74	10.74
T_{10}: FYM (12 t ha^{-1}) + T_9	31.03	7.41	32.91	6.41
T_{11}: T_1 + T_9	35.89	6.35	37.81	6.47
T_{12}: T_2 + T_9	41.95	7.86	44.07	9.10
T_{13}: T_3 +T_7	36.63	7.19	39.21	8.06
T_{14}: T_4 + T_7	36.41	7.30	38.67	7.76
T_{15}: KAU POP	20.60	3.26	22.49	5.39
T_{16}: Absolute control	17.19	1.91	18.12	1.96
SEm (±)	0.73	0.12	2.41	0.16
CD (0.05): for any two treatments in the same block	1.63	0.65	2.95	0.75
CD (0.05): for any two treatments in different blocks	1.70	0.68	3.09	0.79

In the first residual test crop, treatment T_{12} recorded dry matter production of 1298 kg ha^{-1} and was found to be significantly superior than all other treatments. The lowest dry matter of 471.8 kg ha^{-1}was recorded in absolute control treatment.

Dry matter production of second residual crop ranged from 443.5 kg ha^{-1} to 1322 kg ha^{-1}. Comparable dry matter production were observed in treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 1322 kg ha^{-1} and treatment, T_{14} with a mean value of 1302 kg ha^{-1}. Dry matter production was the lowest in absolute control treatment (443.5 kg ha^{-1}).

4.4.1.1.4 Yield

The yield recorded at the harvest of both residual crops are presented in table 45. Among different treatments, T_{12} recorded the highest yield of 5724 kg ha^{-1}. The lowest yield (594.5 kg ha^{-1}) was found in absolute control treatment (T_{16}).

Yield of second residual test crop ranged from 1037 kg ha^{-1} to 4693 kg ha^{-1}. Treatment, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded highest yield of 4693 kg ha^{-1} while absolute control resulted lowest yield of 1037 kg ha^{-1}.

4.4.1.2 Quality parameters of fruit

The data on the quality parameters *viz.,* β carotene, vitamin C, oxalate content and nitrate content of amaranthus are presented in table 46. Quality parameters were significantly affected by different treatment combinations in both residual crops.

4.4.1.2.1 β carotene

The β carotene content of plant ranged between 2614 μg 100 g^{-1} to 2974 μg 100 g^{-1} and is presented in table 46.

Table 45. Residual effect of organic nano NPK formulations on dry matter production and yield of amaranthus, kg ha^{-1}

Treatment	First residual test crop (Expt No. II)		Second residual test crop (Expt No. IV)	
	DMP	Yield	DMP	Yield
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	714.4	3227	736.7	2705
T_2: FYM (12 t ha^{-1}) + T_1	985.2	3040	1097	3612
T_3: Soil application of nano NPK (25 kg ha^{-1})	763.8	3653	872.1	2845
T_4: FYM (12 t ha^{-1}) + T_3	1005	2842	1150	3970
T_5: Soil application of nano NPK (50 kg ha^{-1})	795.1	3028	973.5	3275
T_6: FYM (12 t ha^{-1}) + T_5	1056	2970	1218	4127
T_7: Foliar application of nano NPK (0.2%)	649.9	3849	598.7	1160
T_8: FYM (12 t ha^{-1}) + T_7	879.4	3866	880.1	3335
T_9: Foliar application of nano NPK (0.4%)	670.7	3684	718.7	1572
T_{10}: FYM (12 t ha^{-1}) + T_9	701.8	1992	809.3	3385
T_{11}: T_1 + T_9	828.4	4647	1005	4013
T_{12}: T_2 + T_9	1298	5724	1322	4693
T_{13}: T_3 +T_7	1180	3345	1272	3901
T_{14}: T_4 + T_7	1205	5023	1302	4300
T_{15}: KAU POP	753.8	2571	848.3	3206
T_{16}: Absolute control	471.8	594.5	443.5	1037
SEm (±)	65.98	11420	233.1	2370
CD (0.05): for any two treatments in the same block	15.43	203.1	29.00	92.50
CD (0.05): for any two treatments in different blocks	16.16	212.67	30.38	96.88

Among the different treatments, the highest beta carotene content was recorded in T_{15} (KAU POP) - (FYM 12 t ha^{-1} NPK 110:35:70 kg ha^{-1}) during the first residual test crop. All treatments except T_5, T_8, T_{12} and T_{14} were found to be comparable with each other.

With respect to β carotene content of the second residual crop that ranged from 2822 μg 100 g^{-1} to 2898 μg 100 g^{-1}. The highest β carotene was recorded in T_{15} (KAU POP - (FYM 12 t ha^{-1} NPK 110:35:70 kg ha^{-1}) which was on par with T_7 (2895 μg 100 g^{-1}), T_{16} (2894 μg 100 g^{-1}) and T_9 (2888 μg 100 g^{-1}). The lowest β carotene content was recorded in T_{12} (2822 μg 100 g^{-1}).

4.4.1.2.2 Vitamin C

The data in respect of vitamin C recorded in response to various treatments of both residual crops are presented in table 46.

The vitamin C content of first residual crop ranged from 23.61 mg 100 g^{-1} to 55.03 mg 100 g^{-1}. The maximum vitamin c content of 55.03 mg 100 g^{-1} was recorded by T_{12} which received FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) and was on par with T_6, T_{14}, T_5, T_{11}, T_8, T_1, T_9, T_{13} and T_2. The lowest vitamin C content was reported in T_{16} (Absolute control).

Among the treatments, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest vitamin C content of 59.35 mg 100 g^{-1} in the second residual crop and was on par with T_{14} (56.33 mg 100 g^{-1}), T_6 (55.29 mg 100 g^{-1}), T_{11} (49.34 mg 100 g^{-1}) and T_5 (47.86 mg 100 g^{-1}). The lowest vitamin C content was reported in T_{16}.

4.4.1.2.3 Oxalate content

The application of FYM and nano NPK were found to have an influence on oxalate content of the residual plant (Table 46).

The oxalate content ranged from 0.79 per cent to 2.06 per cent. Among different treatments, the treatment that received KAU POP- (FYM 12 t ha^{-1} NPK 110:35:70 kg ha^{-1}) recorded the highest oxalate content whereas the treatment (T_{12}) FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) was noticed with lowest oxalate content of 0.79 per cent during the first residual test crop.

Oxalate content of the second residual crop ranged from 0.79 per cent to 2.06 per cent and is presented in table 46. Highest Oxalate content was observed in T_{15} (KAU POP). Lowest content was in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)).

4.4.1.2.4 Nitrate

The data with respect to nitrate content in amaranthus is presented in table 46.

The nitrate content in amaranthus ranged from 0.23 per cent to 1.69 per cent. Among different treatments, the treatment that received KAU POP (FYM 12 t ha^{-1} NPK 110:35:70 kg ha^{-1}) recorded the maximum nitrate content (1.69 %) in the first residual crop. The lowest nitrate content (0.23 %) was observed in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + foliar application of nano NPK (0.4 %)).

The highest nitrate content was observed in T_{15} (KAU POP) with a mean value of 1.86 per cent and the lowest was in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which recorded a value of 0.22 per cent in the second residual crop.

Table 46. Residual effect of organic nano NPK formulations on β carotene, vitamin C, oxalate and nitrate contents of amaranthus

Treatment	First residual test crop (Expt No. II)				Second residual test crop (Expt No. IV)			
	β carotene (μg $100g^{-1}$)	Vitamin C (mg $100g^{-1}$)	Oxalate content (%)	Nitrate (%)	β carotene (μg $100g^{-1}$)	Vitamin C (mg $100g^{-1}$)	Oxalate content (%)	Nitrate (%)
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	2828	40.14	1.69	0.54	2873	39.53	1.70	0.55
T_2: FYM (12 t ha^{-1}) + T_1	2798	37.41	1.00	0.31	2848	40.08	1.00	0.32
T_3: Soil application of nano NPK (25 kg ha^{-1})	2820	32.26	1.41	0.50	2852	38.38	1.41	0.50
T_4: FYM (12 t ha^{-1}) + T_3	2822	32.19	0.99	0.30	2831	35.45	1.00	0.30
T_5: Soil application of nano NPK (50 kg ha^{-1})	2776	46.83	1.28	0.39	2856	47.86	1.28	0.40
T_6: FYM (12 t ha^{-1}) + T_5	2804	51.56	0.98	0.28	2827	55.29	0.98	0.29
T_7: Foliar application of nano NPK (0.2%)	2897	33.13	1.89	0.63	2895	33.47	1.89	0.64
T_8: FYM (12 t ha^{-1}) + T_7	2785	43.34	1.03	0.26	2849	42.73	1.03	0.26
T_9: Foliar application of nano NPK (0.4%)	2914	38.65	1.79	0.89	2888	37.63	1.79	0.90
T_{10}: FYM (12 t ha^{-1}) + T_9	2893	31.58	1.73	0.31	2851	34.52	1.73	0.32
T_{11}: T_1 + T_9	2858	44.85	1.02	0.33	2866	49.34	1.03	0.33
T_{12}: T_2 + T_9	2614	55.03	0.79	0.23	2822	59.35	0.79	0.22
T_{13}: T_3 +T_7	2851	37.94	0.94	0.28	2854	36.00	0.94	0.28
T_{14}: T_4 + T_7	2680	50.25	0.86	0.25	2823	56.33	0.86	0.26
T_{15}: KAU POP	2974	34.31	2.06	1.69	2898	40.44	2.06	1.86
T_{16}: Absolute control	2858	23.61	1.98	0.94	2894	20.53	1.99	0.94
SEm (±)	9779	87.77	0.002	0.0001	37.88	38.63	0.0001	0.0001
CD (0.05): for any two treatments in the same block	187.9	17.80	0.009	0.007	11.69	11.81	0.006	0.007
CD (0.05): for any two treatments in different blocks	196.8	18.64	0.009	0.007	12.25	12.37	0.007	0.007

4.4.1.3 Post harvest analysis of soil

Initial soil characteristics of residual crops were taken as the final soil analysis value of the field experiment No I and III. Data on soil physical, chemical, biological and biochemical parameters after the residual crop are presented in table 47-51.

4.4.1.3.1 Bulk density

The bulk density of the post harvest soil of residual crop influenced by various treatments ranged from 1.457 Mg m^{-3} to 1.574 Mg m^{-3} presented in table 47. Treatments did not show any significant influence on bulk density of the soil.

After the second residual crop, different treatments did not significantly affect the bulk density and is presented in table 47.

4.4.1.3.2 Water holding capacity

It was noticed from the data that the water holding capacity of the soil was not significantly influenced by the treatments after the first residual crop (Table 47).

As in the case of first residual crop there was no significant difference in water holding capacity (%) due to various treatments after the second residual crop.

4.4.1.3.3 pH and EC

The soil reaction and EC of the both residue crop are presented in table 48.

Among the treatments, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) (5.53) recorded in high pH after the first residual crop and was on par with treatment T_6 that received FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1}). Absolute control treatment resulted in the lowest pH of 4.83.

Table 47. Residual effect of organic nano NPK formulations on physical properties of soil after harvest of amaranthus

Treatment	First residual test crop (Expt No. II)		Second residual test crop (Expt No. IV)	
	Bulk density ($Mg\ m^{-3}$)	Water Holding Capacity (%)	Bulk density ($Mg\ m^{-3}$)	Water Holding Capacity (%)
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	1.509	23.87	1.665	19.70
T_2: FYM (12 t ha^{-1}) + T_1	1.520	22.45	1.666	19.96
T_3: Soil application of nano NPK (25 kg ha^{-1})	1.508	24.05	1.636	18.60
T_4: FYM (12 t ha^{-1}) + T_3	1.457	24.69	1.696	19.75
T_5: Soil application of nano NPK (50 kg ha^{-1})	1.527	23.58	1.631	18.46
T_6: FYM (12 t ha^{-1}) + T_5	1.559	24.54	1.676	19.39
T_7: Foliar application of nano NPK (0.2%)	1.523	26.34	1.602	20.93
T_8: FYM (12 t ha^{-1}) + T_7	1.516	25.51	1.682	20.30
T_9: Foliar application of nano NPK (0.4%)	1.503	23.97	1.570	21.59
T_{10}: FYM (12 t ha^{-1}) + T_9	1.539	23.96	1.650	19.06
T_{11}: T_1 + T_9	1.574	22.45	1.703	18.73
T_{12}: T_2 + T_9	1.491	24.39	1.631	20.07
T_{13}: T_3 +T_7	1.465	28.01	1.595	19.88
T_{14}: T_4 + T_7	1.501	25.16	1.682	19.76
T_{15}: KAU POP	1.494	24.63	1.673	19.29
T_{16}: Absolute control	1.523	24.46	1.588	18.47
SEm (±)				
CD (0.05): for any two treatments in the same block	NS	NS	NS	NS
CD (0.05): for any two treatments in different blocks	NS	NS	NS	NS

There was considerable difference in pH which ranged between 5.21 and 5.86 in the second residual crop. T_{12} ((FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded higher soil pH which was on par with T_6 (5.84), T_3 (5.82), T_2 (5.81) and T_9 (5.81).The lowest was noted in absolute control treatment.

T_1 (soil application of nano NPK (12.5 kg ha^{-1})) registered the highest EC after the first residual crop with a mean value of 0.224 dS m^{-1} and was significantly superior than all other treatments. T_{16} (Absolute control) recorded the lowest EC (0.149 dS m^{-1}).

Electrical conductivity of second residual crop was significantly affected by different treatment and is given in table 48. It ranged between 0.075 dS m^{-1} and 0.164 dS m^{-1}. Highest EC was recorded in T_1 (Soil application of nano NPK (12.5 kg ha^{-1})) and the lowest in absolute control treatment.

4.4.1.3.4 Organic carbon and labile carbon

The organic carbon and labile carbon status of the post harvest soil of the both residual crops were influenced by different treatments and is presented in table 48.

Among different treatments, T_{12} which received FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) recorded the highest organic carbon content (1.35 %) which was equally benefitted with T_4 with a mean value of 1.29 per cent. The lowest organic carbon was recorded by absolute control treatment (0.74 %).

With respect to the second residual crop, organic carbon content ranged from 0.97 per cent to 1.71 per cent which was significantly affected by various treatment. T_{12} ((FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application

Table 48. Residual effect of organic nano NPK formulations on physico-chemical properties and carbon content of the post harvest soil of experiments II and IV

Treatment	First residual test crop (Expt No. II)				Second residual test crop (Expt No. IV)			
	pH	EC (dS m^{-1})	Organic carbon (%)	Labile carbon (mg kg^{-1})	pH	EC (dS m^{-1})	Organic carbon (%)	Labile carbon (mg kg^{-1})
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	5.16	0.224	1.16	601.4	5.57	0.164	1.11	774.0
T_2: FYM (12 t ha^{-1}) + T_1	5.23	0.188	1.07	624.2	5.81	0.115	1.36	798.4
T_3: Soil application of nano NPK (25 kg ha^{-1})	5.40	0.187	1.09	676.9	5.82	0.110	1.18	823.2
T_4: FYM (12 t ha^{-1}) + T_3	5.28	0.180	1.29	700.5	5.77	0.104	1.55	856.8
T_5: Soil application of nano NPK (50 kg ha^{-1})	5.44	0.154	1.07	603.5	5.56	0.084	1.29	808.9
T_6: FYM (12 t ha^{-1}) + T_5	5.48	0.172	1.16	771.5	5.84	0.100	1.47	873.7
T_7: Foliar application of nano NPK (0.2%)	5.15	0.137	1.16	654.8	5.38	0.083	1.08	656.4
T_8: FYM (12 t ha^{-1}) + T_7	5.17	0.158	1.15	685.1	5.42	0.087	1.54	826.8
T_9: Foliar application of nano NPK (0.4%)	5.42	0.170	1.28	618.3	5.81	0.099	1.50	675.7
T_{10}: FYM (12 t ha^{-1}) + T_9	5.37	0.177	1.11	686.8	5.73	0.102	1.26	853.2
T_{11}: T_1 + T_9	5.30	0.164	1.24	818.6	5.71	0.097	1.25	917.4
T_{12}: T_2 + T_9	5.53	0.157	1.35	855.1	5.86	0.084	1.71	988.4
T_{13}: T_3 +T_7	5.39	0.182	1.16	708.8	5.75	0.107	1.35	856.8
T_{14}: T_4 + T_7	5.39	0.162	1.01	780.9	5.76	0.089	1.37	892.8
T_{15}: KAU POP	5.09	0.207	0.88	656.8	5.39	0.124	1.04	771.4
T_{16}: Absolute control	4.83	0.149	0.74	567.1	5.21	0.075	0.97	605.4
SEm (±)	0.002	0.0001	0.001	86.64	0.001	0.009	0.002	59.25
CD (0.05): for any two treatments in the same block	0.075	0.001	0.07	17.69	0.07	0.005	0.08	14.62
CD (0.05): for any two treatments in different blocks	0.080	0.001	0.07	18.52	0.08	0.006	0.09	15.32

of nano NPK (0.4 %)) recorded the highest percentage organic carbon. The lowest organic carbon was registered by absolute control treatment.

The labile carbon content of post harvest soil of first residual crop ranged between 567.1 mg kg^{-1} to 855.1 mg kg^{-1}. The labile carbon content was found to be highest in treatment T_{12} which received FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %). The lowest mean value was noticed in T_{16}.

Different treatments significantly affected labile carbon of the second residual crop which ranged from 605.4 mg kg^{-1} to 988.4 mg kg^{-1}. T_{12} ((FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest labile carbon and the lowest in absolute control treatment.

4.4.1.3.5 Available Nitrogen

The post harvest available N status of the soil as influenced by various treatments is furnished in table 49. The available N content was found to range from 124.4 kg ha^{-1} to 179.8 kg ha^{-1}.

Among the different treatments, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded maximum available N status (179.8 kg ha^{-1}) after the first residual crop and the lowest was registered with absolute control treatment (124.4 kg ha^{-1}). T_{12} was on par with T_6 (175.1 kg ha^{-1}), T_{14} (168.3 kg ha^{-1}), T_4 (166.8 kg ha^{-1}) and T_8 (159.4 kg ha^{-1}).

With respect to the post harvest analysis of second residual crop, available nitrogen was significantly influenced by the treatment and is presented in table 49. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest nitrogen (208.5 kg ha^{-1}) and was on par with T_6 (202.3 kg ha^{-1}), T_4 (198.1 kg ha^{-1}), T_{14} (190.3 kg ha^{-1}) and T_{13} (184.0 kg ha^{-1}).

Absolute control treatment recorded available nitrogen of 98.83 kg ha^{-1} and was found to be the lowest.

4.4.1.3.6 Available Phosphorous

The analytical results of the post harvest soil available P status in both residual test crops are presented in table 49.

The available P status of post harvest soil ranged from 63.01 kg ha^{-1} to 88.90 kg ha^{-1}. The plot applied with FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) during the experiment No 1 were found to record higher phosphorus content even after the harvest of residual crop. The lowest available P was registered in plot that received no input (63.01 kg ha^{-1}).

Treatment combinations had significant influence on available phosphorus and the highest was recorded in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 83.22 kg ha^{-1} which was comparable with T_{14} (82.18 kg ha^{-1}). The lowest available phosphorous was recorded by absolute control (35.23 kg ha^{-1}).

4.4.1.3.7 Available Potassium

The available K status of post harvest soil of first residual crop ranged from 79.80 to 170.3 kg ha^{-1} (Table 49).

The treatment (T_{12}) with FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) recorded the highest available K (170.3 kg ha^{-1}) and was significantly superior than other treatments after first residual crop. The absolute control treatment registered the lowest available K status.

Significant difference were observed on available potassium in the case of post harvest soil analysis of second residual crop. T_{12} (FYM (12 t ha^{-1}) + Soil application of

Table 49. Residual effect of organic nano NPK formulations on available N, P and K status of the post harvest soil, kg ha^{-1}

Treatment	First residual test crop (Expt No. II)			Second residual test crop (Expt No. IV)		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	146.3	73.57	117.1	161.5	54.71	109.2
T_2: FYM (12 t ha^{-1}) + T_1	154.7	84.33	123.2	181.4	61.62	119.9
T_3: Soil application of nano NPK (25 kg ha^{-1})	145.3	77.88	142.3	160.5	67.21	134.4
T_4: FYM (12 t ha^{-1}) + T_3	166.8	84.52	126.0	198.1	74.37	124.1
T_5: Soil application of nano NPK (50 kg ha^{-1})	152.6	78.72	128.8	178.7	51.78	128.3
T_6: FYM (12 t ha^{-1}) + T_5	175.1	86.11	133.5	202.3	79.75	141.9
T_7: Foliar application of nano NPK (0.2%)	144.8	72.86	113.9	135.4	51.82	107.8
T_8: FYM (12 t ha^{-1}) + T_7	159.4	86.08	104.5	147.5	62.12	104.1
T_9: Foliar application of nano NPK (0.4%)	149.5	72.67	133.5	134.8	63.28	130.7
T_{10}: FYM (12 t ha^{-1}) + T_9	151.0	80.69	147.9	154.2	62.00	140.5
T_{11}: T_1 + T_9	151.6	82.26	124.1	166.2	56.64	120.4
T_{12}: T_2 + T_9	179.8	88.90	170.3	208.5	83.22	163.3
T_{13}: T_3 +T_7	156.80	86.62	112.5	184.0	60.07	108.3
T_{14}: T_4 + T_7	168.3	87.54	137.7	190.3	82.18	135.8
T_{15}: KAU POP	144.8	76.40	128.3	140.6	47.00	125.1
T_{16}: Absolute control	124.4	63.01	79.80	98.83	35.23	73.73
SEm (±)	117.5	0.23	85.62	190.0	0.70	36.46
CD (0.05): for any two treatments in the same block	20.59	0.91	17.58	26.18	1.59	11.47
CD (0.05): for any two treatments in different blocks	21.57	0.95	18.41	27.42	1.66	12.02

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nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) showed the highest available potassium (163.3 kg ha^{-1}). Absolute control treatment recorded potassium status of 73.73 kg ha^{-1} which was the lowest among the treatments.

4.4.1.3.8 Exchangeable Calcium

Perusal of data revealed that the residual effect of the treatments had a significant effect on the exchangeable calcium content of the post harvest soil (Table 50). The treatment (T_{12}) with FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) recorded the maximum exchangeable calcium status of 369.6 mg kg^{-1} and was on par with T_3, T_{14}, T_6, T_7, T_1, T_4, T_2, T_5, T_{15}, T_{11}, T_9 and T_{10} after the first residual test crop. The lowest exchangeable Ca was recorded in T_{16} with a mean value of 227.5 mg kg^{-1}.

Residual effect showed significant difference on exchangeable calcium after the second residual test crop (Table 50). Highest calcium (374.6 mg kg^{-1}) was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) which was comparable with T_6 (356.3 mg kg^{-1}), T_8 (354.2 mg kg^{-1}), T_2 (350.4 mg kg^{-1}), T_4 (347.5 mg kg^{-1}) and T_{13} (340.0 mg kg^{-1}). Absolute control recorded the lowest mean value of 239.2 mg kg^{-1}.

4.4.1.3.9 Exchangeable Magnesium

The results revealed that residual effect of treatments had significant effect on the exchangeable magnesium status of the soil (Table 50). Among different treatments the plot that received FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) was recorded the highest exchangeable magnesium and was found to be on par with all the other treatments except T_8 and T_{16} in case of first residual test crop.

Treatments had significant influence on exchangeable magnesium in soil after the second residual test crop (Table 50). T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest exchangeable magnesium of 98.25 mg kg^{-1} which was on par with T_6 (97.25 mg kg^{-1}), T_{14} (89.75 mg kg^{-1}), T_4 (85.00 mg kg^{-1}) and T_2 (85.00 mg kg^{-1}). The lowest mean value of 33.25 mg kg^{-1} was observed in absolute control treatment.

4.4.1.3.10 Available Sulphur

The analytical results of available sulphur in the post harvest soil of both residual test crops are presented in table 50.

The treatment (T_4) which received FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) registered the highest sulphur content of 20.05 mg kg^{-1} after the first residual crop. The lowest available S (3.75 mg kg^{-1}) was registered in T_{16} (Absolute control).

Sulphur was significantly affected by various treatments. T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})) recorded maximum sulphur status of 18.92 mg kg^{-1}. Absolute control showed a lowest value (2.65 mg kg^{-1}).

4.4.1.3.11 Available Iron

Perusal of data revealed that application of organic nano NPK formulations showed a significant influence on the available Fe of the residual crop after the harvest of the crop and is presented in table 51. Treatment, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest available Fe content (25.16 mg kg^{-1}) and was significantly superior to all other treatments. The lowest available Fe content registered in T_{16} (14.79 mg kg^{-1}).

Table 50. Residual effect of organic nano NPK formulations on soil available secondary nutrients of post harvest soil, mg kg^{-1}

Treatment	First residual test crop (Expt No. II)			Second residual test crop (Expt No. IV)		
	Calcium	Magnesium	Sulphur	Calcium	Magnesium	Sulphur
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	334.6	58.50	8.44	320.8	69.50	3.52
T_2: FYM (12 t ha^{-1}) + T_1	328.3	54.50	11.65	350.4	85.00	8.44
T_3: Soil application of nano NPK (25 kg ha^{-1})	348.8	52.75	12.52	331.7	76.75	8.46
T_4: FYM (12 t ha^{-1}) + T_3	333.3	60.88	20.05	347.5	85.00	18.92
T_5: Soil application of nano NPK (50 kg ha^{-1})	327.1	54.13	10.22	337.5	71.75	7.98
T_6: FYM (12 t ha^{-1}) + T_5	343.3	53.13	8.27	356.3	97.25	6.19
T_7: Foliar application of nano NPK (0.2%)	340.0	58.13	8.49	272.5	41.50	4.52
T_8: FYM (12 t ha^{-1}) + T_7	280.8	44.75	8.44	354.2	54.75	3.65
T_9: Foliar application of nano NPK (0.4%)	314.2	49.00	6.83	267.1	45.25	3.35
T_{10}: FYM (12 t ha^{-1}) + T_9	310.0	52.13	13.32	284.2	59.25	11.54
T_{11}: T_1 + T_9	315.0	60.63	10.04	329.6	68.50	7.88
T_{12}: T_2 + T_9	369.6	63.38	14.77	374.6	98.25	16.56
T_{13}: T_3 +T_7	290.4	58.13	13.80	340.0	72.75	12.42
T_{14}: T_4 + T_7	344.6	62.38	9.76	339.6	89.75	7.10
T_{15}: KAU POP	322.5	47.63	6.33	311.7	45.50	3.67
T_{16}: Absolute control	227.5	33.00	3.75	239.2	33.25	2.65
SEm (±)	1234	63.97	0.60	304.1	109.32	1.15
CD (0.05): for any two treatments in the same block	66.75	15.20	1.46	33.13	19.86	2.03
CD (0.05): for any two treatments in different blocks	69.91	15.92	1.53	34.70	20.81	2.13

With respect to the second residual crop, treatment combinations had significant influence on iron availability in soil (Table 51). Highest mean value of 25.23 mg kg^{-1} was observed in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) while absolute control recorded the lowest available Fe status with a mean value of 16.05 mg kg^{-1}.

4.4.1.3.12 Available Manganese

It is inferred from the table 51 that mean value of available Mn status in post harvest soil of first residual crop ranged from 13.29 mg kg^{-1} to 21.27 mg kg^{-1} (Table 51). T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})) recorded the highest available Mn content and was significantly superior than all other treatments. The lowest mean value was noticed in T_{16}.

In the case of second residual test crop, the treatment, T_4 (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1})) showed the highest manganese status of 21.15 mg kg^{-1} while the lowest (13.12 mg kg^{-1}) was observed in T_{15} (KAU POP-FYM 12 t ha^{-1} NPK 110:35:70 kg ha^{-1}).

4.4.1.3.13 Available Zinc

Table 51 showed that available Zn in the soil was found to be significantly influenced by the treatments after residual test crops. The highest mean value of 6.90 mg kg^{-1} was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was found to be significantly superior than all other treatments. The lowest mean value of 3.35 mg kg^{-1} was registered in T_{16} (Absolute control).

Available zinc content in soil was significantly influenced by various treatment combinations after the second residual test crop and is presented in table 51. Highest mean value of 6.94 mg kg^{-1} was observed in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was significantly superior to all other treatments, while the lowest mean value of 3.32 mg kg^{-1} was registered in absolute control treatment.

4.4.1.3.14 Available Copper

The analytical results of available Cu status is presented in table 51. The mean value of available Cu after the first residual crop ranged between 1.31 mg kg^{-1} to 2.89 mg kg^{-1}. The highest available Cu content in the soil was observed in T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)). T_{16} (Absolute control) registered the lowest mean value of 1.31 mg kg^{-1} and was significantly inferior to all other treatments.

Maximum available copper of the second residual crop with a mean value of 2.93 mg kg^{-1} was recorded in T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and the lowest mean value was recorded in absolute control treatment (1.27 mg kg^{-1}).

4.4.1.3.15 Dehydrogenase activity

The effect of different treatments on the dehydrogenase activity in the post harvest soil of residual test crop is presented in table 52a. The highest dehydrogenase activity in soil was obtained in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 16.50 µg of TPF g^{-1} soil 24 h^{-1} and was superior than all the other treatments. The lowest dehydrogenase activity was noticed in absolute control treatment (T_{16}) with a mean value of 5.01 µg of TPF g^{-1} soil 24 h^{-1}.

T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest dehydrogenase activity (12.19 µg of TPF g^{-1} soil 24 h^{-1}) after the second residual crop and was comparable with T_{14}

Table 51. Residual effect of organic nano NPK formulations on available Fe, Mn, Zn and Cu of the post harvest soil, mg kg^{-1}

Treatment	First residual test crop (Expt No. II)				Second residual test crop (Expt No. IV)			
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	16.08	19.92	4.69	1.72	16.89	19.92	4.74	1.73
T_2: FYM (12 t ha^{-1}) + T_1	19.78	19.54	5.84	2.06	19.75	15.29	5.81	2.08
T_3: Soil application of nano NPK (25 kg ha^{-1})	17.51	15.12	4.77	1.76	17.55	15.31	4.76	1.74
T_4: FYM (12 t ha^{-1}) + T_3	20.12	21.27	6.17	2.38	20.13	21.15	6.14	2.33
T_5: Soil application of nano NPK (50 kg ha^{-1})	17.64	19.75	4.84	1.90	17.65	19.75	4.85	1.85
T_6: FYM (12 t ha^{-1}) + T_5	20.59	19.19	6.41	2.60	20.56	19.19	6.39	2.10
T_7: Foliar application of nano NPK (0.2%)	16.96	19.16	3.78	1.45	14.82	19.16	3.81	1.45
T_8: FYM (12 t ha^{-1}) + T_7	18.46	19.09	5.51	1.82	18.44	19.09	5.50	1.88
T_9: Foliar application of nano NPK (0.4%)	15.19	20.25	4.57	1.58	15.21	20.25	4.54	1.54
T_{10}: FYM (12 t ha^{-1}) + T_9	19.58	18.69	6.31	2.05	19.55	18.69	6.32	2.02
T_{11}: T_1 + T_9	20.18	21.01	4.59	2.20	20.19	21.01	4.58	2.23
T_{12}: T_2 + T_9	25.16	18.21	6.90	2.74	25.23	18.21	6.94	2.74
T_{13}: T_3 +T_7	20.38	20.58	6.37	2.38	20.45	20.58	6.40	2.36
T_{14}: T_4 + T_7	23.45	20.27	6.63	2.89	23.34	20.27	6.64	2.93
T_{15}: KAU POP	18.14	15.31	5.03	2.02	18.11	13.12	5.02	2.02
T_{16}: Absolute control	14.79	13.29	3.35	1.31	16.05	19.54	3.32	1.27
SEm (±)	0.004	0.007	0.004	0.002	0.004	0.007	0.004	0.002
CD (0.05): for any two treatments in the same block	0.12	0.15	0.12	0.09	0.12	0.15	0.12	0.09
CD (0.05): for any two treatments in different blocks	0.13	0.16	0.13	0.097	0.13	0.16	0.13	0.10

(11.37 μg of TPF g^{-1} soil 24 h^{-1}) and T_4 (11.37 μg of TPF g^{-1} soil 24 h^{-1}). Absolute control recorded the lowest dehydrogenase activity (3.59 μg of TPF g^{-1} soil 24 h^{-1}).

4.4.1.3.16 Urease Activity

Perusal of data presented in table 52a revealed that different treatments significantly influenced the urease activity of the residual crops. The mean values of various treatments on urease activity in the post harvest soil ranged from 5.74 ppm urea g^{-1} soil h^{-1} to 14.76 ppm urea g^{-1} soil h^{-1}. Among the treatments, the highest urease activity was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 14.76 ppm urea g^{-1} soil h^{-1}. The second highest urease activity was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was on par with T_6, T_8, T_{13}, T_4 and T_2. The treatment, T_{16} had the lowest mean value of 5.74 ppm urea g^{-1} soil h^{-1} among various treatments.

After the second residual crop, T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded maximum urease activity of 15.16 ppm urea g^{-1} soil h^{-1} and was on par with T_6 (14.78 ppm urea g^{-1} soil h^{-1}), T_{14} (14.75 ppm urea g^{-1} soil h^{-1}), T_{13} (14.41 ppm urea g^{-1} soil h^{-1}), T_2 (14.36 ppm urea g^{-1} soil h^{-1}) and T_4 (14.34 ppm urea g^{-1} soil h^{-1}) while absolute control treatment recorded the lowest activity of 5.77 ppm urea g^{-1} soil h^{-1}.

4.4.1.3.17 Acid phosphatase

Acid phosphatase activity of the soil varied significantly with different treatments with respect to both the residual test crops (Table 52b). The mean values ranged from 4.07 μg of p-nitrophenol g^{-1}soil h^{-1} to 11.31 μg of p-nitrophenol g^{-1} soil h^{-1} of various treatments on the acid phosphatase activity after the first residual crop. Highest acid phosphatase activity was noticed in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and

Table 52 a. Residual effect of organic nano NPK formulations on soil dehydrogenase and urease activity

Treatment	First residual test crop (Expt No. II)		Second residual test crop (Expt No. IV)	
	Dehydrogenase (µg of TPF g^{-1} soil 24 h^{-1})	Urease (ppm urea g^{-1} soil h^{-1})	Dehydrogenase (µg of TPF g^{-1} soil 24 h^{-1})	Urease (ppm urea g^{-1} soil h^{-1})
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	12.08	8.86	8.19	13.72
T_2: FYM (12 t ha^{-1}) + T_1	11.96	10.45	9.29	14.36
T_3: Soil application of nano NPK (25 kg ha^{-1})	10.51	9.52	8.48	13.39
T_4: FYM (12 t ha^{-1}) + T_3	13.53	10.56	11.37	14.34
T_5: Soil application of nano NPK (50 kg ha^{-1})	9.83	9.71	8.57	14.01
T_6: FYM (12 t ha^{-1}) + T_5	12.58	11.18	9.53	14.78
T_7: Foliar application of nano NPK (0.2%)	7.19	7.00	4.05	7.59
T_8: FYM (12 t ha^{-1}) + T_7	6.68	10.86	4.99	10.78
T_9: Foliar application of nano NPK (0.4%)	9.19	8.30	3.82	9.15
T_{10}: FYM (12 t ha^{-1}) + T_9	6.53	8.64	5.29	13.08
T_{11}: T_1 + T_9	11.36	9.74	8.49	13.84
T_{12}: T_2 + T_9	16.50	14.76	12.19	15.16
T_{13}: T_3 +T_7	8.88	10.83	8.63	14.41
T_{14}: T_4 + T_7	12.73	11.77	11.37	14.75
T_{15}: KAU POP	5.34	8.50	4.54	12.47
T_{16}: Absolute control	5.01	5.74	3.59	5.77
SEm (±)	1.33	0.64	0.20	0.22
CD (0.05): for any two treatments in the same block	2.19	1.52	0.84	0.88
CD (0.05): for any two treatments in different blocks	2.29	1.59	0.88	0.92

was significantly superior than all other treatments. The lowest acid phosphatase activity on the soil was registered by T_{16} (Absolute control).

Acid phosphatase activity of the soil varied significantly with different treatments with respect to the second residual crop and ranged from 8.75 μg of p-nitrophenol g^{-1}soil h^{-1} to 16.56 μg of p-nitrophenol g^{-1}soil h^{-1} (Table 52b). Highest value was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was comparable with T_1 (16.46 μg of p-nitrophenol g^{-1}soil h^{-1}). The lowest acid phosphatase activity was recorded by T_{16}.

4.4.1.3.18 Alkaline phosphatase

By observing the alkaline phosphatase activity from the table 52b revealed that the alkaline phosphatase activity showed significant influence among the treatments of the both residual crop. The highest mean value of 4.44 μg of p - nitrophenol g^{-1} soil h^{-1} was registered by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was comparable with T_{12} (3.58 μg of p - nitrophenol g^{-1}soil h^{-1}), T_6 (3.46 μg of p - nitrophenol g^{-1}soil h^{-1}), T_{13} (3.42 μg of p - nitrophenol g^{-1}soil h^{-1}) and T_{11} (3.41 μg of p - nitrophenol g^{-1} soil h^{-1}). The lowest mean value (1.09 μg of p - nitrophenol g^{-1}soil h^{-1}) was noticed in T_{16} (Absolute control).

The alkaline phosphatase activity of second residual crop, from the table 52b revealed that alkaline phosphatase activity showed significant influence among the treatments of the second residual crop. T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) recorded maximum alkaline phosphatase with a mean value of 6.14 μg of p-nitrophenol g^{-1}soil h^{-1}. The lowest alkaline phosphatase activity was registered by T_3 with a mean value of 3.07 μg of p-nitrophenol g^{-1}soil h^{-1}.

Table 52 b. Residual effect of organic nano NPK formulations on soil acid and alkaline phosphatase

Treatment	First residual test crop (Expt No. II)		Second residual test crop (Expt No. IV)	
	Acid phosphatase (μg of p-nitrophenol g^{-1} soil h^{-1})	Alkaline phosphatase (μg of p-nitrophenol g^{-1}soil h^{-1})	Acid phosphatase (μg of p-nitrophenol g^{-1} soil h^{-1})	Alkaline phosphatase (μg of p-nitrophenol g^{-1}soil h^{-1})
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	10.23	2.17	16.46	3.30
T_2: FYM (12 t ha^{-1}) + T_1	7.23	1.84	13.60	4.05
T_3: Soil application of nano NPK (25 kg ha^{-1})	8.13	1.82	13.08	3.07
T_4: FYM (12 t ha^{-1}) + T_3	9.66	1.53	14.48	4.18
T_5: Soil application of nano NPK (50 kg ha^{-1})	7.32	1.70	13.48	3.73
T_6: FYM (12 t ha^{-1}) + T_5	10.18	3.46	14.99	4.22
T_7: Foliar application of nano NPK (0.2%)	6.95	3.24	10.48	4.86
T_8: FYM (12 t ha^{-1}) + T_7	8.34	2.1	11.77	4.15
T_9: Foliar application of nano NPK (0.4%)	6.77	2.79	11.54	4.87
T_{10}: FYM (12 t ha^{-1}) + T_9	6.96	2.89	13.11	4.53
T_{11}: T_1 + T_9	9.80	3.41	13.87	5.14
T_{12}: T_2 + T_9	11.31	3.58	16.56	5.25
T_{13}: T_3 +T_7	6.29	3.42	14.25	4.61
T_{14}: T_4 + T_7	7.74	4.44	14.86	6.14
T_{15}: KAU POP	4.72	3.27	10.35	3.79
T_{16}: Absolute control	4.07	1.09	8.75	4.79
SEm (±)	0.21	0.32	0.07	0.16
CD (0.05): for any two treatments in the same block	0.87	1.07	0.50	0.76
CD (0.05): for any two treatments in different blocks	0.91	1.13	0.52	0.79

4.4.1.3.19 Bacteria

Residual effect of organic nano NPK formulations showed the significant influence on the soil microbial population and is presented in table 53. The mean values of the bacterial count of the post harvest soil of the first residual test crop ranged from 5.92 log cfu g^{-1} soil to 7.05 log cfu g^{-1} soil. T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) recorded the highest bacterial count and was on par with T_6 (6.96 log cfu g^{-1} soil). The lowest bacterial count was recorded by T_{16} (Absolute control).

After the second residual test crop, bacteria varied among treatments with a range of 6.39 log cfu g^{-1} soil to 7.36 log cfu g^{-1} soil. The bacterial count recorded higher in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) and was found to be on par with T_6 (7.35 log cfu g^{-1} soil), T_{14} (7.20 log cfu g^{-1} soil) and T_{13} (7.19 log cfu g^{-1} soil) after the second residual test crop. The lowest bacteria count was found in the absolute control treatment.

4.4.1.3.20 Fungi

From the analytical data presented in table 53 inferred that different treatments showed significant effect on the fungal population of first residual test crop with mean values ranged from 3.51 log cfu g^{-1} soil to 4.17 log cfu g^{-1} soil. The highest mean value was recorded by T_6 (FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1})) which was on par with T_{12} (4.12 log cfu g^{-1} soil), T_2 (4.08 log cfu g^{-1} soil), T_{14} (4.07 log cfu g^{-1} soil) and T_{13} (4.06 log cfu g^{-1} soil). T_{16} recorded the lowest fungal population.

During the confirmatory residual crop, fungal counts varied from 3.73 log cfu g^{-1} soil to 4.30 log cfu g^{-1} soil. The highest fungi activity was noted in T_6 (FYM (12 t ha^{-1}) + soil application of nano NPK (50 kg ha^{-1})) which was on par with T_{12} (4.29 log cfu g^{-1} soil), T_{14} (4.16 log cfu g^{-1} soil), T_2 (4.14 log cfu g^{-1} soil), and

T_{13} (4.11 log cfu g^{-1} soil). The lowest Fungal count was found in T_{16} (Absolute control) with a mean value of 3.73 log cfu g^{-1} soil.

4.4.1.3.21 Actinomycetes

A perusal of data (Table 53) reported that different treatments have significant effect on actinomycetes count in the soil after both the residual test crops. The highest actinomycetes count of 4.22 log cfu g^{-1} soil was recorded by T_6 (FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1})) and was on par with T_{12} (4.19 log cfu g^{-1} soil), T_{14} (4.12 log cfu g^{-1} soil) and T_{11} (4.07 log cfu g^{-1} soil). T_{16} (Absolute control) recorded the lowest actinomycetes count of 3.56 log cfu g^{-1} soil.

Among 16 treatments, T_6 (FYM (12 t ha^{-1}) + Soil application of nano NPK (50 kg ha^{-1})) exhibited high actinomycetes count of 4.39 log cfu g^{-1} soil which was significantly superior than all other treatments after the second residual test crop. The lowest value of 3.58 log cfu g^{-1} soil was found in T_{16} (Absolute control).

4.4.1.4 Plant uptake

All the treatments imposed significantly influenced nutrient uptake by residual test crop, amaranthus. The results are presented in table 54-56.

4.4.1.4.1 Nitrogen uptake

The residual effect due to the application of organic nano NPK formulations to the direct test crop (okra) significantly influenced the uptake of nitrogen by the residual test crop (amaranthus) and the results are presented in table 54.

The mean value of nitrogen uptake by the first residual test crop ranged from 14.61 kg ha^{-1} to 67.56 kg ha^{-1}. The highest N uptake by plant was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano

Table 53. Residual effect of organic nano NPK formulations on microbial population of post harvest soil, log cfu g^{-1} soil

Treatment	First residual test crop (Expt No. II)			Second residual test crop (Expt No. IV)		
	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	6.44	3.68	3.98	6.87	3.89	4.04
T_2: FYM (12 t ha^{-1}) + T_1	6.62	4.08	3.95	6.89	4.14	4.00
T_3: Soil application of nano NPK (25 kg ha^{-1})	6.46	3.90	4.03	6.87	4.00	4.14
T_4: FYM (12 t ha^{-1}) + T_3	6.77	3.91	4.00	7.11	4.00	4.06
T_5: Soil application of nano NPK (50 kg ha^{-1})	6.42	3.76	3.84	6.75	3.91	3.73
T_6: FYM (12 t ha^{-1}) + T_5	6.96	4.17	4.22	7.35	4.30	4.39
T_7: Foliar application of nano NPK (0.2%)	6.12	3.61	3.92	6.62	3.84	4.00
T_8: FYM (12 t ha^{-1}) + T_7	6.63	3.99	3.97	7.09	4.08	4.02
T_9: Foliar application of nano NPK (0.4%)	6.14	3.60	3.92	6.73	3.86	3.80
T_{10}: FYM (12 t ha^{-1}) + T_9	6.78	3.80	4.00	7.14	3.94	4.11
T_{11}: T_1 + T_9	6.32	3.96	4.07	6.71	4.04	4.15
T_{12}: T_2 + T_9	7.05	4.12	4.19	7.36	4.29	4.26
T_{13}: T_3 +T_7	6.80	4.06	3.92	7.19	4.11	3.96
T_{14}: T_4 + T_7	6.87	4.07	4.12	7.20	4.16	4.24
T_{15}: KAU POP	6.35	3.98	4.00	6.42	4.04	4.07
T_{16}: Absolute control	5.92	3.51	3.56	6.39	3.73	3.58
SEm (±)	0.007	0.005	0.006	0.010	0.012	0.001
CD (0.05): for any two treatments in the same block	0.16	0.14	0.15	0.19	0.21	0.06
CD (0.05): for any two treatments in different blocks	0.17	0.14	0.15	0.20	0.22	0.07

NPK (0.2 %)) and was significantly superior than all other treatments. The lowest mean value of 14.61 kg ha^{-1} was observed in T_{16} (Absolute control).

In the case of second residual test crop the mean values of nitrogen uptake by plant ranged from 9.51 kg ha^{-1} to 52.58 kg ha^{-1}. The highest N uptake by plant was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was comparable with T_{12} (51.53 kg ha^{-1}). The lowest value of 9.51 kg ha^{-1} was observed in T_{16} (Absolute control).

4.4.1.4.2 Phosphorous uptake

Table 54 showed the residual effect of organic nano NPK formulations applied to the direct test crop (okra). The treatment effects significantly influenced the phosphorus uptake by the residual test crop (amaranthus).

The maximum P uptake by first residual crop, amaranthus was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with a mean value of 8.93 kg ha^{-1} and was on par with T_{12} (8.53 kg ha^{-1}). The lowest P uptake was registered in the absolute control treatment.

The maximum P uptake by the second residual crop was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with a mean value of 12.22 kg ha^{-1} and was significantly superior to all other treatments. The absolute control treatment recorded the lowest P uptake with a mean value of 1.85 kg ha^{-1}.

4.4.1.4.3 Potassium uptake

Potassium uptake by residual amaranthus crop as influenced by different treatments is presented in table 54. All the treatments imposed significantly influenced the K uptake by the first residual crop. The highest K uptake value (53.26 kg ha^{-1}) was observed by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was comparable with T_{13} (52.13 kg ha^{-1}), T_{12} (51.41 kg ha^{-1}) and T_4 (45.98 kg ha^{-1}). The absolute control treatment (T_{16}) recorded the lowest K uptake (19.60 kg ha^{-1}).

All the treatments imposed significantly influenced the K uptake by the second residual amaranthus also and is presented in table 54. Highest K uptake of 73.93 kg ha^{-1} was observed by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was not significantly different from T_{12} (73.20 kg ha^{-1}). The absolute control treatment (T_{16}) recorded the lowest K uptake of 13.28 kg ha^{-1} by the second residual crop (amaranthus).

4.4.1.4.4 Calcium uptake

Significant variation in calcium uptake between the treatments are recorded in table 55. In the case of first residual crop, T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) observed the highest value of 26.11 kg ha^{-1} and was on par with T_{12} (25.16 kg ha^{-1}), T_{13} (22.66 kg ha^{-1}) and T_6 (20.77 kg ha^{-1}). Absolute control (T_{16}) registered the lowest mean value of 5.42 kg ha^{-1}.

From the result it was revealed that T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) recorded the highest calcium uptake (29.07 kg ha^{-1}) by the second residual crop and was significantly superior than all other treatments. Absolute control treatment (T_{16}) observed the lowest value of 5.48 kg ha^{-1}.

4.4.1.4.5 Magnesium uptake

The analytical results of data on Mg uptake of both residual crop are presented in table 55. From the result it was revealed that T_{14} (FYM (12 t ha^{-1}) + Soil application

Table 54. Residual effect of organic nano NPK formulations on N, P and K uptake by amaranthus, kg ha^{-1}

Treatment	First residual test crop (Expt No. II)			Second residual test crop (Expt No. IV)		
	Nitrogen	Phosphorous	Potassium	Nitrogen	Phosphorous	Potassium
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	31.86	4.11	28.65	19.68	5.03	31.43
T_2: FYM (12 t ha^{-1}) + T_1	40.32	5.39	40.49	34.05	8.80	52.04
T_3: Soil application of nano NPK (25 kg ha^{-1})	34.33	4.30	34.77	25.28	6.32	38.22
T_4: FYM (12 t ha^{-1}) + T_3	40.95	6.07	45.98	36.42	9.20	56.16
T_5: Soil application of nano NPK (50 kg ha^{-1})	42.82	6.08	29.18	29.97	7.00	45.50
T_6: FYM (12 t ha^{-1}) + T_5	37.83	7.64	42.14	41.14	10.39	61.58
T_7: Foliar application of nano NPK (0.2%)	27.05	3.73	22.51	12.06	3.01	17.98
T_8: FYM (12 t ha^{-1}) + T_7	31.73	5.43	32.64	30.76	6.10	36.09
T_9: Foliar application of nano NPK (0.4%)	28.80	3.61	26.77	18.50	4.48	24.83
T_{10}: FYM (12 t ha^{-1}) + T_9	32.20	5.16	28.96	26.11	5.92	36.78
T_{11}: T_1 + T_9	48.85	6.01	36.30	31.83	7.42	46.57
T_{12}: T_2 + T_9	56.78	8.53	51.41	51.53	11.44	73.20
T_{13}: T_3 +T_7	52.65	7.76	52.13	36.98	10.71	65.37
T_{14}: T_4 + T_7	67.56	8.93	53.26	52.58	12.22	73.93
T_{15}: KAU POP	23.39	5.13	29.93	23.11	5.77	34.89
T_{16}: Absolute control	14.61	2.01	19.60	9.51	1.85	13.28
SEm (±)	0.63	0.21	16.14	1.78	0.09	5.06
CD (0.05): for any two treatments in the same block	1.51	0.87	7.63	2.53	0.55	4.28
CD (0.05): for any two treatments in different blocks	1.58	0.91	7.99	2.65	0.58	4.48

of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) recorded the highest magnesium uptake (22.35 kg ha^{-1}) by the first residual crop and was on par with T_{12} (21.58 kg ha^{-1}) and T_{13} (20.41 kg ha^{-1}). The lowest magnesium uptake (5.42 kg ha^{-1}) was noticed in T_{16} (Absolute control).

A significant variation in magnesium uptake between the treatments was observed in the case of second residual test crop (Table 55). T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) recorded the highest value of 18.22 kg ha^{-1} and was on par with T_{12} (18.07 kg ha^{-1}) and T_8 (14.12 kg ha^{-1}). The lowest magnesium uptake (1.52 kg ha^{-1}) was noticed in T_{16} (Absolute control).

4.4.1.4.6 Sulphur uptake

The sulphur uptake by both residual crops are presented in table 55. The different treatments imposed significantly influenced the S uptake by the residual test crop, amaranthus. Among the different treatments, S uptake was maximum in T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with a mean value of 6.08 kg ha^{-1} and was not significantly different from T_{12} (5.61 kg ha^{-1}). The lowest S uptake was reported in T_{16} (Absolute control) with a mean value of 0.66 kg ha^{-1}.

The different treatments imposed significantly influenced the S uptake of the second residual crop. Among the treatments imposed, S uptake was maximum in T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with a mean value of 7.08 kg ha^{-1} and was significantly superior than all other treatments. The lowest S uptake was reported in T_{16} (Absolute control) with a mean value of 1.43 kg ha^{-1}.

Table 55. Residual effect of organic nano NPK formulations on uptake of secondary nutrients by amaranthus, kg ha^{-1}

Treatment	First residual test crop (Expt No. II)			Second residual test crop (Expt No. IV)		
	Calcium	Magnesium	Sulphur	Calcium	Magnesium	Sulphur
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	13.69	8.19	2.15	13.50	4.73	3.91
T_2: FYM (12 t ha^{-1}) + T_1	18.95	11.19	4.01	20.20	8.27	4.80
T_3: Soil application of nano NPK (25 kg ha^{-1})	13.01	8.94	2.51	19.49	2.20	3.60
T_4: FYM (12 t ha^{-1}) + T_3	19.10	14.62	4.16	14.29	9.26	6.16
T_5: Soil application of nano NPK (50 kg ha^{-1})	15.37	9.81	3.01	15.24	10.46	4.40
T_6: FYM (12 t ha^{-1}) + T_5	20.77	14.28	4.87	17.64	12.77	4.66
T_7: Foliar application of nano NPK (0.2%)	11.17	5.81	1.61	8.37	7.91	2.86
T_8: FYM (12 t ha^{-1}) + T_7	16.30	13.39	3.41	11.43	14.12	4.00
T_9: Foliar application of nano NPK (0.4%)	10.17	7.93	1.87	12.31	5.16	2.98
T_{10}: FYM (12 t ha^{-1}) + T_9	12.52	7.16	2.69	14.76	8.46	3.83
T_{11}: T_1 + T_9	15.68	13.74	3.53	17.03	8.84	4.57
T_{12}: T_2 + T_9	25.16	21.58	5.61	22.48	18.07	6.61
T_{13}: T_3 +T_7	22.66	20.41	5.44	24.88	8.83	6.15
T_{14}: T_4 + T_7	26.11	22.35	6.08	29.07	18.22	7.08
T_{15}: KAU POP	13.42	11.50	2.59	14.00	3.37	3.22
T_{16}: Absolute control	5.42	5.42	0.66	5.48	1.52	1.43
SEm (±)	11.09	14.76	0.06	4.23	4.74	0.009
CD (0.05): for any two treatments in the same block	6.33	7.30	0.47	3.91	4.14	0.18
CD (0.05): for any two treatments in different blocks	6.63	7.64	0.49	4.09	4.33	0.20

4.4.1.4.7 Iron uptake

The analytical reports from the table 56 indicated that Fe uptake by both residual crop had significant differences among the treatments. The mean values of Fe uptake by the first residual test crop ranged from 0.98 kg ha^{-1} to 2.37 kg ha^{-1}. The maximum uptake was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was significantly superior to all other treatments. T_7 recorded the lowest Fe uptake by the first residual test crop.

The analytical reports from the table 56 showed that Fe uptake by the second residual crop had significant difference among the treatments. The mean values of Fe uptake by plants ranged from 0.94 kg ha^{-1} to 2.43 kg ha^{-1}. The maximum uptake was recorded by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) and was on par T_{12} (2.31 kg ha^{-1}). T_{16} (Absolute control) recorded the lowest Fe uptake (0.94 kg ha^{-1}) by the plant.

4.4.1.4.8 Manganese uptake

The uptake of manganese by residual crop was significantly influenced by the application of different treatments to the direct test crop (okra) and the result is presented in table 56. The highest Mn uptake was observed by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with a mean value of 3.38 kg ha^{-1} and was superior to all other treatments in the first residual test crop. T_{16} (Absolute control) recorded the lowest Mn uptake by the plants.

In the case of second residual test crop (amaranthus), the highest Mn uptake was registered by T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) with a mean value of 3.50 kg ha^{-1} and was superior to all other treatments. T_{16} recorded the lowest Mn uptake by the second residual test crop.

4.4.1.4.9 Zinc uptake

The results of the statistical analysis of the uptake of zinc by residual test crops as influenced by the application of treatments for the direct test crop, okra is presented in table 56. The result indicated that T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) had the highest uptake of Zn with a mean value of 3.27 kg ha^{-1}. The treatment, T_7 (Foliar application of nano NPK 0.2 %) recorded the lowest uptake with a mean value of 1.09 kg ha^{-1}.

The data in table 56 revealed that T_{14} (FYM (12 t ha^{-1}) + Soil application of nano NPK (25 kg ha^{-1}) + Foliar application of nano NPK (0.2 %)) resulted in significantly highest uptake of Zn in the second residual crop compared to other treatments with the mean value of 3.33 kg ha^{-1}. Absolute control treatment recorded the lowest uptake with a mean value of 1.04 kg ha^{-1}.

4.4.1.4.10 Copper uptake

The perusal of data (Table 56) indicated that the uptake of Cu by amaranthus plants ranged from 0.08 kg ha^{-1} to 0.33 kg ha^{-1}. Significantly highest Cu uptake was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 0.33 kg ha^{-1}. T_{16} (Absolute control) treatment registered the lowest Cu uptake.

The results of data (Table 56) revealed that second residual test crop showed a significant difference in uptake of Cu by amaranthus plants and ranged between 0.08 to 0.41 kg ha^{-1}. The highest Cu uptake was recorded by T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) with a mean value of 0.41 kg ha^{-1}. T_{16} (Absolute control) registered the lowest Cu uptake.

Table 56. Residual effect of organic nano NPK formulations on uptake of micronutrients by amaranthus, kg ha^{-1}

Treatment	First residual test crop (Expt No. II)				Second residual test crop (Expt No. IV)			
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	1.15	1.38	1.52	0.13	1.15	1.49	1.63	0.15
T_2: FYM (12 t ha^{-1}) + T_1	1.84	2.01	1.67	0.20	2.12	2.33	1.92	0.26
T_3: Soil application of nano NPK (25 kg ha^{-1})	1.51	1.59	1.24	0.26	1.70	1.89	1.47	0.32
T_4: FYM (12 t ha^{-1}) + T_3	2.06	2.00	1.90	0.27	2.24	2.37	2.26	0.34
T_5: Soil application of nano NPK (50 kg ha^{-1})	1.43	1.60	1.68	0.26	1.50	2.04	2.14	0.35
T_6: FYM (12 t ha^{-1}) + T_5	2.09	1.65	1.70	0.21	1.97	1.98	2.05	0.31
T_7: Foliar application of nano NPK (0.2%)	0.98	1.89	1.09	0.11	1.01	1.78	1.25	0.12
T_8: FYM (12 t ha^{-1}) + T_7	1.51	1.77	1.96	0.17	1.58	1.83	2.05	0.19
T_9: Foliar application of nano NPK (0.4%)	1.32	1.29	1.22	0.15	1.29	1.41	1.38	0.15
T_{10}: FYM (12 t ha^{-1}) + T_9	1.36	1.25	1.18	0.18	1.26	1.47	1.42	0.21
T_{11}: T_1 + T_9	1.54	1.58	1.75	0.20	1.88	1.99	2.24	0.29
T_{12}: T_2 + T_9	1.91	2.88	2.55	0.33	2.31	3.26	2.95	0.41
T_{13}: T_3 +T_7	2.08	2.59	2.18	0.18	2.23	2.88	2.46	0.19
T_{14}: T_4 + T_7	2.37	3.38	3.27	0.24	2.43	3.50	3.33	0.30
T_{15}: KAU POP	1.39	2.84	2.03	0.22	1.62	3.28	2.31	0.28
T_{16}: Absolute control	1.02	1.66	1.31	0.08	0.94	1.59	1.04	0.08
SEm (±)	0.001	0.001	0.003	0.005	0.005	0.003	0.003	0.004
CD (0.05): for any two treatments in the same block	0.06	0.062	0.11	0.04	0.13	0.10	0.10	0.04
CD (0.05): for any two treatments in different blocks	0.07	0.07	0.11	0.09	0.14	0.10	0.10	0.04

4.4.1.5 Correlation study

4.4.1.5.1 Correlation analysis of yield with soil nutrients

Correlation of yield with various physico-chemical and chemical properties of the post harvest soil of both residual crop are presented in table 57-58.

Correlation of yield with physico-chemical and chemical properties of soil after the first residual crop are presented in Table 57. From the result it was revealed that yield was positively correlated with all parameters except EC, available K, available Ca and available Mn.

Similarly for the second residual crop, yield was positively correlated with all parameters except EC and available Mn which were nonsignificant.

4.4.1.6 Economic analysis

Residual effect of both experiments with regard to B:C ratio is given in table 59. FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %) (T_{12}) was found to be more economical with a B:C ratio of 1.99. Absolute control treatment registered the lowest B:C ratio.

With respect to the second residual test crop, the treatment T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4 %)) was found to be more economical with a B:C ratio of 1.81. Absolute control treatment registered the lowest B:C ratio.

Table 57. Correlation analysis between yield and available soil nutrients of first residual test crop (n=13) (Expt No. II)

	Yield	pH	EC	Available N	Available P	Available K	Available Ca	Available Mg	Available S	Available Cu	Available Fe	Available Zn	Available Mn
yield	1.000												
pH	0.436**	1.000											
EC	-0.127^{NS}	0.140^{NS}	1.000										
Available N	0.464**	0.500**	0.050^{NS}	1.000									
Available P	0.552**	0.599**	0.041^{NS}	0.717**	1.000								
Available K	0.272^{NS}	0.527**	0.100^{NS}	0.472**	0.505**	1.000							
Available Ca	0.212^{NS}	0.388**	0.190^{NS}	0.264^{NS}	0.370**	0.309*	1.000						
Available Mg	0.333*	0.514**	0.217^{NS}	0.325*	0.265^{NS}	0.157^{NS}	0.195^{NS}	1.000					
Available S	0.416**	0.423**	0.158^{NS}	0.499**	0.577**	0.446**	0.205^{NS}	0.328*	1.000				
Available Cu	0.374**	0.445**	0.052^{NS}	0.672**	0.863**	0.568**	0.179^{NS}	0.229^{NS}	0.483**	1.000			
Available Fe	0.312*	0.257^{NS}	-0.081^{NS}	0.580**	0.787**	0.507**	-0.008^{NS}	0.009^{NS}	0.456**	0.912**	1.000		
Available Zn	0.337*	0.520**	0.152^{NS}	0.681**	0.889**	0.607**	0.202^{NS}	0.176^{NS}	0.590**	0.883**	0.827**	1.000	
Available Mn	0.249^{NS}	-0.140^{NS}	-0.344*	0.097^{NS}	0.004^{NS}	-0.213^{NS}	-0.088^{NS}	0.172^{NS}	0.069^{NS}	0.124^{NS}	0.014^{NS}	-0.022^{NS}	1.000

** = Significant at 1% level   * = Significant at 5% level   NS = Non-significant

Table 58. Correlation analysis between yield and available soil nutrients of second residual test crop (n=13) (Expt No. IV)

	Yield	pH	EC	Available N	Available P	Available K	Available Ca	Available Mg	Available S	Available Cu	Available Fe	Available Zn	Available Mn
Yield	1.000												
pH	0.616**	1.000											
EC	0.086 NS	0.162 NS	1.000										
Available N	0.826**	0.722**	0.062 NS	1.000									
Available P	0.668**	0.762**	-0.069 NS	0.783**	1.000								
Available K	0.578**	0.716**	-0.015 NS	0.627**	0.769**	1.000							
Available Ca	0.841**	0.510**	0.088 NS	0.761**	0.662**	0.479**	1.000						
Available Mg	0.735**	0.678**	0.103 NS	0.749**	0.717**	0.583**	0.639**	1.000					
Available S	0.648**	0.556**	-0.082 NS	0.653**	0.535**	0.455**	0.441**	0.587**	1.000				
Available Cu	0.887**	0.625**	-0.055 NS	0.833**	0.799**	0.647**	0.733**	0.738**	0.586**	1.000			
Available Fe	0.855**	0.507**	-0.219 NS	0.732**	0.705**	0.555**	0.689**	0.645**	0.609**	0.912**	1.000		
Available Zn	0.857**	0.672**	0.022 NS	0.780**	0.817**	0.659**	0.712**	0.681**	0.641**	0.883**	0.827**	1.000	
Available Mn	-0.017 NS	-0.087 NS	-0.232 NS	0.075 NS	0.069 NS	-0.139 NS	-0.070 NS	-0.010 NS	0.101 NS	0.124 NS	0.014 NS	-0.022 NS	1.000

** = Significant at 1% level * = Significant at 5% level NS = Non-significant

Table 59. Residual effect of organic nano NPK formulations on gross income, net returns and B:C ratio of amaranthus

Treatment	First residual test crop (Expt No. II)			Second residual test crop (Expt No. IV)		
	Gross income (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio	Gross income (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
T_1: Soil application of nano NPK (12.5 kg ha^{-1})	96819	10456	1.12	81165	-9.90	1.00
T_2: FYM (12 t ha^{-1}) + T_1	91221	4859	1.06	108374	27198	1.34
T_3: Soil application of nano NPK (25 kg ha^{-1})	109610	23248	1.27	85374	4199.40	1.05
T_4: FYM (12 t ha^{-1}) + T_3	85278	-1084	0.99	119123	37947	1.47
T_5: Soil application of nano NPK (50 kg ha^{-1})	90861	4498	1.05	98271	17095	1.21
T_6: FYM (12 t ha^{-1}) + T_5	89111	2748	1.03	123813	42637	1.53
T_7: Foliar application of nano NPK (0.2%)	115471	29108	1.34	34813	-46362	0.43
T_8: FYM (12 t ha^{-1}) + T_7	115986	29623	1.34	100062	18887	1.23
T_9: Foliar application of nano NPK (0.4%)	110541	24179	1.28	47186	-33988	0.58
T_{10}: FYM (12 t ha^{-1}) + T_9	59763	-26598	0.69	101563	20388	1.25
T_{11}: T_1 + T_9	139416	53053	1.61	120396	39220	1.48
T_{12}: T_2 + T_9	171749	85386	1.99	146811	65635	1.81
T_{13}: T_3 +T_7	100374	14011	1.16	129000	47825	1.59
T_{14}: T_4 + T_7	150708	64346	1.75	117041	35865	1.44
T_{15}: KAU POP	41137	-45224	0.48	96207	15032	1.19
T_{16}: Absolute control	17834	-68528	0.21	31124	-50051	0.38

Discussion

5. DISCUSSION

The present experimental investigation entitled "Organic nano NPK formulations for enhancing soil health and productivity" was conducted at College of Agriculture, Vellayani during the period from July 2017 to February 2019. The study was done for the characterization of organic nano NPK formulations, to screen the release of nutrients from granular nano NPK formulation under the laboratory conditions and to assess the effectiveness of soil and foliar applications of organic nano NPK formulations on crop growth, yield, quality and soil health using okra as direct test crop and amaranthus as residual test crop.

Significant investigational findings acquired during the sequences of experimentation were briefly discussed below with possible justifications and suggestions wherever required in order to find out the cause and effect relationship among the different treatments with respect to various aspects studied and to sort informations of practical value.

PART I

5.1 CHARACTERIZATION OF GRANULAR AND LIQUID ORGANIC NANO NPK FORMULATIONS

5.1.1 Physical properties

5.1.1.1 Particle size analysis

Particle size of granular and liquid nano NPK formulations were analyzed using zetasizer analyzer and the average particle size of the materials were recorded as 83.20 nm and 71.79 nm, respectively (Table 4, Fig. 7 and 8). Holister *et al.* (2003) opined that there is an increase in volume to surface ratio as the particle size got reduced that leads to increased dominance of the behavior of the atom on the surface of the particle than that of interior of the particle. The results validate with the findings in the literature proposed that ball milling is the easiest mechanical method to attain the nano dimension (Alizera and Gholamhosein, 2012 and Subramanian and Rahale, 2012).

5.1.1.2 Zeta potential

Granular organic nano NPK formulation exhibited the zeta potential of -14.4 mV which means that the sample was stable (Table 4 and Fig. 9). Nanoparticles having zeta potential (+) or (-) 40 mV shows higher stability of sample and also prevent agglomeration that leads to increase the durability of nutrient release. Kottegoda *et al.* (2011) reported high stability of nano emulsion of urea modified hydroxyapatite nanoparticle encapsulated wood. Similar results were also reported by Thirunavukkarasu and Subramanian (2015).

5.1.1.3 Surface morphology

The SEM image showed that the granular nano NPK formulation was circular to irregular in shape and surface looked rough (Table 4 and Fig. 10). Similar results were obtained by Thanh (2006), Hu *et al.* (2009) and Mohanraj (2013).

5.1.1.4 Surface area

Physical and chemical properties of a material may be greatly influenced by the extent of its surface area. BET theory explains the physical adsorption of gas molecules on a solid surface and serves as the important analysis technique to measure the surface area of the granular nano NPK formulation and was analyzed using surface area analyzer. The surface area of nano NPK formulation was 138.95 $m^2 g^{-1}$ (Table 4 and Fig. 11). The size reduction exponentially increased the surface area which provides extensive surface area for nutrient adsorption and release. Similar results were reported by Holister *et al.* (2003) that there was an increase in surface area of nanofertilizers which assists in the extensive adsorptive sites for release of nutrients or retention.

Similarly, Subramanian and Rahale (2013) reported that nano sized clay particles have more adsorptive sites and act as the reservoir of nutrients.

5.1.1.5 Physico-chemical and chemical characters of granular and liquid organic nano NPK formulations

Granular and liquid nano NPK formulations had the chemical properties *viz.,* pH (7.68, 6.55), electrical conductivity (0.141, 0.184 dS m^{-1}), organic carbon (2.25 %), total nitrogen (1.96, 1.82 %), total phosphorous (1.76, 1.89 %), total potassium (2.75, 3.53 %), total calcium (0.37, 0.21 %), total magnesium (0.30, 0.09 %), total sulphur (0.59, 0.75 %), total copper (104.0, 3.10 mg kg^{-1}), total iron (465.7, 152.8 mg kg^{-1}), total manganese (662.5, 41.77 mg kg^{-1}), total zinc (398.3, 318.1 mg kg^{-1}) and total boron (47.54, 9.37 mg kg^{-1}), respectively. Regarding the heavy metal content, As and Cd were not detected in granular and liquid nano NPK formulations, whereas, Pb (6.90 mg kg^{-1} in liquid formulation), Ni (6.00, 5.40 mg kg^{-1} in granular and liquid nano NPK formulations, respectively) and Cr (9.67, 3.43 mg kg^{-1} in granular and liquid nano NPK formulations, respectively) were detected. In general the composition of organic nano NPK formulations are of standard quality as per FAI, 2017. The above results are similar to the studies of Noori *et al.* (2006) and Perez-Caballero *et al.* (2008) who reported that the zeolites are known to be alkaline in nature and are widely used for buffering the soil pH. The chemical properties of fabricated fertilizers closely validate with findings of Perrin *et al.* (1998) and Quijon (2013). The results closely accorded with the reports of Subramanian and Rahale (2013) stated that nano sized clay particles had adsorptive sites and serve as a reservoir of nutrient ions. Organic nano NPK formulations included in the present study are proteino-lacto-gluconate formulations, articulated with organic and chelated micronutrients, vitamins, probiotics, humic acid besides nitrogen, phosphorus and potash (Tarafdar *et al.,* 2013).

5.1.1.6 Biochemical properties

Total amino acid content present in the granular and liquid organic nano NPK formulations was found to be 270 mg kg^{-1} and 370 mg kg^{-1}, respectively. Patented nano-composite which contains major, micronutrients, amino acid thereby increased the uptake of nutrients (Jinghua, 2004). The amino acid content in the nanofertilizers helped in their translocation to the reproductive organs and thereby enhanced the growth and yield (Dongarkar *et al.,* 2005).

Characterization study indicated that organic matter fractions *viz.,* fulvic acid (29.86 %), humic acid (16.73 %) and humin (5.90 %) present in the granular nano NPK formulation. Humic acid is considered as the main element that maintain soil fertility, provide carbon and nitrogen and indirectly improve pH and soil microbial growth. Fulvic acid and humic acids are very effective carbon containing chelating compounds. Pettit (2004) stated that carbon bonds of humic substances trapped energy for soil microbes, because of the large surface area and electrical charges, humic substance also helped to improve the water holding capacity of the soil.

PART II

5.2 LABORATORY INCUBATION STUDY

The laboratory incubation experiment was conducted to assess the nutrient release pattern of organic nano NPK formulation for a period of 75 days and the results are discussed below.

5.2.1 Changes in pH and EC

Significant differences were noticed in soil pH and EC during the period of incubation and recorded an increasing trend on advancement of incubation period (Fig. 12 and 13). Treatments received FYM along with granular nano NPK formulation

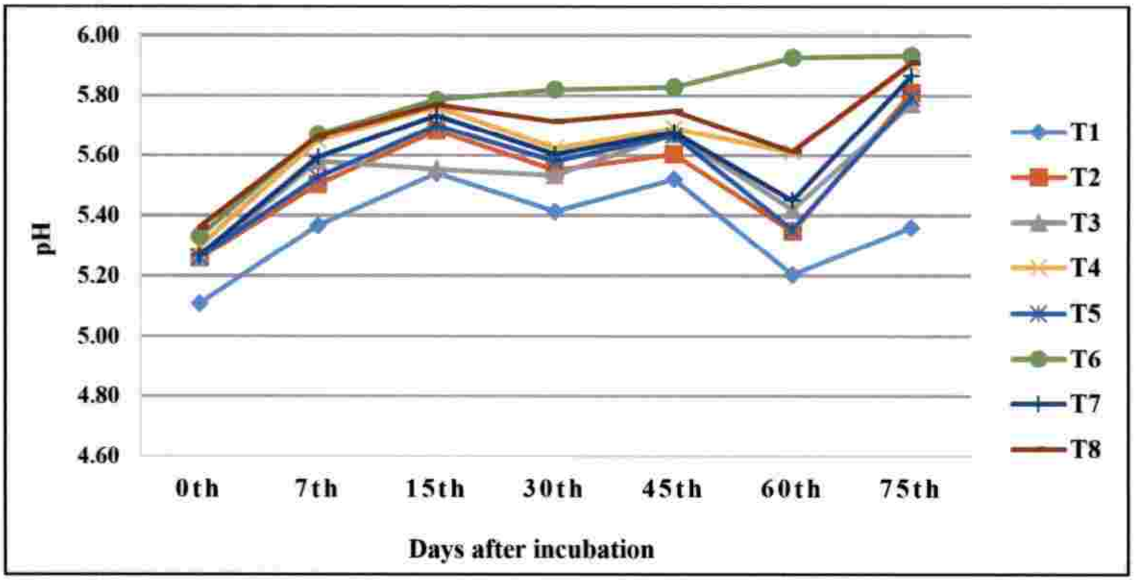

Fig. 12. Influence of granular nano NPK formulation on pH of the soil at different periods of incubation

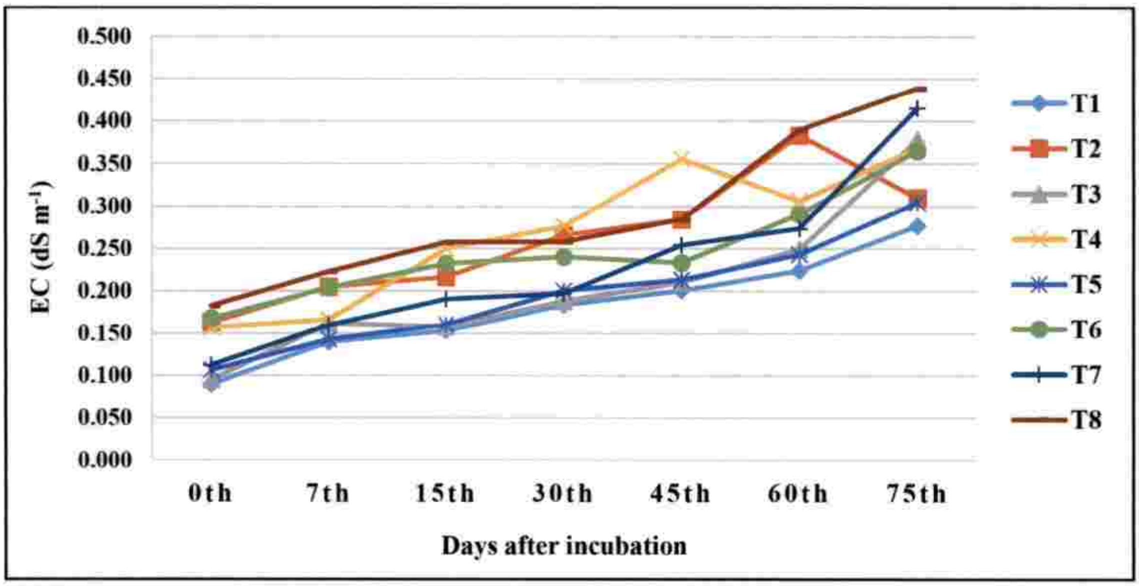

Fig. 13. Influence of granular nano NPK formulation on EC (dS m^{-1}) of the soil at different periods of incubation

recorded higher soil pH and EC than soil application of nano NPK formulation alone. Increase in soil pH may be due to increase in bases by active degradation of organic matter and suppression of Fe and Al oxides and hydroxides activities. Sarwar *et al.* (2008) opined that acid forming compounds released during the decomposition of organic manure reacted with sparingly soluble salt present in soil and converted them to soluble salts that leads to increased electrical conductivity in the soil. From the characterization study of organic nano NPK formulations, the granular nano NPK formulation recorded the pH of 7.68 and EC 0.141 dS m^{-1} which might have influenced the increased soil pH and EC. Similar results were reported by Liu and Lal (2012) that generally zeolites having alkaline properties with pH around 8, which could able to increase the pH of acidic soils. This is in agreement with the findings of Ming and Allen (2001) that when zeolite was added to the soil, which resulted in an increase in pH of the soil. The soil pH drastically affects the availability of most of the nutrients required for the plant growth and optimum availability of all the soil nutrients are near neutral pH (Brady, 1990).

EC shows an indirect assessment of soluble salt concentration in the soil. The increased EC during the incubation period might be due to the quicker release of bases and soluble fractions to the soil by the process of mineralization. However all the EC values are in the permissible limit. Ming and Boettinger (2001) reported that application of zeolite to the soil increases their EC which in turn increases the nutrient retention capacity of the soil. This is similar to the findings of Mia *et al.* (2010) and Rus *et al.* (2004) who stated that EC of the soil increased due to the high dissolution rate and the salty nature of nanofertilizers.

5.2.2 Changes in organic carbon

Treatments showed significant variation in the organic carbon content of the soil (Fig. 14). All the treatments exhibited increasing trend and the maximum OC was recorded on 75^{th} day of incubation. Characterization study indicated that granular nano

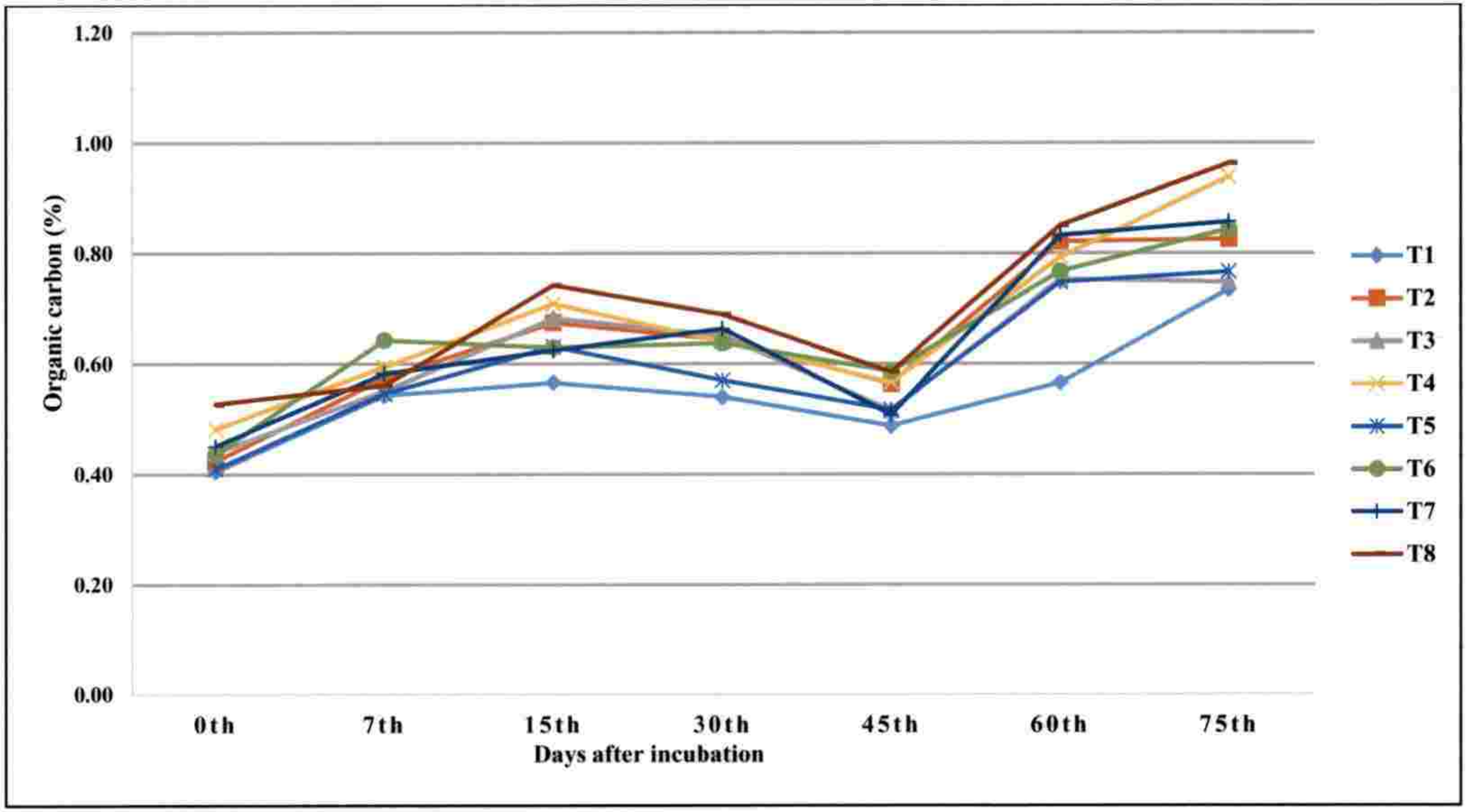

Fig. 14. Influence of granular nano NPK formulation on organic carbon content (%) of the soil at different periods of incubation

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NPK formulation had the fulvic acid (29.86 %), humic acid (16.73 %) and humin (5.90 %) content. Tarafdar *et al.* (2013) reported that organic nano NPK formulations are proteino-lacto-gluconate formulations, articulated with organic and chelated micronutrients, vitamins, probiotics, humic acid besides nitrogen, phosphorus and potash. The increase in organic carbon content in soil might be due to the carbonaceous materials contributed to soil organic carbon after their decomposition. Nanofertilizers manifest an initial burst and a subsequent slow release, even 60 days after application. Similarly Mia *et al.* (2010) reported that due to the high dissolution rate of nano silica and their salty nature may contribute to increase in the conductivity and OC content in the soil.

5.2.3 Changes in primary and secondary nutrients

Treatments showed the significant differences in available N (Fig. 15), available P (Fig. 16) and available K (Fig. 17) content during the periods of incubation. Available N and P were increased upto 45th day of incubation subsequently declined. The lowest available N and P were found in absolute control treatment throughout the incubation period. The higher release of N, P and K was might be due to the application of nano NPK formulation which enhanced the soil microbial activities thereby increased the available nutrient content in soil. This is similar to the findings of Suriyaprabha *et al.* (2012) who reported that application of nano silica into the soil leads to increase in the soil microorganisms that specifies the enhanced soil fertility and their availability of nutrients to the plants. Perrin *et al.* (1998) reported that clinoptilolite zeolite improve the nitrogen fertilization efficacy, but it also reduces the leaching of nitrate by inhibiting the nitrification of ammonium to nitrate. Similar results were also reported by Junxi *et al*. (2013) release of nutrients from nanofertilizer in the soil is slowed down due to the tight bondage of the ammonium ions in the nano pores of zeolite.

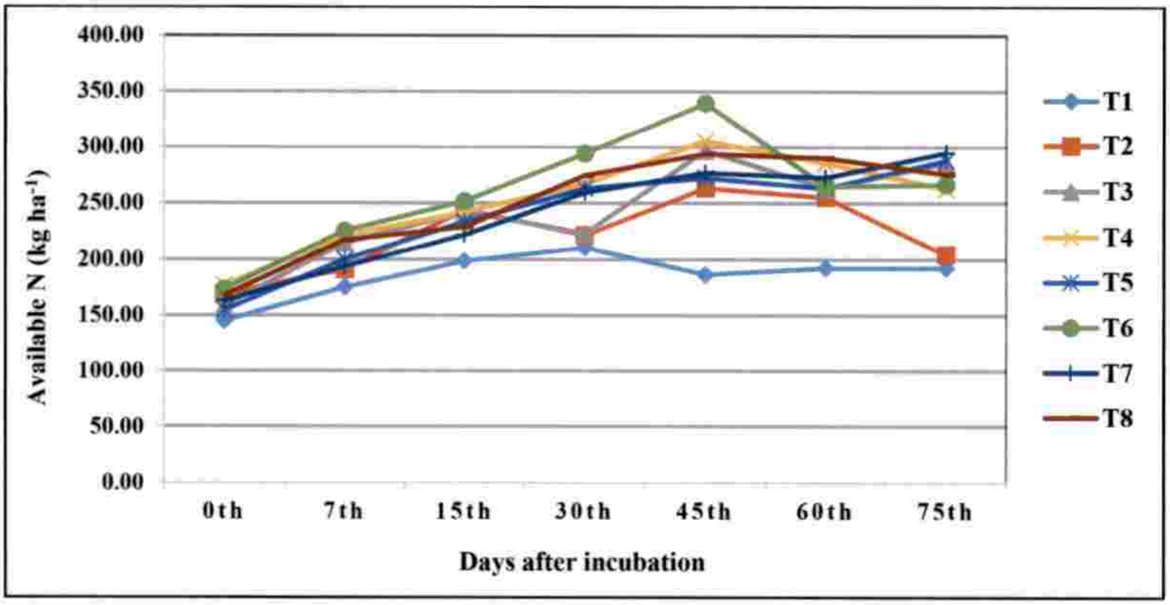

Fig. 15. Influence of granular nano NPK formulation on available N content (kg ha^{-1}) of the soil at different periods of incubation

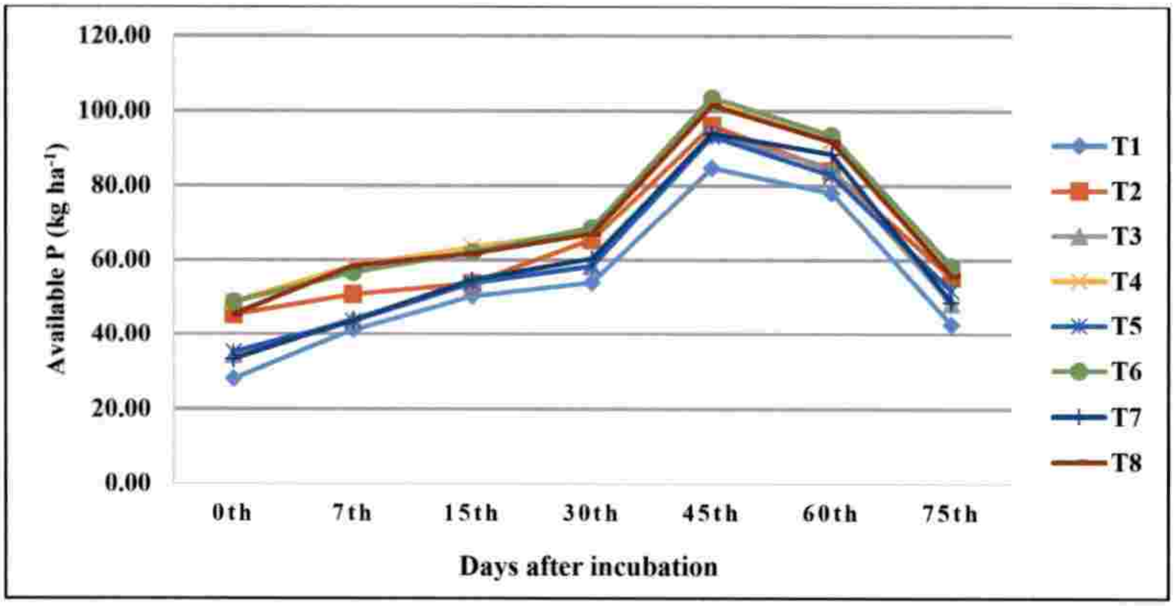

Fig. 16. Influence of granular nano NPK formulation on available P content (kg ha^{-1}) of the soil at different periods of incubation

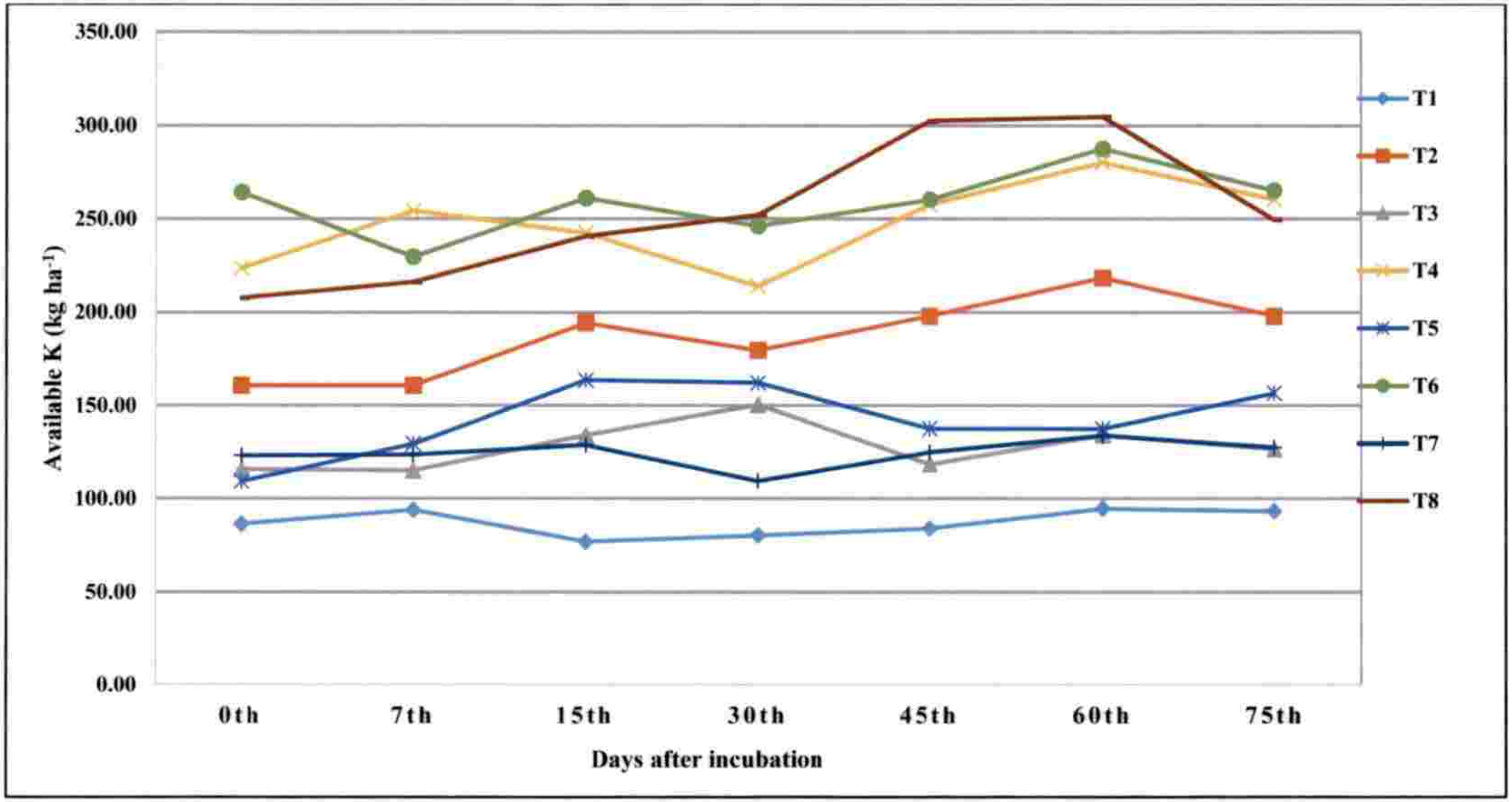

Fig. 17. Influence of granular nano NPK formulation on available K content (kg ha^{-1}) of the soil at different periods of incubation

In general, available K_2O increased gradually upto 60^{th} day of incubation afterwards showed decreasing trend. This might be due to the high potassium content (2.75 %) and release from granular nano NPK formulation. Zhou and Huang (2007) stated that potassium is released in a slow and steady manner from nano zeolite.

Absolute control treatment (Soil alone) recorded the lowest available nutrient content throughout the incubation period which indicated that the increased availability of nutrients from soil treated with granular nano NPK formulation might be due to the slow release of nutrients throughout the incubation period.

Treatments showed significant differences in secondary nutrients *viz.,* exchangeable Ca, exchangeable Mg and available S content. The release of secondary nutrients increased upto 45^{th} day of incubation (Fig. 18, 19 and 20) and thereafter showed a decreased tendency. Characterization study indicated that granular nano NPK formulation had total Ca, Mg and S contents of 0.37 per cent, 0.30 per cent and 0.59 per cent, respectively. Preetha (2011) reported that application of nano composite have enhanced the available calcium, magnesium and sulphur content of the soil. Olsen *et al.* (1954) pointed out that application of organic manure could increase the exchangeable calcium and magnesium content in the soil. Perez-Caballero *et al.* (2008) in their research work reported that treatments that received with zeolite have increased the P, K and Ca contents in the soil. Similar findings were reported by Kallo *et al.* (1986) and concluded that zeolite containing both macro and micronutrients, provide large surface area on which the chemical reactions taken place by slow release of ammonium nitrate, potassium, magnesium, calcium as well as trace elements as and when it is needed.

Tarafdar *et al.* (2012a) suggested the release of nutrients from the fertilizers encapsulated in nanoparticles can be accelerated without harming the environment at a particular time for a desired period of time.

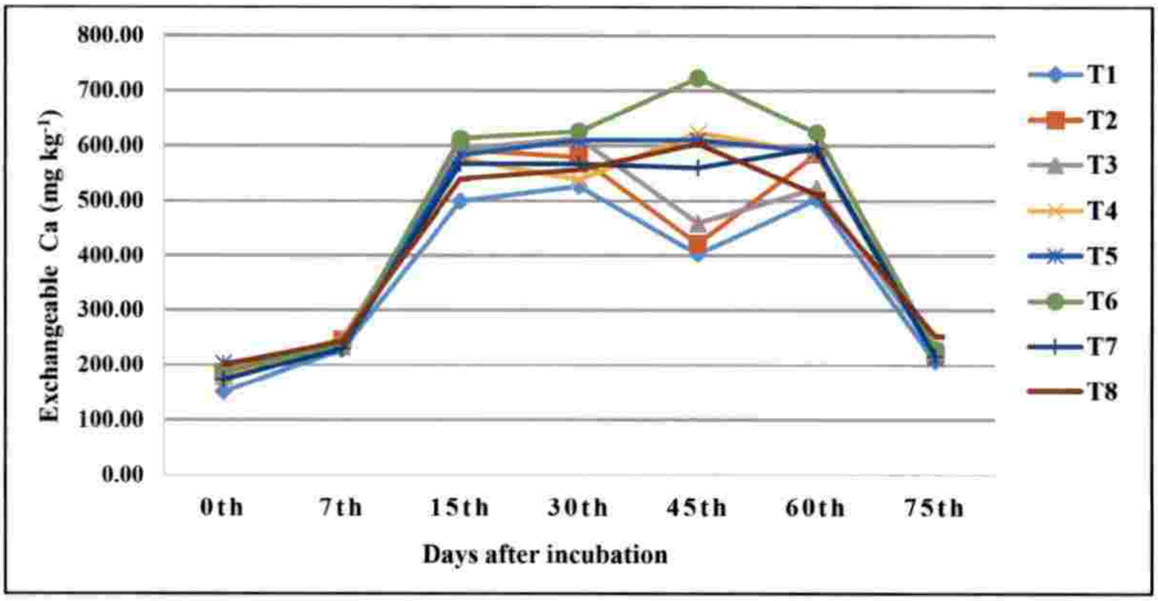

Fig. 18. Influence of granular nano NPK formulatio on exchangeable Ca content (mg kg^{-1}) of the soil at different periods of incubation

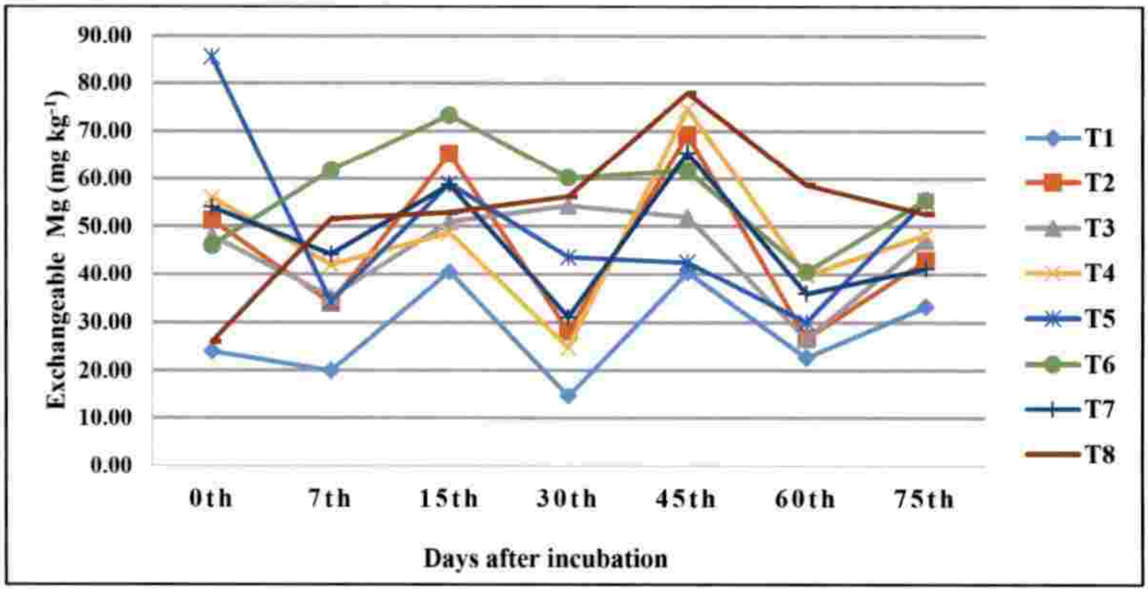

Fig. 19. Influence of granular nano NPK formulation on exchangeable Mg content (mg kg^{-1}) of the soil at different periods of incubation

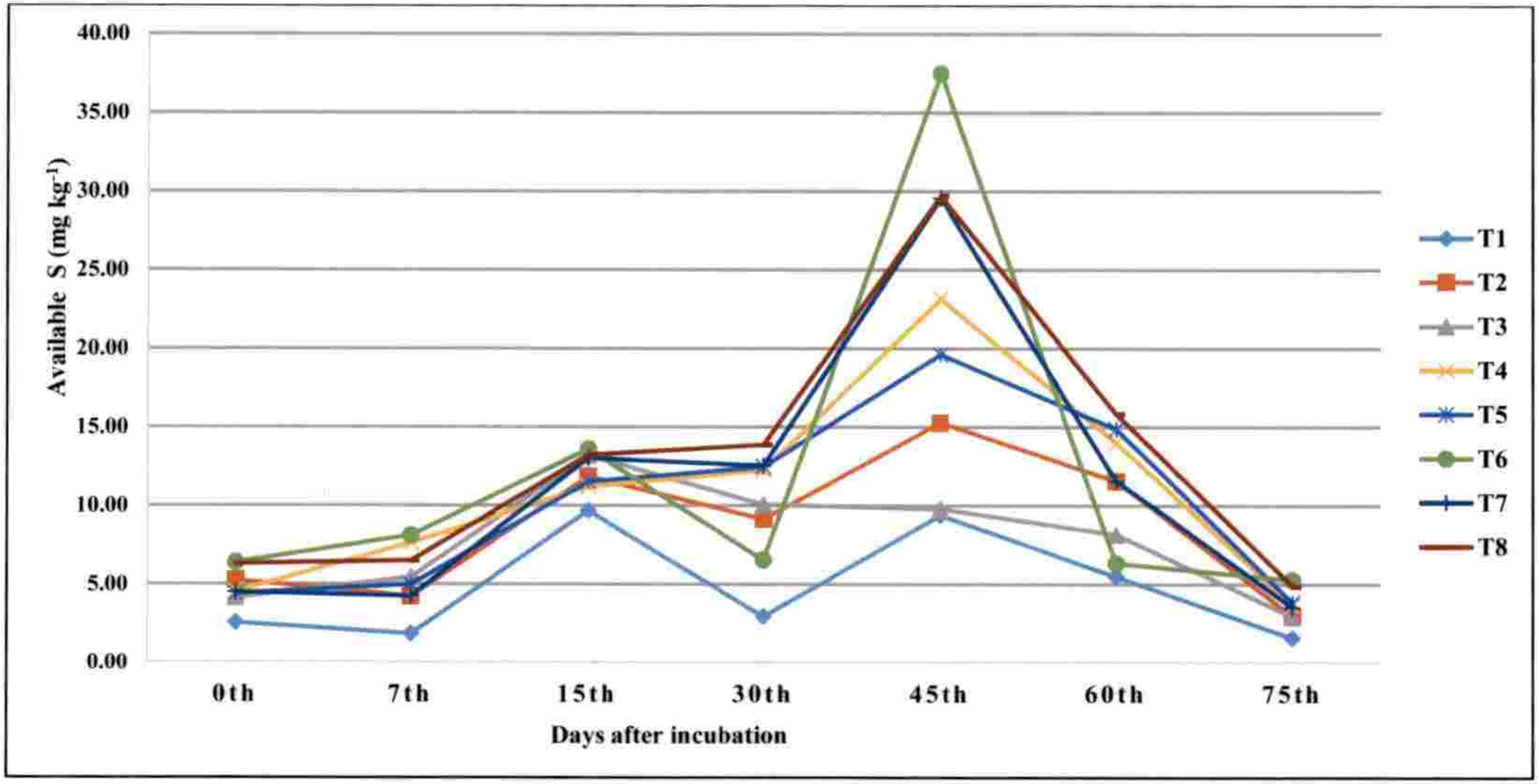

Fig. 20. Influence of granular nano NPK formulation on available S content (mg kg^{-1}) of the soil at different periods of incubation

5.2.4 Changes in micronutrients

Treatments showed the significant variations due to the release of micronutrients from the soil (Fig. 21, 22, 23 and 24). Treatments showed a gradual increase in available iron content upto 45th day of incubation and afterwards showed a decline trend. Same trends were observed for available Mn, Zn and Cu. This might be due to the availability of micronutrients amplified due to incremental levels of application of granular nano NPK formulation. Mazur *et al.* (1986) pointed out that nanofertilizer significantly increased the available Fe, Mn, Zn and Cu content in the soil. Treatments that received granular nano NPK formulation released more available micronutrients compared to soil alone treatments. This might be due to the presence of humic acid and fulvic acid in the granular nano NPK formulation as evident from the characterization study (Table 4). This is in conformity with the findings of Tavakoli and Khoshkam (2013) that organic acid present in the nanofertilizer improve the micronutrient chelation rate and thereby maintaining the soil fertility.

PART III

5.3 FIELD EXPERIMENT

Effects of granular and liquid nano NPK formulations on crop growth, yield, quality and soil health were evaluated in the field experiments using okra variety Varsha Uphar as the direct test crop for the first experiment and for confirmatory experiment (Expt No. III). The important biometric observations *viz.,* plant height, number of branches per plant, leaf area index, dry matter production, root length and root volume were recorded and the results are discussed below.

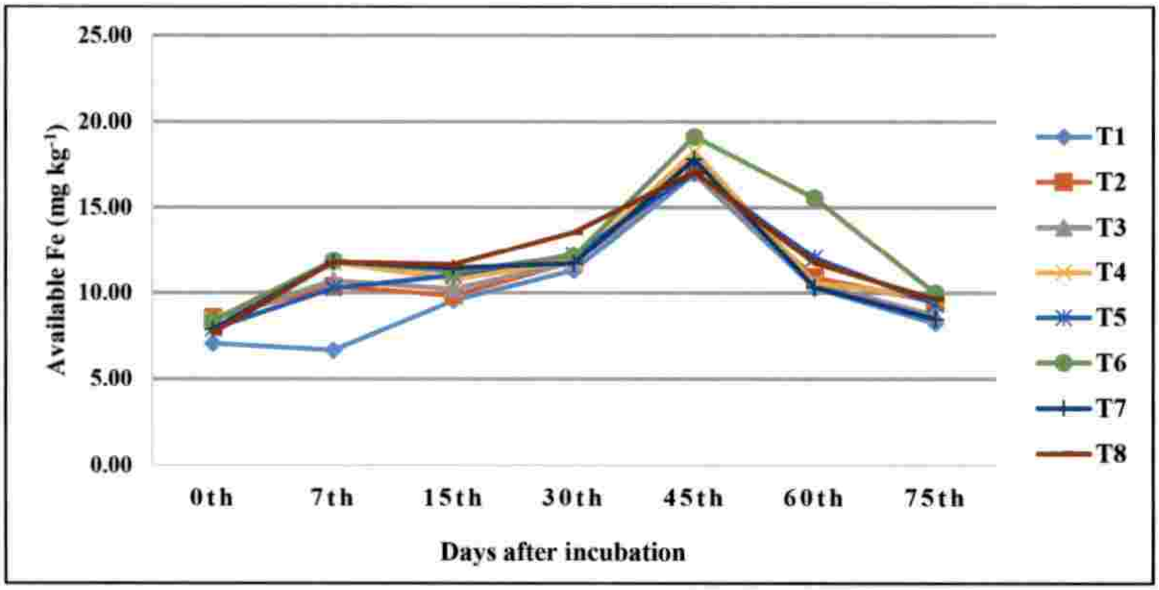

Fig. 21. Influence of granular nano NPK formulation on available Fe content (mg kg^{-1}) of the soil at different periods of incubation

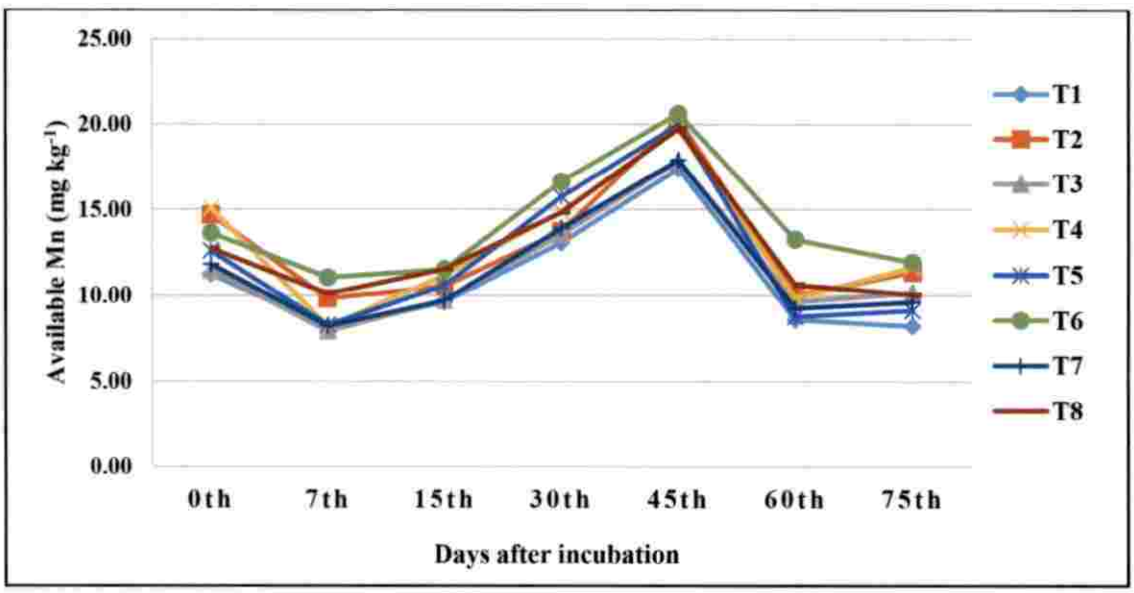

Fig. 22. Influence of granular nano NPK formulation on available Mn content (mg kg^{-1}) of the soil at different periods of incubation

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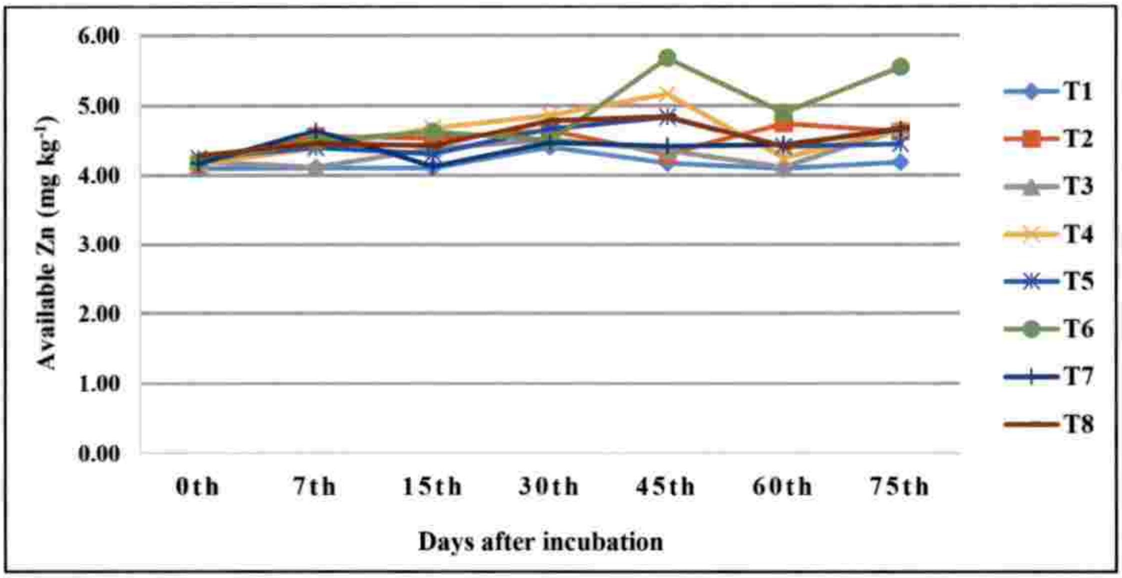


Fig. 23. Influence of granular nano NPK formulation on available Zn content ($mg\ kg^{-1}$) of the soil at different periods of incubation

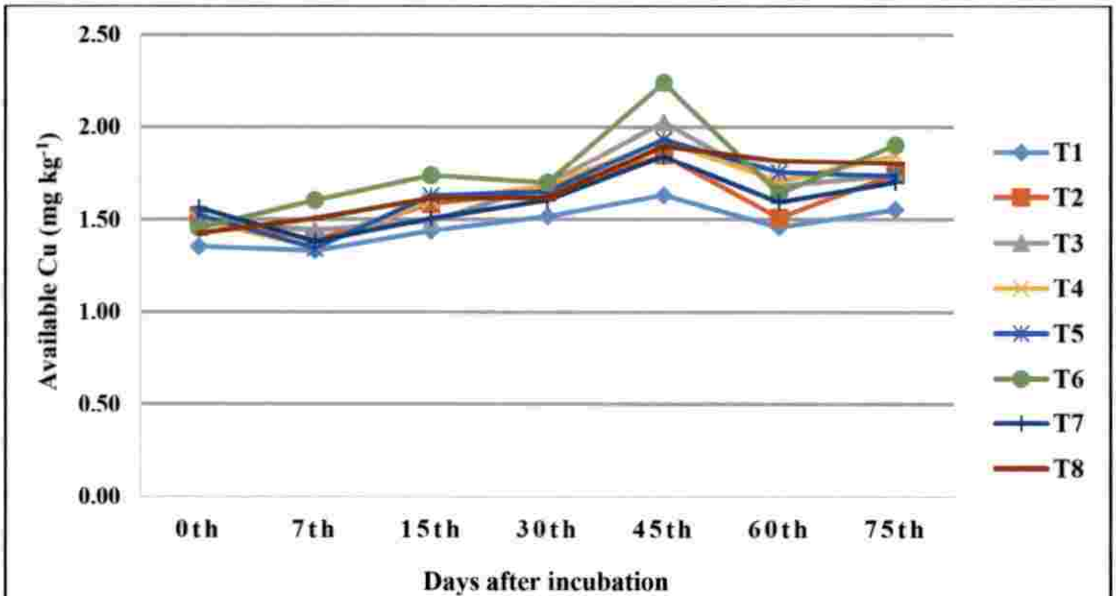
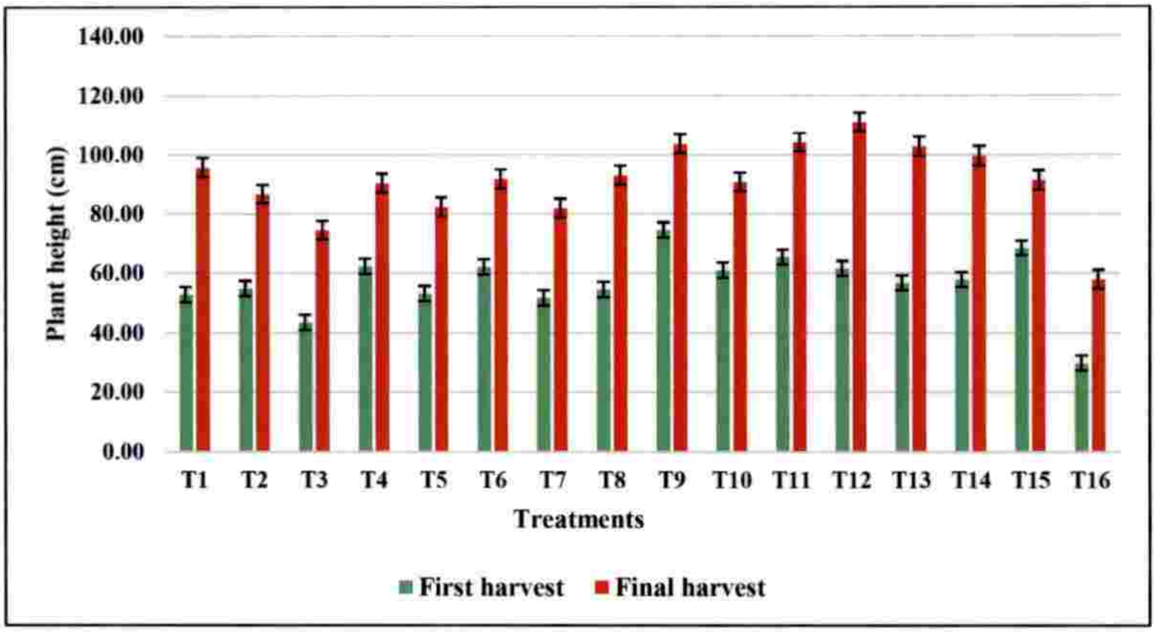


Fig. 24. Influence of granular nano NPK formulation on available Cu content ($mg\ kg^{-1}$) of the soil at different periods of incubation

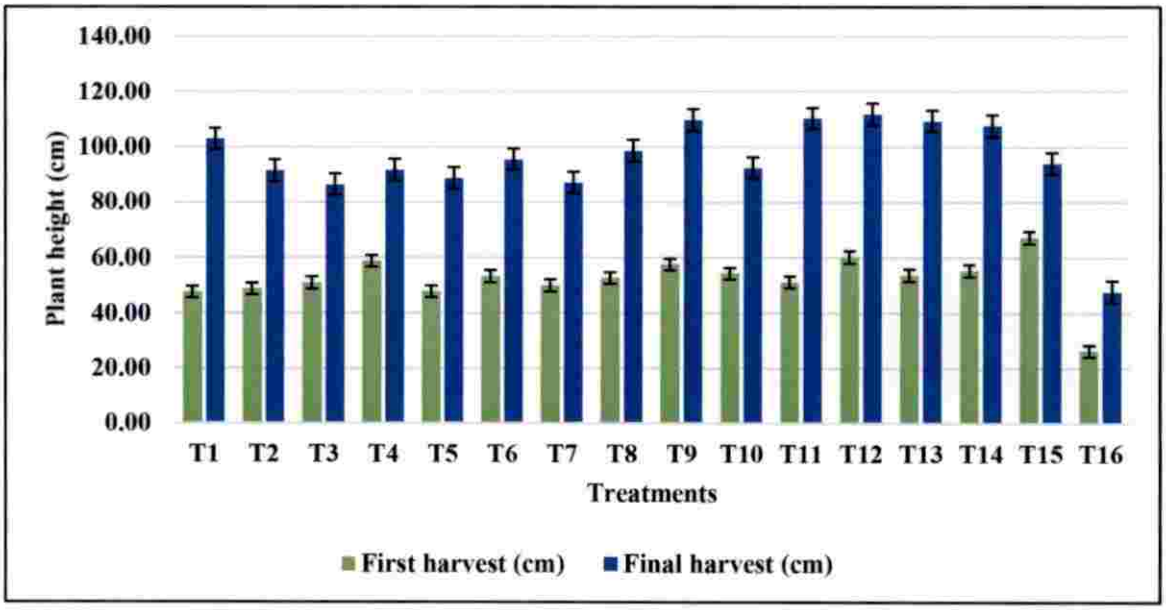
5.3.1 Effect of granular and liquid nano NPK formulations on biometric observations of okra

5.3.1.1 Plant height

The different treatments tried produced significant effect on plant height during the first harvest and final harvest of both direct test crops. The data presented in (Fig. 25 a) pointed out that at first harvest stage, T_9 recorded maximum plant height and followed by T_{15}. Application of FYM (12 t ha^{-1}) along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK (0.4 %) (T_{12}) recorded the highest plant height in the final harvest of the first direct test and was comparable with T_{11}. For the second direct test crop (Fig. 25 b) T_{15} which consisted of KAU POP at the first harvest recorded the maximum plant height and the trend observed in the final harvest was same as the first experiment. In general combined application of granular and liquid nano NPK formulations resulted in maximum plant height due to the better availability of plant nutrients. The result obtained are in corroboration with the findings of Junrungreang *et al.* (2002) stated that when zeolite was added along with chemical fertilizer the growth of the sugarcane increased significantly. This reveals that increase in plant height might be due to the application of nano NPK which released in a slow and steady manner that may enabled for better growth of the plants. The obtained results suggested that nanofertilizers can provide either nutrients for plant or help in the transport or absorption of plant available nutrients resulted in better crop growth (Dimkpa *et al.,* 2018). Similarly, increase in plant height was greater with respect to foliar application than that of soil application in case of NPK nanofertilizers (Rochester *et al.,* 2001). Ghormade *et al.* (2011) reported that, nanofertilizers can result in alteration of plant gene expression and associated biological pathways which finally resulted in plant height.



a. Plant height, cm (Experiment No: I)



b. Plant height, cm (Experiment No: III)

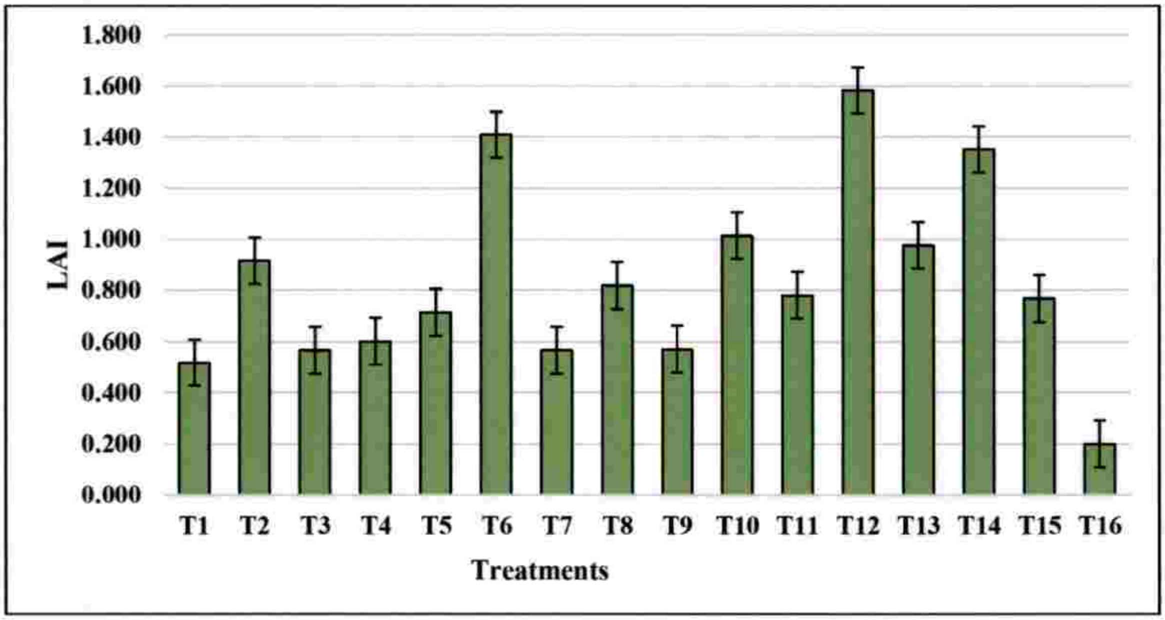
Fig.25. Influence of organic nano NPK formulations on plant height of okra

5.3.1.2 Number of branches per plant

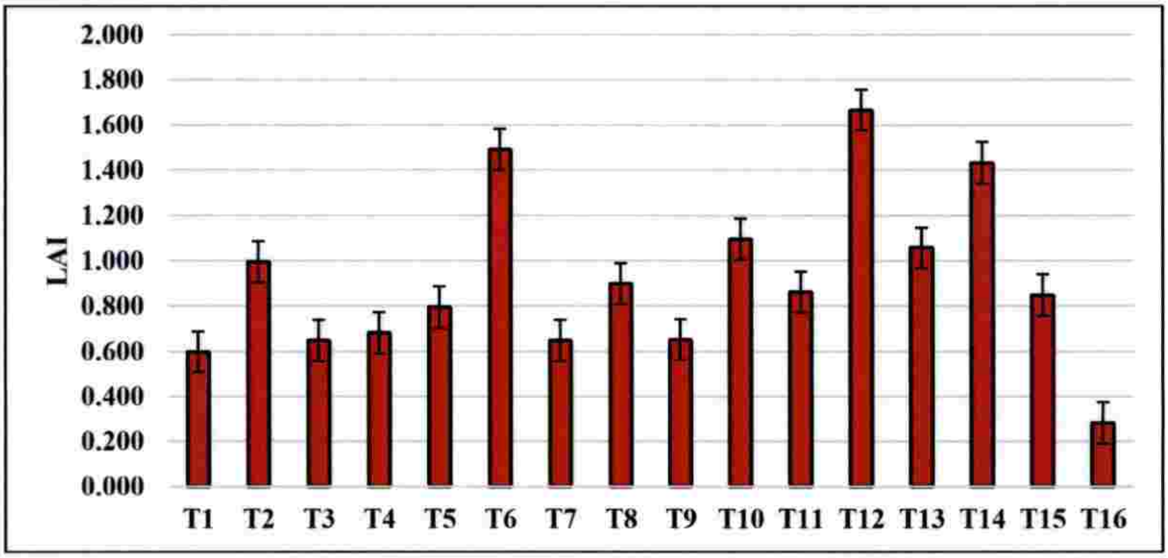
Number of branches per plant showed significant variation due to the effect of treatments (Table 20). Treatment which received FYM along with soil application of nano NPK formulation 25 kg ha^{-1} (T_4) recorded maximum number of branches per plant in first and second direct test crops. In the case of first direct test crop T_4 was on par with T_9, T_{12} and T_6. In the case of second direct test crop, T_4 was comparable with T_9 (Foliar application of nano NPK 0.4 %) and the least number of branches per plant was in absolute control treatment. Increased number of branches might be due to the increased production and accumulation of carbohydrates and improved the vegetative growth resulted by the application of organic nano NPK formulations. El-Hamd and Elwahed (2018) reported that foliar application of nanofertilizer resulted in the highest biometric characters such as plant height, number of branches per plant and leaf area in okra, while unsprayed plants recorded the lowest values.

5.3.1.3 Leaf area index

Concerning leaf area index (Fig. 26 a and b), during both direct test crops the highest LAI was recorded in treatment, T_{12} which received with FYM along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK (0.4 %). Increased leaf area index might resulted in achieving more photosynthetic efficiency resulting larger leaf area for harvesting more sunlight. According to Kottegoda *et al.* (2011) when nano urea is applied in the soil it released slowly in soil and thereby increases the leaf area and photosynthetic activities in the plant. Abdel-Aziz *et al.* (2016) opined that when wheat plants were influenced due to the foliar application of nano NPK fertilizers, this might be described on the basis that sprayed nanofertilizers absorbed through the stomata and translocated in the plants.



a. Leaf area index (Experiment No: I)



b. Leaf area index (Experiment No: III)

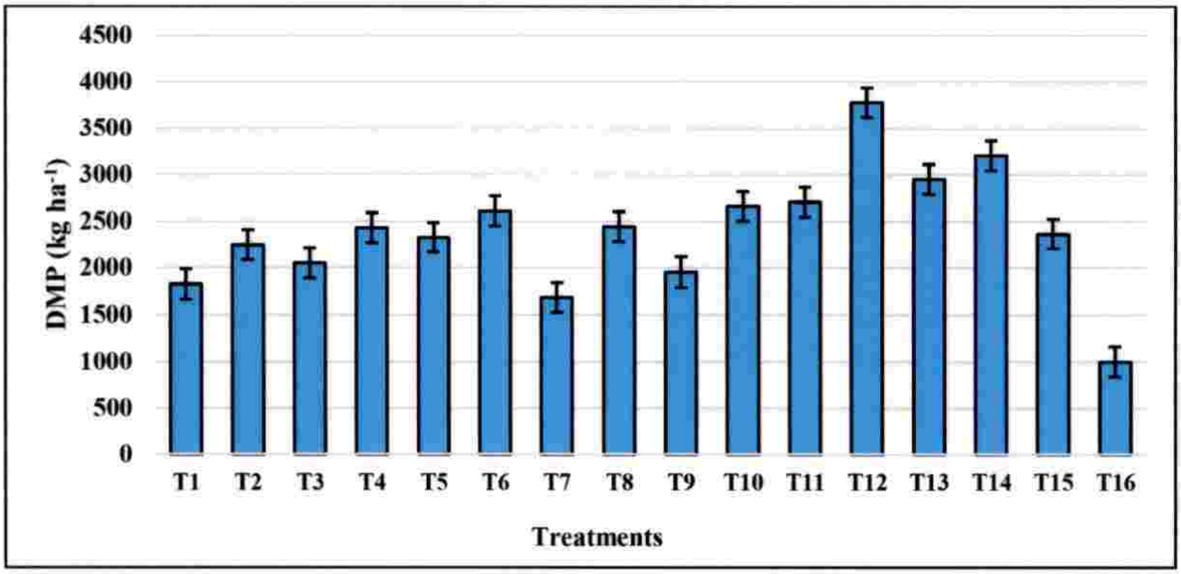
Fig. 26. Influence of organic nano NPK formulations on leaf area index of okra

5.3.1.4 Dry matter production

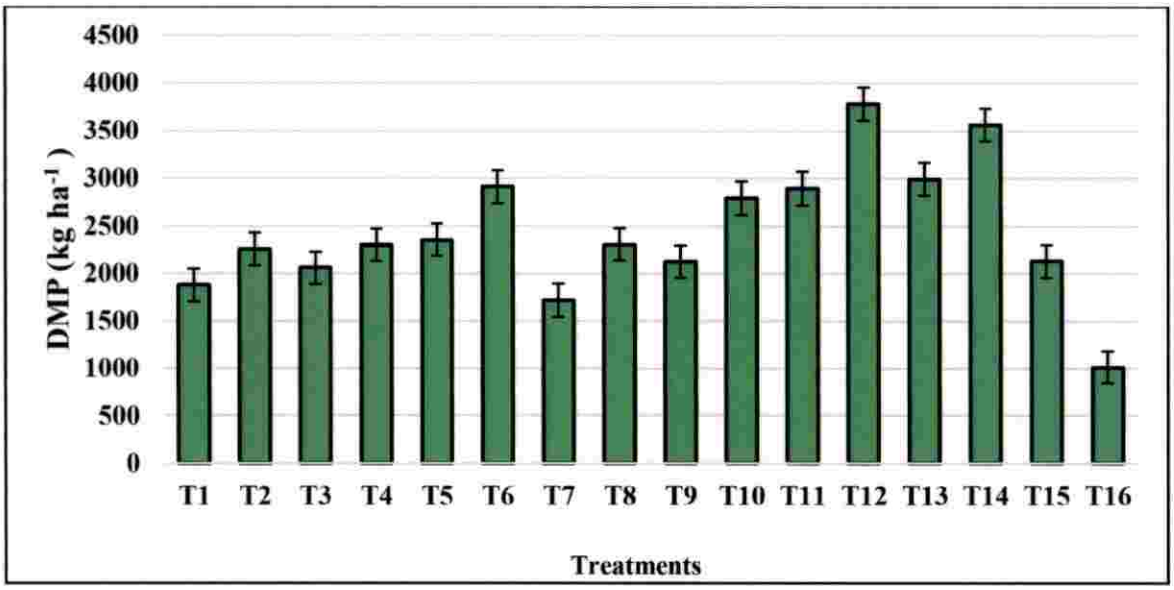
Data pertaining to dry matter production of both direct test crops were presented in fig. 27 a and b. Dry matter accumulation of okra plants varied significantly due to the application of organic nano NPK formulations. The highest dry matter production was obtained in T_{12} for both the direct test crops. This might be due to the combined soil and foliar application of organic nano NPK formulations which increased the bioavailability through root and stomata resulted in overall growth of the plants. This might also be due to the unique properties of nanoparticles such as large surface area and the presence of more reactive oxygen that enhances the photosynthetic rate and metabolic activities. Similar results were also reported by Suriyaprabha *et al.* (2012). According to Liu and Liao (2008) observed enhanced uptake of N, P and K leads to the accumulation of biomass due to the application of nanomaterials. Manikandan and Subramanian (2015) stated that when zeolite based nano nitrogen were applied to maize plants that leads to the increase in biomass production because of increased N availability and reduced nitrogen loss. Characterization study of organic nano NPK formulations showed that both formulations contained primary, secondary, micronutrients, amino acid, humic acid etc which inturn enhanced the availability of all the nutrients in a steady rate. The significant and positive relationship of DMP with yield, number of fruits per plant, number of branches per plant and plant height of first and second direct crops in the present investigation adds support for the above inference.

5.3.1.5 Root length and root volume

From table 22 it was clear that root length and root volume were significantly influenced by the treatments in both direct test crop experiments. The results indicated that in general, combined soil and foliar application of organic nano NPK formulations enhanced the root length and root volume. Addition of organic manure (FYM) also might have enhanced the root biomass production. Increased root parameters might be



a. Dry matter production, kg ha^{-1} (Experiment No: I)



b. Dry matter production, kg ha^{-1} (Experiment No: III)

Fig. 27. Influence of organic nano NPK formulations on dry matter production in okra

due to the fact that nanofertilizers can easily enter into the seeds and thereby increase the availability of nutrients to the seedling resulted in healthy root growth. Prasad *et al.* (2012) reported that zinc oxide nano formulation recorded higher root growth as compared to that of bulk zinc sulphate. Sudha and Staline (2015) opined that increased root weight resulted in higher nitrogen fixation that leads to enhanced root enlargement can enable the plants to uptake nutrients. Similar results were also reported by Rico *et al.* (2011) that nanofertilizer have positive effect on root length and vegetative biomass of crop plants. Maximum root length of maize plant was observed when nano sized clinoptilolite was applied at 0.1 per cent (Trinchera *et al.*, 2010).

5.3.2 Influence of granular and liquid nano NPK formulations on physiological characteristics of okra (Varsha Uphar)

Data on various physiological parameters *viz.*, chlorophyll a, chlorophyll b and total chlorophyll content are presented in table 23.

The chlorophyll a, chlorophyll b and total chlorophyll content varied significantly with treatments. In the both direct test crop experiments chlorophyll a, chlorophyll b and total chlorophyll content were found to be higher in treatments that received combined soil and foliar application of organic nano NPK formulations. This might be due to increased availability of nutrients through root and stomata which resulted in increased chlorophyll content and overall growth of the plants which inturn enhanced the photosynthetic activities. The results obtained was similar to the result of Zheng *et al.* (2005) who reported that when TiO_2 nano particles were applied at lower concentration to spinach plants resulted in higher chlorophyll content and photosynthetic activity. Mohanraj (2013) reported that the chlorophyll content of rice was increased upto the flowering stage when NH_4^+-N loaded nano zeolite was applied. When nanofertilizers were applied leads to increment in the physiological activities of the plants like photosynthesis, resulting increased chlorophyll content, which in turn leads to increase in dry weight content (Tantawy *et al.*, 2014).

5.3.3 Effect of granular and liquid nano NPK formulations on yield and yield attributes of okra (Varsha Uphar)

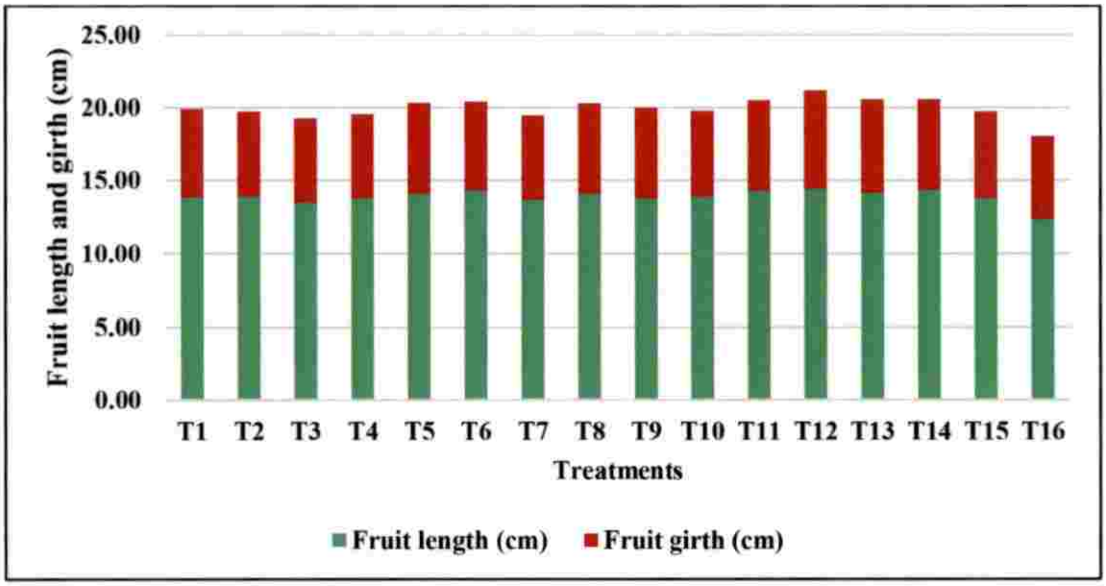
Important parameters recorded were days to first flowering, days to 50 % flowering, fruit length, fruit girth, number of fruits per plant, crop period, average fruit weight and total fruit yield (Plate 11-12).

5.3.3.1 Days to first flowering and days to 50% flowering

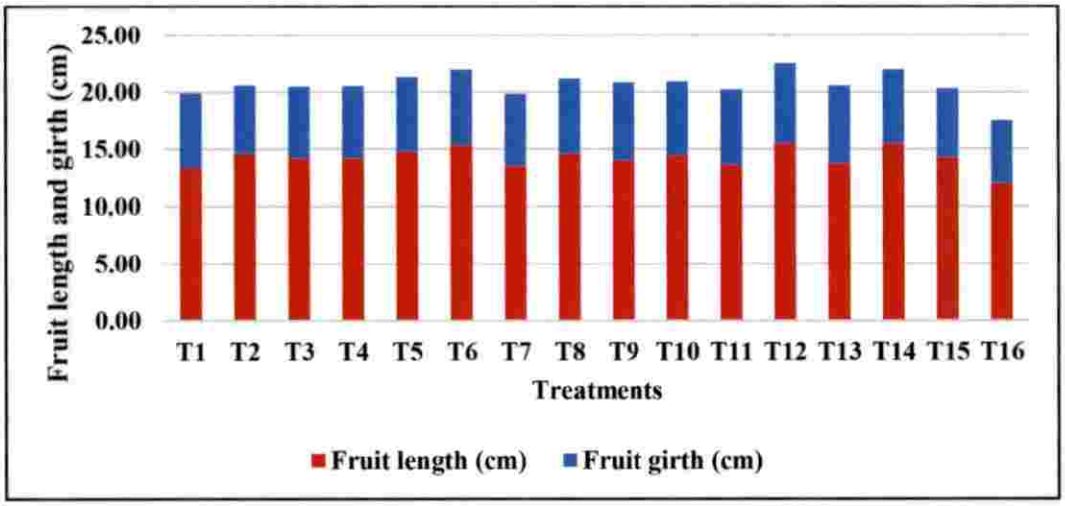
Different treatments significantly influenced the days to first flowering and days to 50 per cent flowering in both direct test crops. In general, application of nano NPK formulations with and without FYM increased the earliness of flowering and 50 per cent flowering which might be due to the presence of primary, secondary, micronutrients, amino acids and organic acids present in organic nano NPK formulations. From the results it can be claimed that plant nutrition is the factor that partially affect the mechanism behind the flowering. These results are in line with that reported by Kumar *et al.* (2009) and Kobraee *et al.* (2011). Janmohammadi *et al.* (2016 a) reported that application of nano SiO_2 along with high rate of FYM could reduce the duration of vegetative phase, days to flowering. The time taken for 50 per cent flowering was slightly triggered in the treatments received with nano calcite application (Kumara *et al.,* 2017).

5.3.3.2 Fruit length and girth

The treatments imparted significant effect on both fruit length and girth (Fig. 28 a and b). The longer fruits were recorded in FYM along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK (0.4 %) which was comparable with T_{14} and T_6. For the confirmatory crop also similar trend was observed. In case of fruit girth, the highest fruit girth was recorded in T_{12} for both direct test crop.



a. Fruit length and fruit girth, cm (Experiment No: I)



b. Fruit length and fruit girth, cm (Experiment No: III)

Fig. 28. Effect of organic nano NPK formulations on fruit length and fruit girth of okra, cm

Plate 11. Effect of treatments on fruit length of okra

Plate 12. Effect of treatments on fruit yield of okra

T_{12} was on par with T_{13}, T_9, T_5, T_{14}, T_8 and T_{11} with respect to the first direct test crop. In general, combined soil and foliar application of nano NPK formulations registered higher fruit length and fruit girth compared to other treatments. This might be due the simultaneous absorption of plant nutrients through root and stomata. Yassen *et al.* (2017) reported that the increase in application of nano-Si spray enhanced the growth parameters *viz.,* fruit length and girth. According to Bozorgi (2012) enriched nano chelated iron fertilizer significantly improved the fruit length and fruit width.

5.3.3.3 Number of fruits per plant

The treatments imparted significant effect on number of fruits per plant (Table 26). Maximum number of fruits per plant was obtained in treatment which received FYM along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK (0.4 %) formulations for both direct test crops. This might be due to the fact that organic nano NPK formulations are considered as the biological pump for the absorption of nutrients and increased activity of chloroplast. Keshavarz *et al.* (2011) reported that the nano iron chelate fertilizer increment the yield because of complete uptake of fertilizer throughout the growing season and thereby improved the crop yield.

5.3.3.4 Crop period

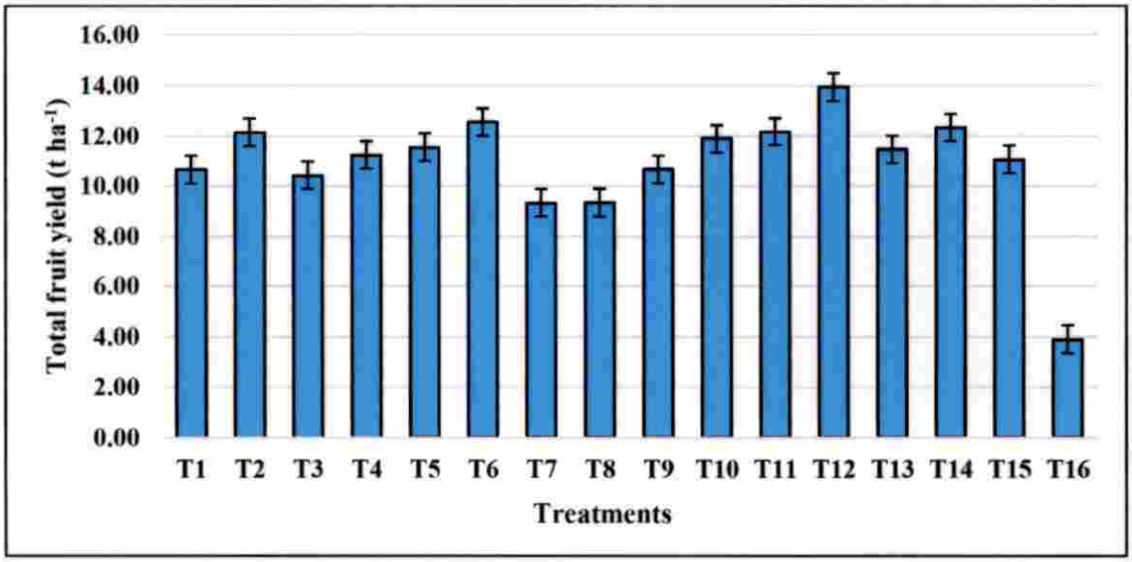
Data presented in table 24 revealed that treatments varied significantly with respect to crop period. Application of FYM along with soil application of nano NPK and foliar application of nano NPK formulations (T_{12}) recorded the highest crop period and was on par with T_{14} for both direct test crops. This might be due to the fact that balanced nutrition helped in the better partitioning of photosynthates and helped in keeping the plants in physiologically active stage for longer period and delayed senescence. Similar findings were reported by Qureshi *et al.* (2018).

5.3.3.5 Average fruit weight and total fruit yield

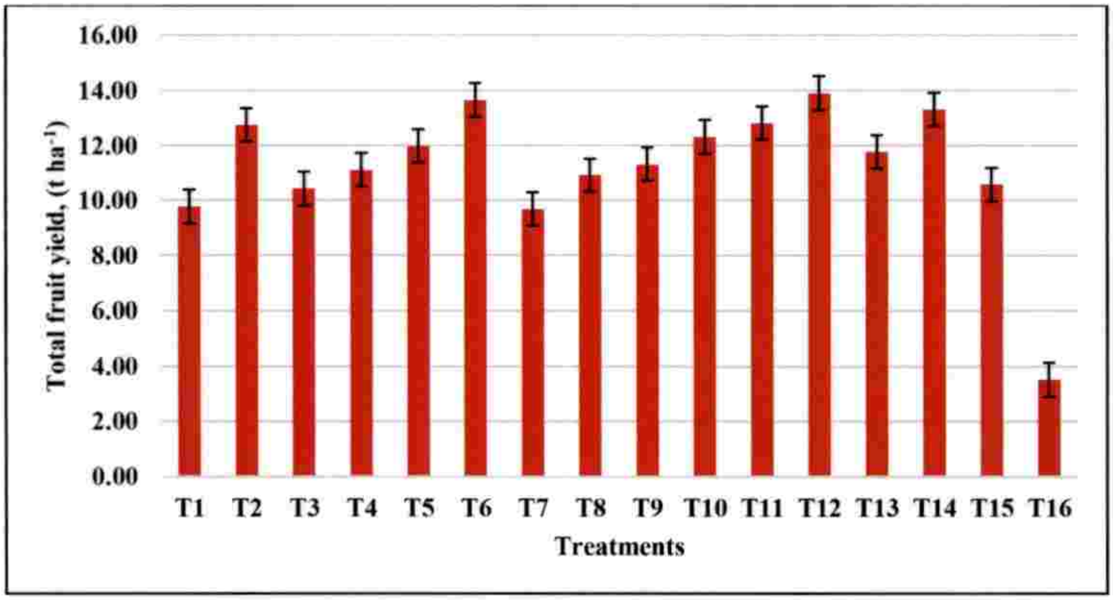
Characterization study of organic nano NPK formulations indicated that primary, secondary and micronutrients which are essential for plant growth are present in organic nano NPK formulations which might have improved the physiological activities and leading to better fruit production in okra. The highest average fruit weight (Table 26) and total fruit yield (Fig. 29 a and b) were registered by the treatment, T_{12} that received combined soil and foliar application of nano NPK formulations along with FYM for first and third field experiments. Application of organic nano NPK resulted in increased growth of plant parts, increased metabolic activities such as photosynthesis and higher accumulation and translocation of photosynthates to the economic parts of the plant. Many scientific reports support that nanoparticles will penetrate in the plant cell through stomatal opening and natural nanopores which may enhance plant cell metabolic activity that leads to higher crop production.

Application of organic manure could able to improve the availability of native nutrients to the crops which stimulated root system in better absorption of water and nutrients from lower layers resulting in higher uptake and yield (Thenmozhi and Paulraj, 2009). Similar findings were reported by (Benzon *et al.*, 2015). Similarly, Tarafdar *et al.* (2012b) reported that crop yield could be increased due to the foliar application of nanofertilizers. Wu (2013) also reported that yield attributes of the crop could be increased because nano NPK fertilizers promote the plants to absorb water as well as nutrient. The yield attributes like fruit length (r=0.889**, 0.801**), fruit girth (r=0.474**, 0.706**) and number of fruits per plant (r=0.687**, 0.660**) infirst and second direct test crop had positive and significant relationship with yield further confirmed the above results. Bozorgi (2012) opined that nano iron chelate applied as foliar spray could able to increment the yield and yield components of eggplant.

When nanofertilizers was compared with that of chemical fertilizers due to the slow and sustainable release of nutrients to the plants, also act as the growth stimulator



a. Total fruit yield, t ha^{-1} (Experiment No: I)



b. Total fruit yield, t ha^{-1} (Experiment No: III)

Fig. 29. Effect of organic nano NPK formulations on total fruit yield of okra

and carrier of nutrient absorption by the plants that leads to enhanced yield and the yield attributing characters (Hatwar *et al.,* 2003, Liu *et al.,* 2009 and Liu *et al.,* 2017). El-Tanahy *et al.* (2012) observed a positive relation between chitosan applied and its response to all plant growth parameters and yield attributes. When TiO_2 nanoparticles were applied as foliar spray it improve the photosynthesis, metabolism and also improve the crop yield (Choi *et al.,* 2005).

The characterization study of organic nano NPK formulations (Table 4) contained amino acid which helped in their translocation to the reproductive organs and thereby enhanced the growth and yield. This is in agreement with the findings of Dongarkar *et al.* (2005). Liu and Lal (2014) reported that nanofertilizers, are nanomaterials that can supply one or more nutrients to the plants, enhanced growth and yield when compared to conventional fertilizers. The findings was confirmed by positive correlation between available macro, secondary and micronutrients with yield of first and second direct test crop.

It is scientifically proved from the present study that conventional fertilizers can be totally substituted with organic nano NPK formulations with respect to yield and yield attributes of okra. On an average 30 per cent increase in yield was obtained by substituting conventional fertilizers with combined application of granular (12.5 kg ha^{-1}) and liquid organic nano NPK (0.4 %) formulations.

5.3.4 Effect of granular and liquid nano NPK formulations on quality parameters of okra (Varsha Uphar)

5.3.4.1 Crude protein

With respect to crude protein content of okra fruits, treatments exhibited significant influence (Table 27). In general, most of the treatments that received nano NPK formulations with and without FYM had recorded higher content of crude protein. It was observed that soil application of lower dose of nano NPK formulation

(12.5 kg ha^{-1}) along with foliar application of liquid nano NPK (0.4%) with FYM recorded the maximum crude protein content in both the experiments. The observed increase in crude protein content may be due to slow and steady release of nutrients from organic nano NPK formulations that balancing and increasing the nitrogen content and uptake by the plants, which resulted in improved protein content in plants. Soliman *et al.* (2016) reported that due to the greater density and reactive areas of hydroxyapatite nanoparticle increased the uptake of nitrogen that leads to enhanced crude protein content of plants. According to Manikandan and Subramanian (2015) and Qiang *et al.* (2008) the prolonged availability of nutrients to the plants resulted in grain nutrient content and protein content.

5.3.4.2 Crude fibre

The treatments imposed significantly influenced the crude fibre content of okra fruit in both direct test crops (Table 27). The lowest crude fibre content was noticed in treatment which received FYM along with soil application of nano NPK (25 kg ha^{-1}) and foliar application of nano NPK (0.2 %) formulations (T_{14}) for both direct test crops. In general, crude fibre content of the treatments that received organic nano NPK formulations were found to be lower than treatment that received conventional fertilizers. This might be due to the availability of plant nutrients in a balanced state due to the application of organic nano NPK formulations along with FYM. According to Sulc *et al.* (2015) reported impact of nanofertilizers on quality of forage that an increase in crude protein content resulted a decrease in crude fibre content. When forage plants were applied with the combination of Agricolle + Nagro at an optimal combination resulted in decrease in fibre content of the plants (Nikolova *et al.,* 2018).

5.3.4.3 Ascorbic acid

There was significant difference between the treatments with regard to ascorbic acid content (Table 27). In the case of first direct test crop the highest ascorbic acid content in okra fruit was registered in T_{14} and was found to be on par with T_6, T_{12}, T_{10}, T_{13} and T_{11}. With respect to the confirmatory direct test crop significantly higher content of ascorbic acid content was recorded by T_{12} and it was on par with the effects of T_{13}, T_{14}, T_6 and T_{10}. The enhanced ascorbic acid content in the fruit might be due to the better photosynthetic efficiency and uptake of nutrients from organic nano NPK formulations by the plants which help in the synthesis of chlorophyll and increased ascorbic acid content of the fruit. Kallo *et al.* (1986) reported that increase in ascorbic acid might be due to the combined effect of humic substance, nano zeolite and biofertilizers resulted in release of nutrients in available form for the uptake of plants and vitamin synthesis in the plant tissue.

Treatments that received combined application of organic nano NPK formulations recorded higher crude protein content, lower crude fibre content and higher ascorbic acid content than treatment that received conventional fertilizers.

5.3.5 Incidence of pest and diseases

Incidence of pest and disease was observed rarely during the crop growth stages. Incidence of semi loopers, fruit and shoot borers were noticed initially and controlled by using nimbicidine during the first crop and in the confirmatory crop. The characterization of organic nano NPK formulations indicated that primary, secondary, micronutrients, amino acid and organic matter fractions were present in the two nano formulations and released the nutrients in a slow and steady rate which helped in maximum absorption by the plant that might have imparted resistance against pest and diseases. Kumara *et al.* (2017) reported that application of nano calcite increased the crop biomass, productivity and also improve the plants to resist against pest and diseases. Several studies reported that calcium application can strengthen against pest and diseases. Jarrell and Beverly (1981) noticed that nano calcium application can reduce the incidence of grey mould symptoms and the severity of *Botrytis blight* in rose during the post harvest stage. Similar results were reported by Hua *et al.* (2015) stated that application of nano calcium carbonate increased the plant resistance against insect pests.

5.3.6 Effect of granular and liquid nano NPK formulations on post harvest soil properties

5.3.6.1 Physical properties

5.3.6.1.1 Bulk density and water holding capacity

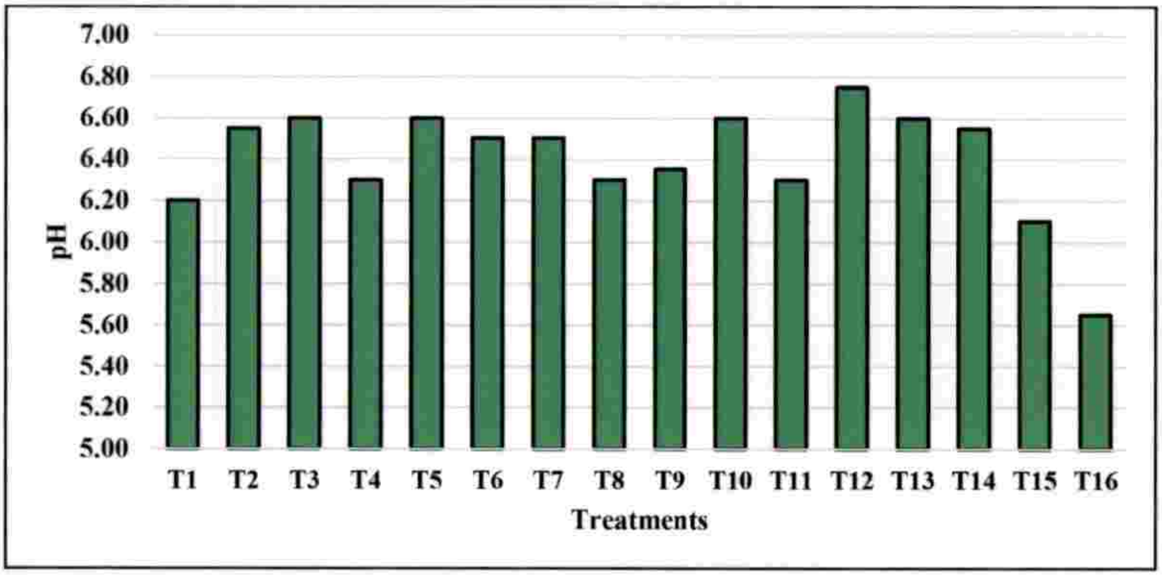
After first direct test crop and confirmatory direct crop the bulk density of the post harvest soil did not showed any significance due to the application of various treatments.

Regarding the water holding capacity significant difference was observed with different treatments. WHC was higher in treatments received soil application of nano NPK formulations. This might be due to the fact that when organic nano NPK formulations were applied to the field which resulted in improved soil physical and chemical properties of the soil which inturn resulted in increased water holding capacity of the soil. According to Pisey *et al.* (2011) reported that zeolite based nanofertilizers could improve the water holding capacity of the soil. Liu and Lal, (2012) opined that fine grained zeolite when applied to the mined soil improve the silt and clay fractions, thereby resulted in improved water holding capacity and lower bulk density.

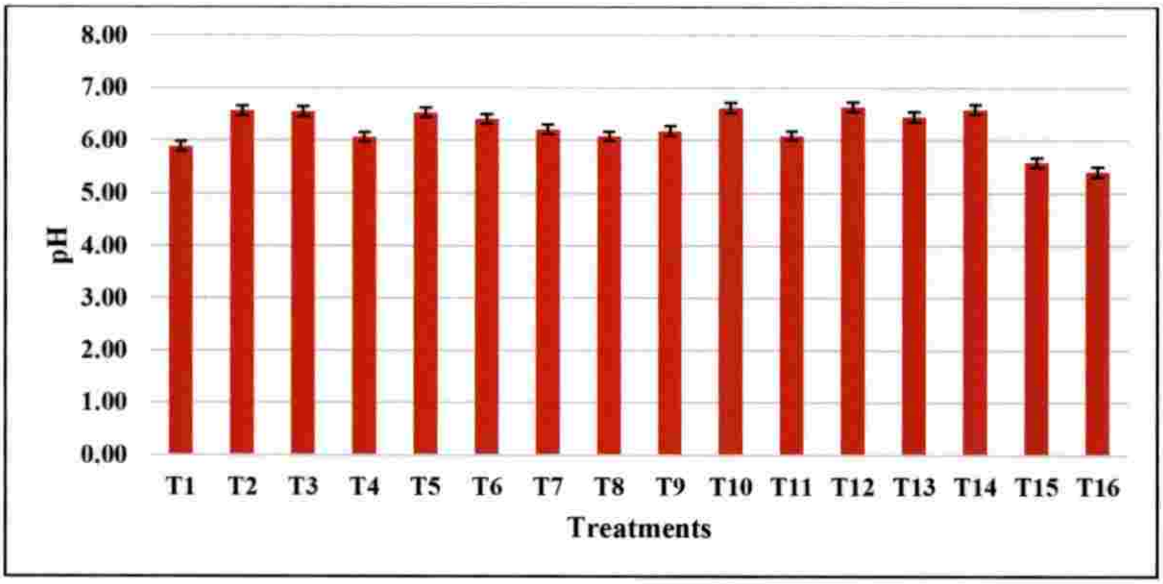
5.3.6.2 Chemical properties

5.3.6.2.1 pH

Application of organic nano NPK formulations resulted in significant effect on the pH of the soil (Fig. 30 a and b). pH of the soil increased after both direct field experiments when compared to their initial pH which ranged from strongly acidic to



a. Soil pH (Experiment No: I)



b. Soil pH (Experiment No: III)

Fig. 30. Effect of organic nano NPK formulations on pH of the post harvest soil of okra

slightly acidic. Application of FYM along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK formulations (0.4%) (T_{12}) registered the highest pH for both direct test crops. From the characterization study, the granular and liquid nano NPK formulations recorded the pH of 7.68 and 6.55, respectively. Increase in soil pH may be due to increase in bases by active degradation of organic matter and suppression of Fe and Al oxides and hydroxides activities. Liu *et al.* (2006) stated that nanoformulation could improve the physical condition of the soil because of the soil reaction between nano composite and natural organic mineral granules. Ahmed *et al.* (2010) reported that application of zeolite improved the nutrient availability in the soil and resulted in increase in soil pH. Application of silicon nanofertilizers in acidic soil registered an increase in soil pH. Similar study was showed by Tubana *et al.* (2012) that addition of silicon resulted in decrease in Mehlich-3 extractable Fe and Ni and thereby resulted increase in soil pH. Similarly Ming and Allen (2001) reported that when zeolite was added to the soil the pH of the soil was increased.

5.3.6.2.2 Electrical conductivity

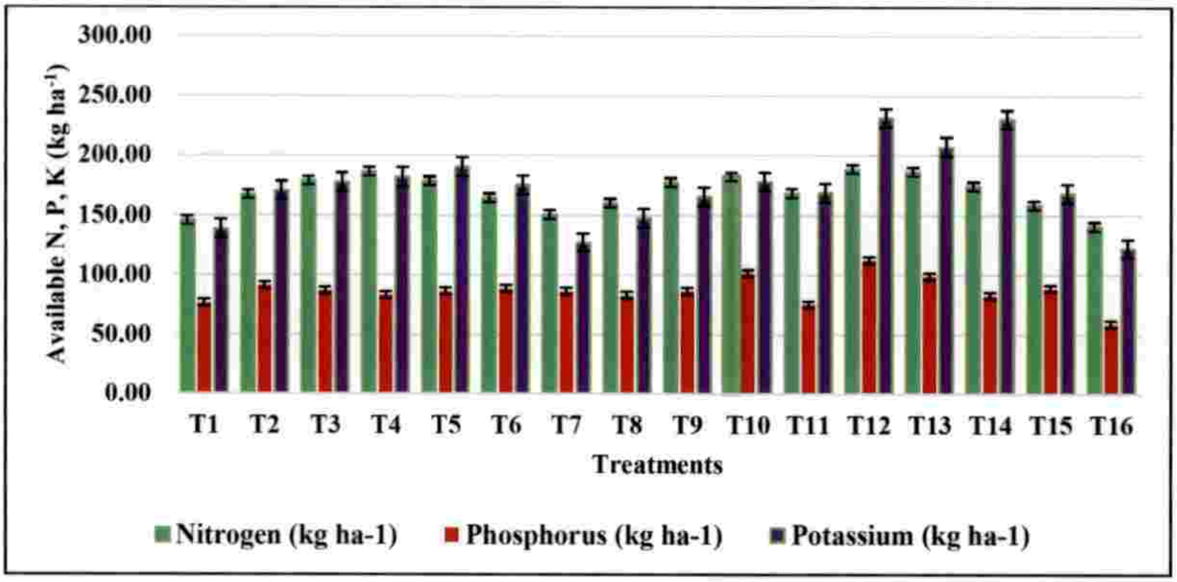
The electrical conductivity of post harvest soil shows significant difference between the treatments (Table 29). The highest EC was noticed in treatment T_4, which received FYM along with soil application of nano NPK formulation 25 kg ha^{-1} in first and second direct test crops. This might be due to faster release of bases and soluble fractions to the soil from organic nano NPK formulations. EC of the soil also increased due to the application of organic manures. Ming and Boettinger (2001) opined that application of zeolite to the soil resulted an increase in EC which leads to increment in the nutrient retention capacity of the soil. Similarly Mia *et al.* (2010) and Rus *et al.* (2004) reported that EC of the nanofertilizer treated soil increased due to high dissolution rate and salty nature.

5.3.6.2.3 Organic carbon and labile carbon

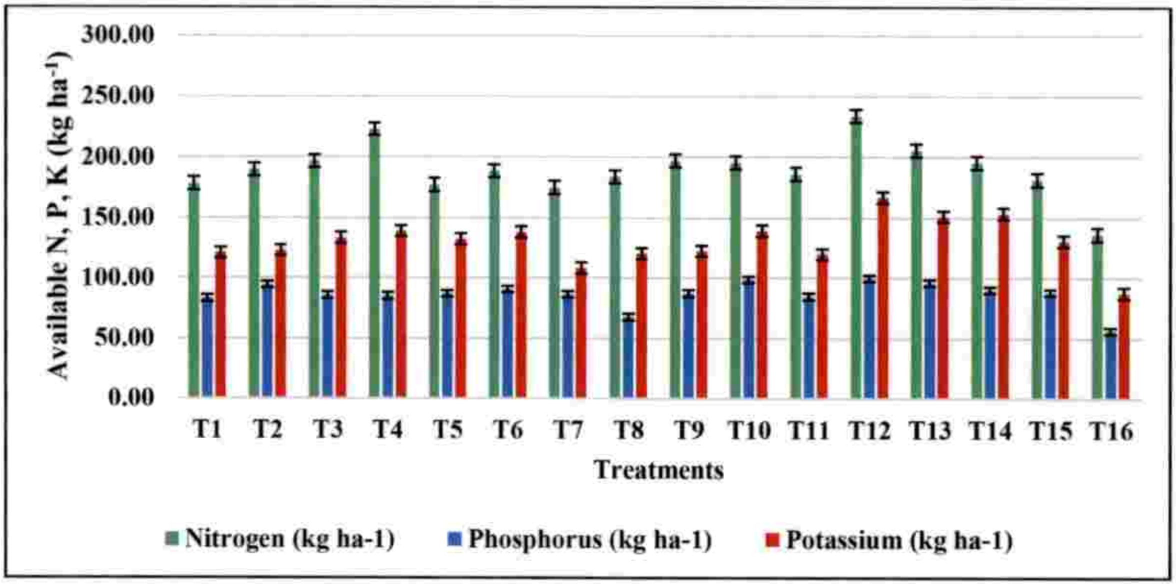
Regarding organic carbon content, application of FYM along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK formulations (0.4 %) (T_{12}) registered the highest organic carbon content in the post harvest soil of both direct test crop and was on par with T_{10} and T_4 in first direct test crop. In the case of confirmatory crop T_{12} was on par with T_4. For both okra crop the highest labile carbon was registered in T_{12} and for the first crop it was found to be on par with T_{13} and T_4. The increase in OC might be due to the application of organic nano NPK formulations (OC=2.25 %) which resulted in root biomass accumulation with enhanced growth of crop. Labile carbon means active pool of carbon and are considered to respond more quickly to the management practices in soil than that of SOC and sensitive indicators of SOC changes. This might be due to interaction taking place between microbial-soil-plant at the nanosites in the rhizosphere that may stimulus the balance of organic matter and the availability of the nutrients for crop uptake. Mia *et al.* (2010) reported that the high dissolution rate of nano silica and their salty nature may contribute to an increase in the conductivity and OC content in soil. The soil fertility of the nanofertilizer treated soil improved due to the organic acid present in the nanofertilizer which improve the chelation rate of micronutrients (Tavakoli and Khoshkam, 2013). Characterization study of organic nano NPK formulation indicated the presence of humic acid (29.86 %), fulvic acid (16.73 %) and humin content (5.90 %) which might have influenced the organic carbon and labile carbon content of the post harvest soil.

5.3.6.2.4 Primary nutrients

The effect of treatments on available nitrogen, phosphorus and potassium of soil after the harvest of both direct test crops are represented in fig. 31 a and b. Characterization study indicated that organic nano NPK formulations contained



a. Available N P K, kg ha^{-1} (Experiment No: I)



b. Available N P K, kg ha^{-1} (Experiment No: III)

Fig. 31. Available N P K status (kg ha^{-1}) of post harvest soil of okra as influenced by organic nano NPK formulations

primary, secondary, micronutrients, amino acid, organic acid etc that might have effected the available nutrients in the post harvest soil.

The highest post harvest soil available nitrogen after both direct test crop was recorded by treatment T_{12} and it was comparable with T_4, T_{13}, T_{10}, T_3, T_5, T_9 and T_{14} after the first direct test crop. Similarly for the confirmatory test crop, T_{12} was on par with T_4. The increased available nitrogen might be due to the combined application of FYM along with organic nano NPK formulations. Nitrogen was released from organic nano NPK formulations by mineralization and the mineralization of organic matter also resulted in the increased availability of soil nitrogen. Hussein *et al.* (2015) reported that nanofertilizers having both positive and negative charged binding site adsorbed the available nitrogen in the soil and thereby reduce the loss and resulted in increased uptake of nitrogen by the crop. The release of nanofertilizer to the soil is slowed down due to the tight bondage of ammonium ions in the nano pores of zeolite (Junxi *et al.*, 2013 and Perrin *et al.*, 1998). Application of chitosan nano particle increased the key enzymatic activities of nitrogen metabolism thereby enhanced the crop growth and development (Ke *et al.*, 2001).

Available P in the post harvest soil of both direct test crop were found to be the highest for T_{12}. In the case of second direct test crop T_{12} was on par with T_{10}. This might be due to the availability of P present in organic nano NPK formulations released slowly and are absorbed by roots and thereby improve the plant growth. This is similar to the findings of Suriyaprabha *et al.* (2014) who reported that application of nano silica into the soil leads to an increase in soil microorganisms that specifies the enhanced soil fertility and their availability of nutrients to the plants. Soliman *et al.* (2016) stated that when nano phosphatic fertilizer applied to the soil because of the large surface area of nanoparticle leads to enhance the fixation of plant nutrients thereby resulted in minimize the losses and enhanced the crop growth.

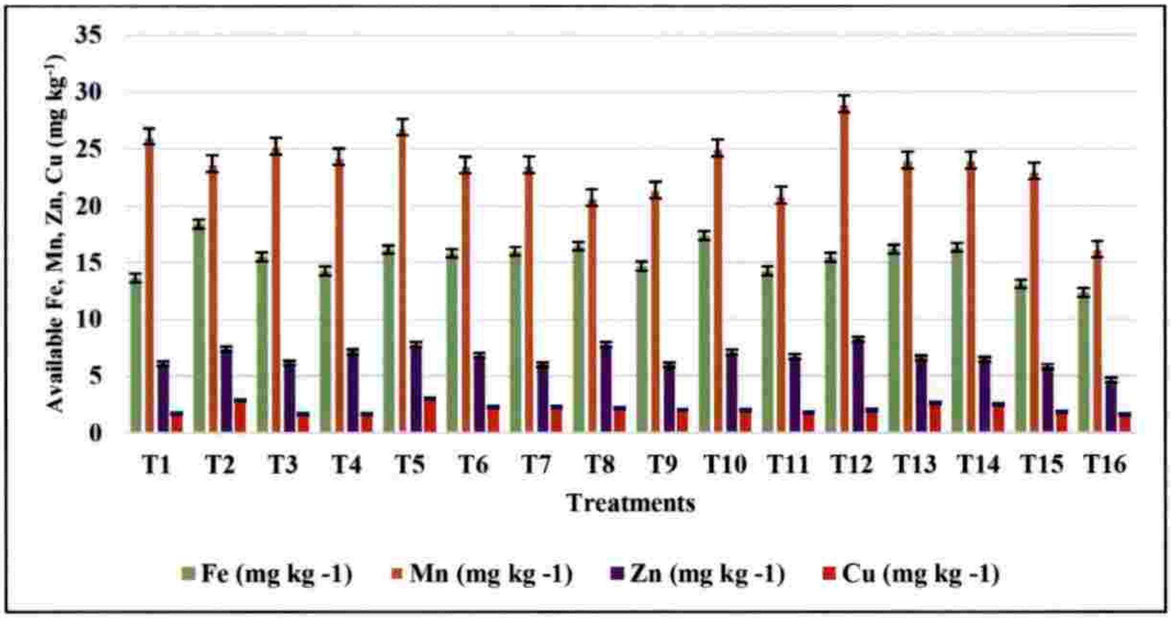
Highest available potassium was recorded in treatment which received application of FYM along with soil application of nano NPK formulation and foliar application of nano NPK formulation (T_{12}) and was followed by T_{14} for both direct field experiments. This might be due to the high potassium content of organic nano NPK formulations as specified in the characterization study. Junrungreang *et al.* (2002) and (Zhou and Huang, 2007) stated that potassium is released in a slow and steady manner from nano zeolite. Kallo *et al.* (1986) reported that natural zeolite loaded with nano nitrogen attain large surface area and release ammonium, nitrate, potassium, magnesium and calcium in a slow manner.

5.3.6.2.5 Secondary nutrients

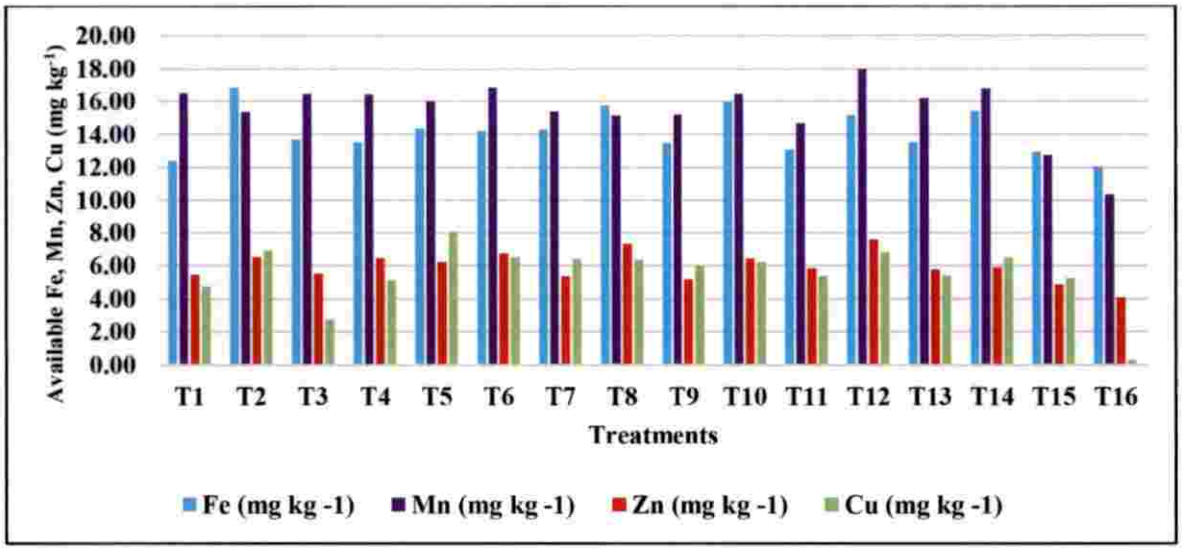
Application of organic nano NPK formulations showed a significant influence on the treatments (Table 31). The maximum exchangeable calcium for both direct test crop was found in T_{12}. But in the case of first direct test crop T_{12} was on par with T_2, T_{10}, T_4, T_5, T_{14}, T_6, T_7 and T_3. In the case of exchangeable magnesium of post harvest soil of two direct test crops, treatment T_2 which received application of FYM along with soil application of nano NPK formulation 12.5 kg ha^{-1} recorded the highest exchangeable magnesium and was comparable with T_7, T_5, T_{12} and T_{14} in the case of first direct test crop. The highest available S was recorded by T_{14} after the two direct field experiments. In case of confirmatory crop T_{14} was comparable with T_{13}, T_{12} and T_{10}. This might be due to the decreased susceptibility of nutrients due to adsorption, fixation or precipitation reaction in soil resulting in an increased availability of calcium, magnesium and sulphur. Similar results were also reported by Pandya and Bhatt (2008) who reported that the sulphur status in soil was improved when sulphur was applied. Application of nano composite have enhanced the available calcium, magnesium and sulphur of soil (Preetha, 2011). Perez-Caballero *et al.* (2008) observed that treatments which received zeolite improved the concentration of P, K and Ca in the soil because zeolite had the ability to adsorb nutrients from the fertilizer as well as reduce the leaching loss. Similar observations were reported by Kallo *et al.* (1986) that zeolite containing both macro and micronutrients, provide large surface area on which the chemical reactions take place by slow release of ammonium, nitrate, potassium, magnesium, calcium as well as trace elements as and when it is needed. The nanoparticles can prevent fixation as they can be adsorbed on the clay lattice, thereby leading to the release of nutrients into the soil solution (Das, 2011).

5.3.6.2.6 Available micronutrients

Application of organic nano NPK formulations showed a significant influence on the available micronutrient after first direct test crop and confirmatory direct test crop and is represented in fig. 32 a and b. Treatment which received FYM along with soil application of nano NPK formulation 12.5 kg ha^{-1} recorded the highest available Fe after the harvest of two direct test crops. T_{12} recorded the highest available Mn and Zn in post harvest soil of first and third field experiments, but in the case of available Mn after the first direct test crop T_{12} and was on par with T_5. The highest available Cu in the soil was observed in T_5 in first direct test and confirmatory direct test crops. This might be due to application of organic nano NPK formulations which are more available at nano scale resulting in enhanced uptake of nutrients and improved the efficiency. Broos *et al.* (2007) reported that Zn is slowly released due to the sparingly solubility of minerals thereby releasing trace elements to zeolite exchange sites resulting in increased uptake of nutrients by the plants. Tavakoli and Khoshkam (2013) observed that application of nanofertilizer which contain metal and non-metal oxide nano particle resulted in improved availability of nutrients. Mazur *et al.* (1986) pointed out that nanofertilizer significantly enhanced the available Fe, Mn, Zn and Cu in the soil. In general nanofertilizers application showed more effect on available micronutrients status than the conventional fertilizer application.



a. Available micronutrients, mg kg $^{-1}$ (Experiment No: I)



b. Available micronutrients, mg kg $^{-1}$ (Experiment No: III)

Fig. 32. Effect of organic nano NPK formulations on available Fe, Mn, Zn and Cu content of the post harvest soil

5.3.6.2.7 Nutrient use efficiency

The highest nutrient use efficiency was recorded in T_{12} in both direct test crops. This might be due to the fact that organic nano NPK formulations have large surface area and less pore size of root and leaves of the plant improve the penetration of nutrients by the plants and resulted in uptake of nutrients as well as improved nutrient use efficiency of the nanofertilizer. Organic nano NPK formulations facilitates slow and steady release of nutrients thereby reduced loss of nutrients and enhanced nutrient use efficiency by the crops. Similar results were reported by Datta (2011) and Liscano *et al.* (2000) that nanoparticle facilitate slow and steady release of nutrients resulting enhanced nutrient use efficiency. Subramanian *et al.* (2008) and Chang (1997) reported that nutrient use efficiency increased due to the control release of nutrients from nano-composites by preventing nutrient ions get fixed or lost to the environment. Nanofertilizer is known to release nutrients for longer period of time particularly nitrogen which has an added advantage of environmental protection. Nanofertilizers are target specific and deliver the nutrients to the rhizosphere, thereby improving the nutrient use efficiency of the crop. Owing to the small size, nanoparticles have very high surface area, ion adsorption capacity, cation exchange capacity and complexation capacity (Mukhopadhyay, 2014). The propensity of nanoparticles to adsorb even on clay lattice, preventing the fixation of nutrients and makes the nutrients available into the soil solution which can help in efficient nutrient uptake by the plants.

5.3.6.3 Biochemical properties

Soil enzymes are considered as the best indicator of microbial diversity of the soil because they are secreted microorganism extracellularly thereby help in nutrient recycling and microbial propagation. Enzymes play an important role during the initial phase of decomposition for the proliferation of microorganisms (Kiss *et al.,* 1975). Some important enzymes discussed below were dehydrogenase, urease, acid phosphatase and alkaline phosphatase. A view of enzymatic assay of dehydrogenase, urease, acid phosphatase and alkaline phosphatase are shown in Plate 13.

5.3.6.3.1 Dehydrogenase

Dehydrogenase enzyme which catalyze various oxidation reactions in the soil are considered as the indicator enzyme that reflect the overall microbial activity. Dehydrogenase activity of the post harvest soil of both direct test crop as influenced by different treatments is presented in table 34 a. The highest dehydrogenase activity in the soil was obtained in T_{12} after the two direct test crops. After the harvest of first direct test crop T_{12} was comparable with T_9 and T_{14}. Dehydrogenase activity is known to oxidize soil organic matter by moving protons and electrons from substrate to acceptors. Wang *et al.* (2012) reported that oxidized nano carbon tubes enhanced the root growth this might be due to the improved dehydrogenase enzymes activities in the roots. Application of chitosan nano particle increased the key enzymatic activities of nitrogen metabolism thereby enhanced the crop growth and development (Ke *et al.*, 2001).

5.3.6.3.2 Urease

The highest urease activity was recorded by T_{12} of the post harvest soil of two direct test crop. In the case of first direct test crop T_{12} was on par with T_{14}, T_6, T_7 and T_{13}. With respect to second direct test crop, T_{12} was on par with T_{14}, T_{13}, T_6, T_4 and T_2. Enzymatic activities were significantly influenced due to the application of nanoparticle and enzymes are considered as the bio indicators of soil health. Rai and Yadav (2011) reported that increased microbial population showed an enhanced in dehydrogenase and urease activity in the soil and also stated that both the enzymes were positively and significantly correlated with organic carbon content in the soil. Similarly, Hossain *et al.* (2008) reported that release of nitrogen by urea hydrolysis can be controlled by insertion of urease enzymes into nanoporous silica.

Dehydrogenase

Urease

Acid phosphatase

Alkaline phosphatase

Plate 13. A view of colour development in estimation of different enzyme activity

5.3.6.3.3 Acid and alkaline phosphatase

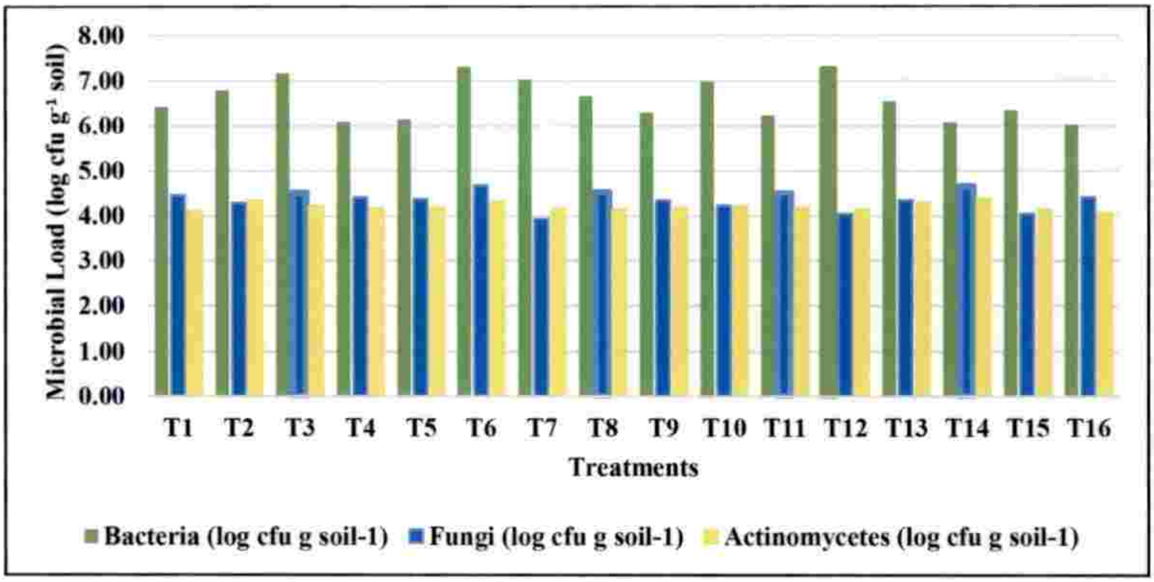
The highest value of acid phosphatase activity was obtained in treatment that received with FYM along with soil application of nano NPK 12.5 kg ha^{-1} and foliar application of nano NPK 0.4% for both direct test crops. In case of first direct test crop T_{12} was on par with T_{14}, T_6 and T_4. You *et al.* (2017) reported incubation of metal oxide nanoparticle could influence the soil enzymatic activities and soil bacterial community. Phosphatase is a common enzyme seen in all microorganisms, more over its activity is mainly influenced by increase in microbial biomass. The temporal sequence of this enzyme might be due to the differential production rates, influenced by the physiological ages of various groups of microorganism (Srinivas *et al.*, 2003).

The highest mean value of alkaline phosphatase was reported in T_{12} on the post harvest soil after first and third field experiments. But in the case of first direct test crop T_{12} was comparable with T_2, T_4 and T_7. Le *et al.* (2014) reported that application of nano SiO_2 stimulate the enzymatic activities in the soil and also enhanced the antioxidant activity.

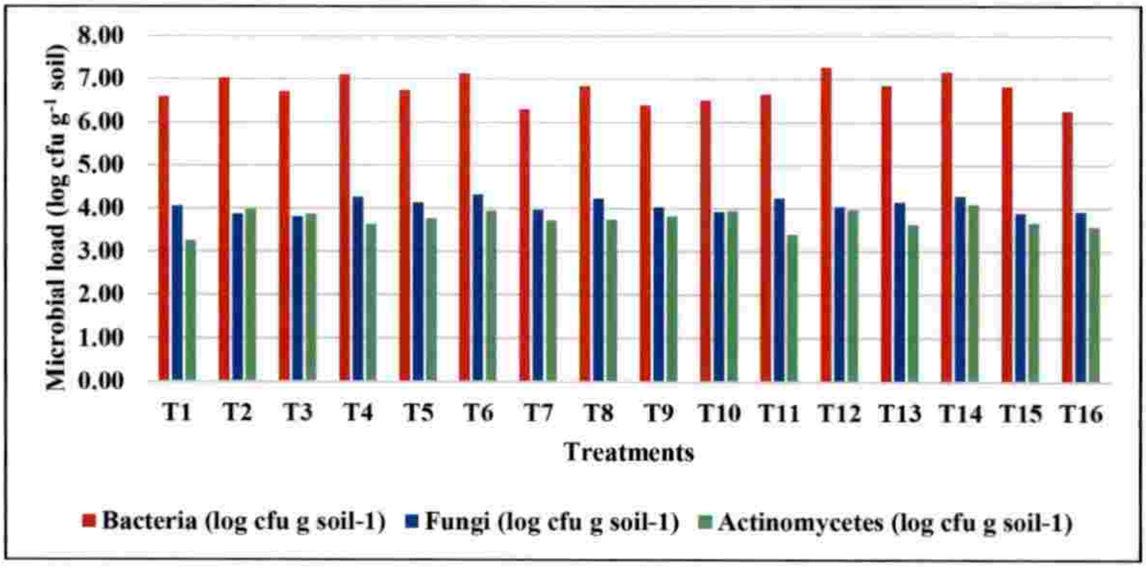
5.3.6.4 Biological properties

Soil biological properties (Fig. 33 a and b) showed that application of organic nano NPK formulations significantly influenced the bacterial, fungal and actinomycetes counts in the post harvest soil of both direct test crops.

The highest bacterial and fungal counts were noticed in treatment which received FYM along with soil application of organic nano NPK 50 kg ha^{-1} for both direct test crops. But in the case of bacterial count for first direct test crop T_6 was on par with T_{12}. The highest actinomycetes count was obtained in treatment which received FYM along with soil application of nano NPK 25 kg ha^{-1} and foliar application of nano NPK 0.2 per cent (T_{14}) with respect to post harvest soil of two direct test crops. After the second direct test crop T_{14} was on par T_2. Soil microorganisms are considered



a. Soil microbial population, log cfu g^{-1} soil (Experiment No: I)



b. Soil microbial population, log cfu g^{-1} soil (Experiment No: III)

Fig. 33. Effect of organic nano NPK formulations on microbial population of post harvest soil, log cfu g^{-1} soil

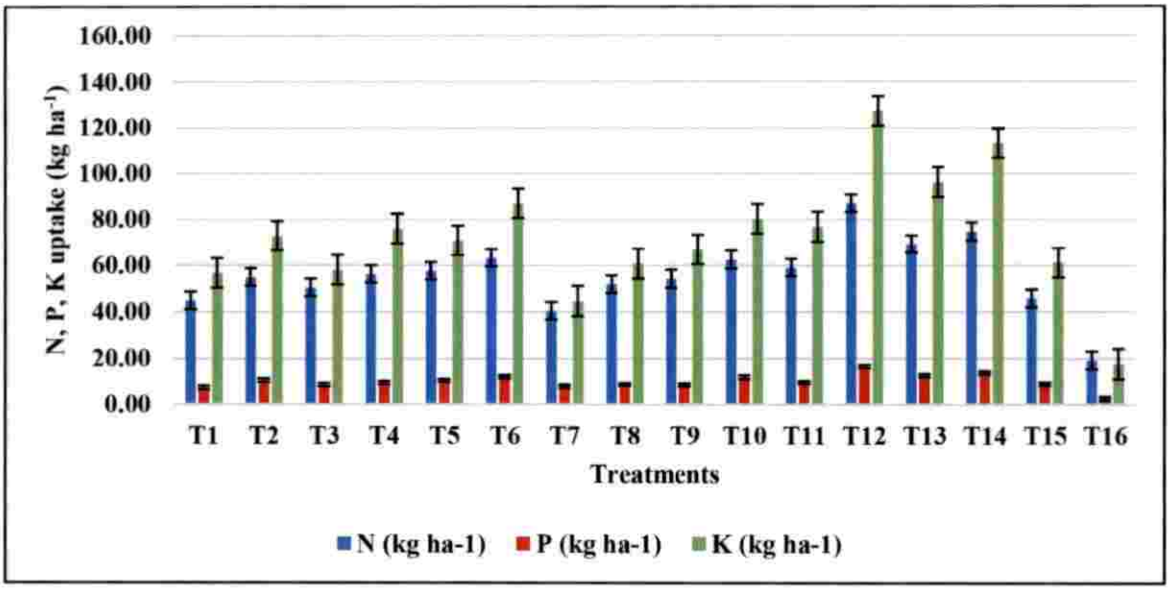
as one of the most important and active components of soil. Organic nano NPK formulations release large amount of humic acid during mineralization. Humic acid is considered as the main element to maintain soil fertility, provide carbon and nitrogen, also indirectly improve pH and soil microbial growth. Raliya and Tarafdar, (2013) reported that nanoparticles induced plant growth due to mobilization of nutrients and also increased the microbial population especially in the rhizhosphere. Rai and Yadav (2011) stated that increased microbial population leads to increased dehydrogenase activity and was also positively correlated to organic carbon content in the soil. The application of nanofertilizers improved the microbial population and colonization (Rahale, 2010)). This might be due to microorganisms present in the soil utilize nanoparticles and help in growth and energy synthesis.

5.3.7 Effect of granular and liquid nano NPK formulations on nutrient uptake

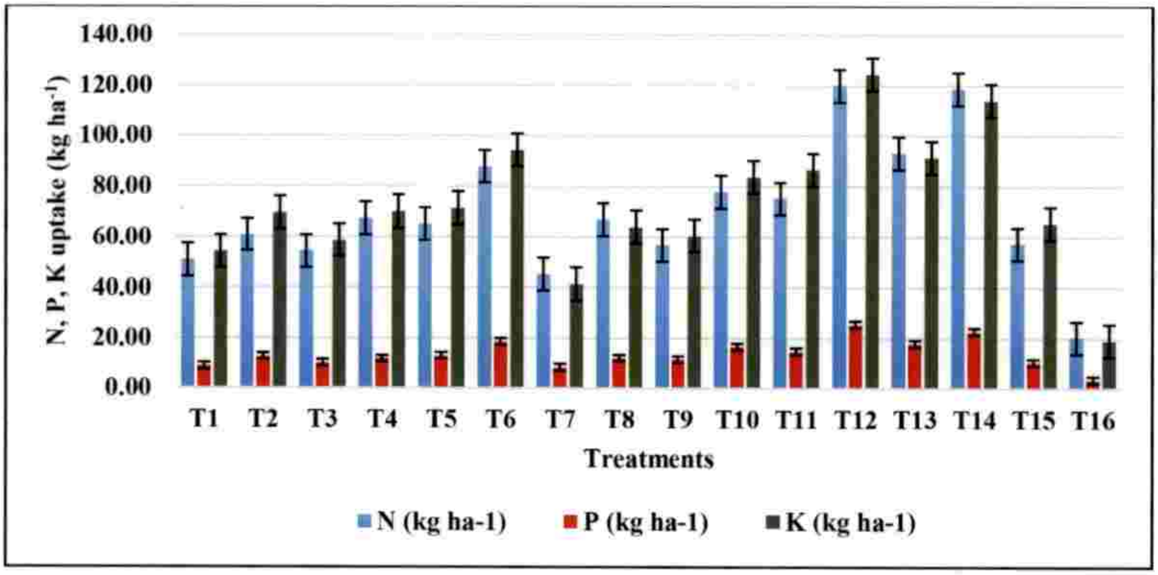
5.3.7.1 Uptake of primary nutrients

Different treatments significantly influenced the uptake of primary nutrients in both direct test crops and are presented in fig. 34 a and b. Treatment T_{12} which received FYM along with soil application of nano NPK 12.5 kg ha^{-1} and foliar application of nano NPK 0.4 per cent registered the highest uptake of primary nutrients in both direct test crops.

This might be due to the fact that organic nano NPK formulations have large surface area and particle size less than pore size of root and leaves helped the nanoparticle to enter into the plant and thereby improved the uptake. Uptake rate of nanofertilizer depend upon the size of the nanoparticles. Jinghua (2004) opined that nano engineered composite which consisted of N, P and K applied to plants led to enhanced uptake of nutrients by grains because nanofertilizers helped in synchronized release of N and P preventing nutrient loss and avoided interaction with soil and microorganisms (De-Rosa *et al.,* 2010). Liu and Liao (2008) reported that application



a. Uptake of major nutrients, kg ha^{-1} (Experiment No: I)



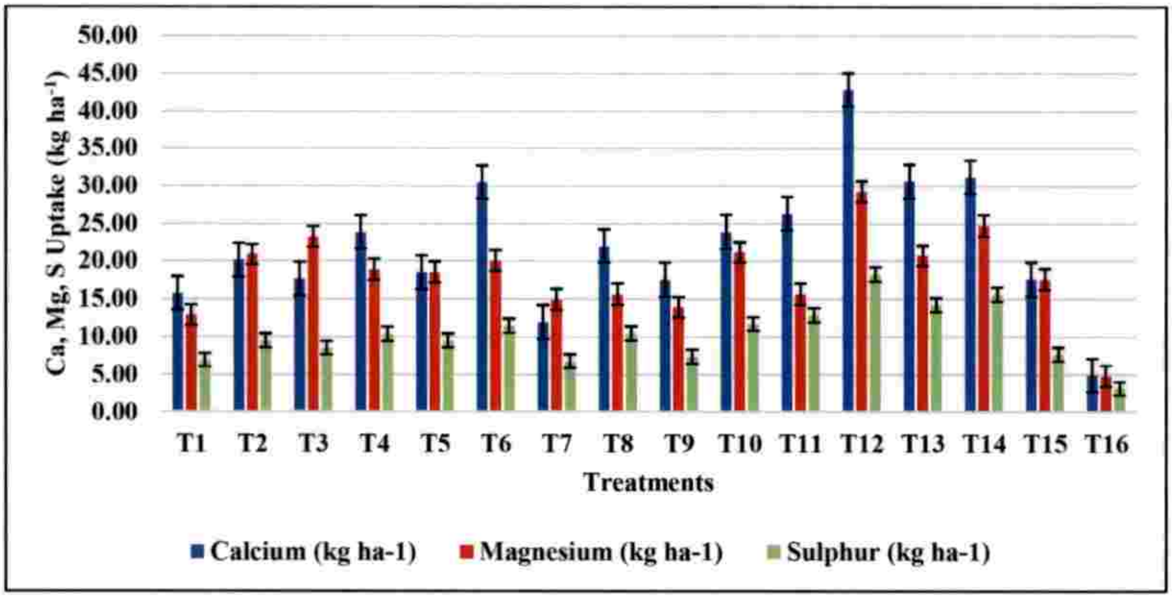
c. Uptake of major nutrients, kg ha^{-1} (Experiment No: III)

Fig. 34. Effect of organic nano NPK formulations on N, P and K uptake by okra plant

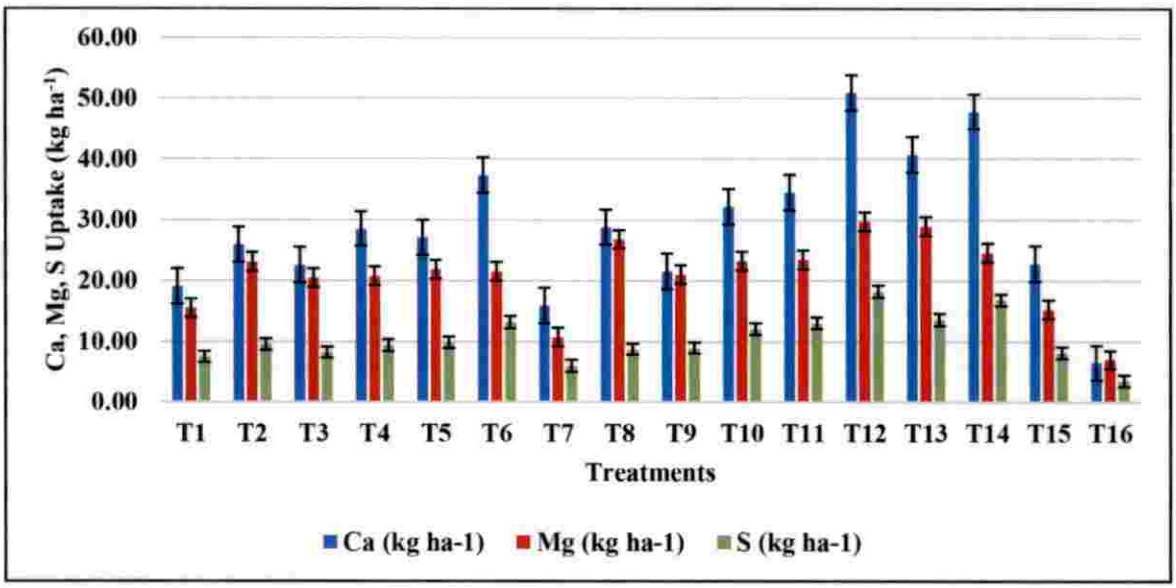
of nanomaterial enhanced the uptake of N, P and K which leads to increased accumulation of biomass. Similar results were also reported by Manikandan and Subramanian (2015), Ahmed *et al.* (2010), Subramanian and Rahale (2010). Soliman *et al.* (2016) stated that positive interaction occurs between phosphorous and nitrogen indicated that when phosphorous uptake increased which inturn increased the nitrogen uptake. Hussein *et al.* (2015) reported that nanofertilizers having both positive and negative charged binding site adsorbed the available nitrogen in the soil and thereby reduce the loss and resulted in increased uptake of nitrogen by the crop. Plant cell walls have pore diameters ranging from 5 to 20 nm (Fleischer *et al.*, 1999). Pores in the order of one to a few tens of nanometers in diameter, important for ionic and molecular transport processes, have been detected in roots (Carpita *et al.*, 1979). Nanofertilizers can result in improved uptake of nutrients through these pores, or accelerate the uptake by complexation with molecular transporters or root exudates, creating new pores or ion channels (Rico *et al.*, 2011).

5.3.7.2 Uptake of secondary nutrients

Analysis of the data (Table 37) showed that application of organic nano NPK formulations significantly influenced the uptake of secondary nutrients (Fig. 35 a and b) and the treatment T_{12} recorded the highest uptake of Ca, Mg and S by the first and second direct test crops. This might be due to the slow and steady availability of secondary nutrients that is released from the organic nano NPK formulations resulted in enhanced uptake by the crops. When chitosan nanoparticles applied to the leaves translocated to stem resulted in uptake of nutrients, enhanced the growth and productivity (Malerba and Cerana, 2016). Van *et al.* (2013) reported that when chitosan nanoparticles applied to robusta coffee plants resulted in enhanced uptake of nitrogen, phosphorous, potassium, calcium and magnesium when compared to that of control. Dongarkar *et al.* (2005) revealed that sulphur uptake of crop was increased due to the application of surface modified nano zeolite enhanced the accumulation of amino acids



a. Plant uptake of secondary nutrients, kg ha^{-1} (Experiment No: I)



b. Plant uptake of secondary nutrients, kg ha^{-1} (Experiment No: III)

Fig. 35. Effect of organic nano NPK formulations on uptake of secondary nutrients by okra

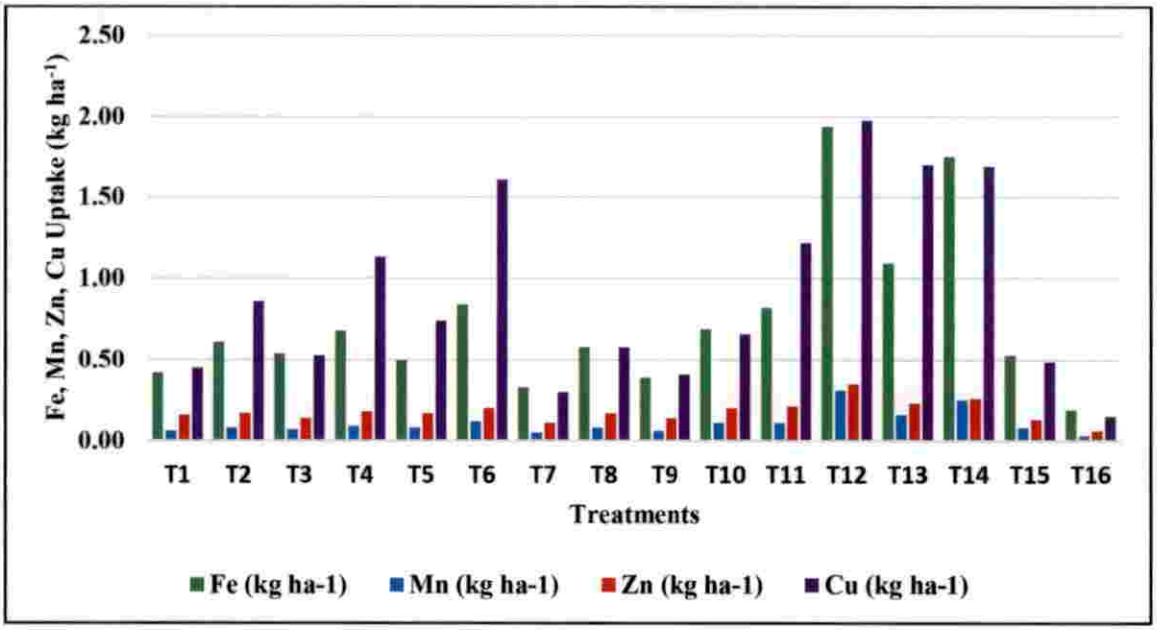
and amide substances leads to translocation to the reproductive system thereby enhance the growth.

5.3.7.3 Uptake of micronutrients

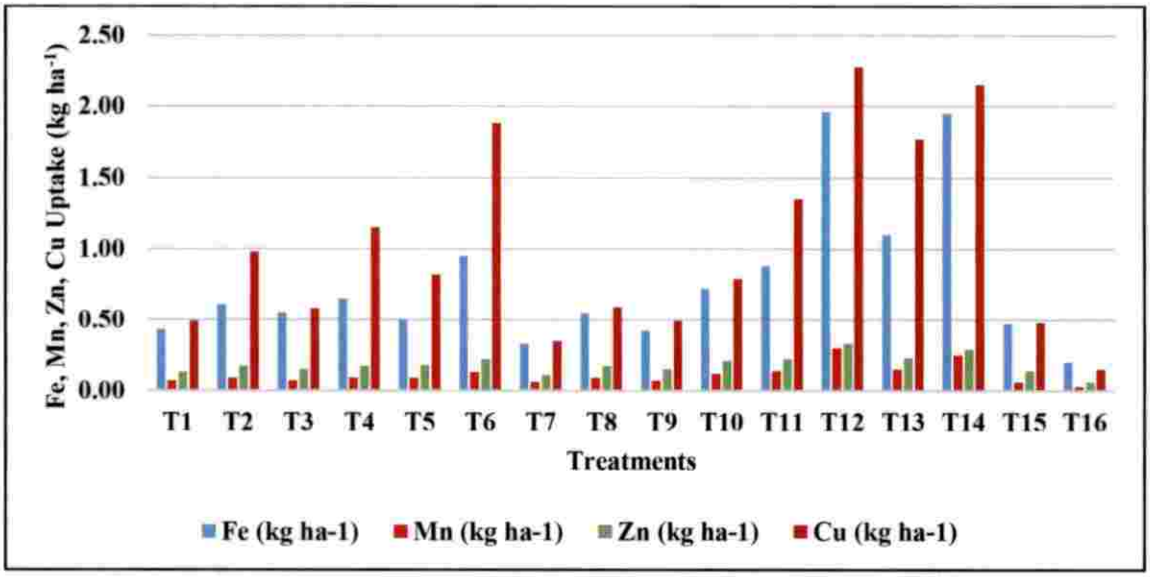
Significant variations in micronutrients uptake between the treatments were recorded (Fig. 36 a and b). The highest Fe, Mn, Zn and Cu uptake by both direct test crops (okra) were recorded by the treatment that received FYM (t ha^{-1}) along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK (0.4 %). Organic matter chelated the micro nutrients cations present in organic nano NPK formulations and they were become water soluble and readily available to the plants. Assimilation of micronutrients and their mineralization by microorganisms resulted in rapid availability. According to Mastronardi *et al.* (2015) nano chelated micronutrient sources were available for longer periods for plant uptake by preventing rapid reaction with soil clay colloids. Keshavarz *et al.* (2011) reported that number of spikes in wheat were increased due to the application of nanoiron. This might be due to the complete uptake of fertilizers at an optimum speed throughout the growing season. Kamiab and Zamanibahramabadi, (2016) stated that foliar application of nano chelate super plus zinc, iron and manganese in apricot resulted in significant increase in the micronutrient concentration and uptake of micronutrients by the plants. Sheta *et al.* (2003) proposed that application of clintopillonite have a high potential for Zn and Fe with a high capacity for slow release fertilizers. Slow release Zn is released to the exchange sites of soil and they were more available for uptake by plants.

5.3.8 Economics

The table 43 revealed economics of organic nano NPK formulations on both direct test crops. It was recorded that benefit cost ratio was found to be the highest for T_{12} (FYM along with soil application of nano NPK 12.5 kg ha^{-1} and foliar application of nano NPK 0.4 %) for the first and second direct test crop. This might be due to the



a. Plant uptake of micronutrients, kg ha^{-1} (Experiment No: I)



b. plant uptake of micronutrients, kg ha^{-1} (Experiment No: III)

Fig. 36. Uptake of micronutrients (kg ha^{-1}) as influenced by organic nano NPK formulations in okra

fact that nanofertilizers are beneficial over conventional fertilizers because they enhance the soil fertility, quality parameters of the crops and also minimize the cost and maximize the profit. Janmohammadi, (2015) opined that the combined application of nanofertilizers along with FYM could be able to provide balance nutrition for the crops which facilitate profitable crop production when compared to that of conventional fertilizer. Kumar *et al.* (2014) reported that when chemical fertilizers were compared with nanofertilizers, nanofertilizers have large surface area which allow the nutrients to be easily absorbed by the plants thereby leading to increased fertilizer efficiency and had a significant economic benefits. A key benefit of nanofertilizers is that the frequency of application of nanofertilizers is much lower than other fertilizers, thereby reducing the labour cost and cost of cultivation. Nanotechnology is thus a boon in achieving sustainable agriculture and for attaining food security especially in developing countries like India.

5.4 Residual crop Amaranthus

This experiment was conducted to study the residual effect of organic nano NPK formulations on amaranthus that was raised in the same plots.

5.4.1 Biometric and yield attributes

5.4.1.1 Plant height and number of branches per plant

Biometric characters such as plant height and number of branches per plant were significantly influenced due to the residual effect of organic nano NPK formulations applied for the direct test crop and the data are presented in table 44. The maximum plant height was recorded in T_{12} for both residual test crops. In the case of number of branches per plant T_9 recorded the maximum number of branches per plant for the two residual crops followed by T_2 and T_3 but for second residual crop T_9 was on par with T_3. The positive influences on plant height and number of branches might be due to the residual effect of nutrients released from organic nano NPK formulations applied for the direct test crops (okra). Akanbi and Togun (2002) opined that significant reduction in the growth parameters of plant was observed when soil is deficient in available nutrients. Organic nitrogen readily converted to ammoniacal and nitrate nitrogen through bacterial action and available for longer period (Neff *et al.,* 2003).

5.4.1.2 Dry matter production and yield

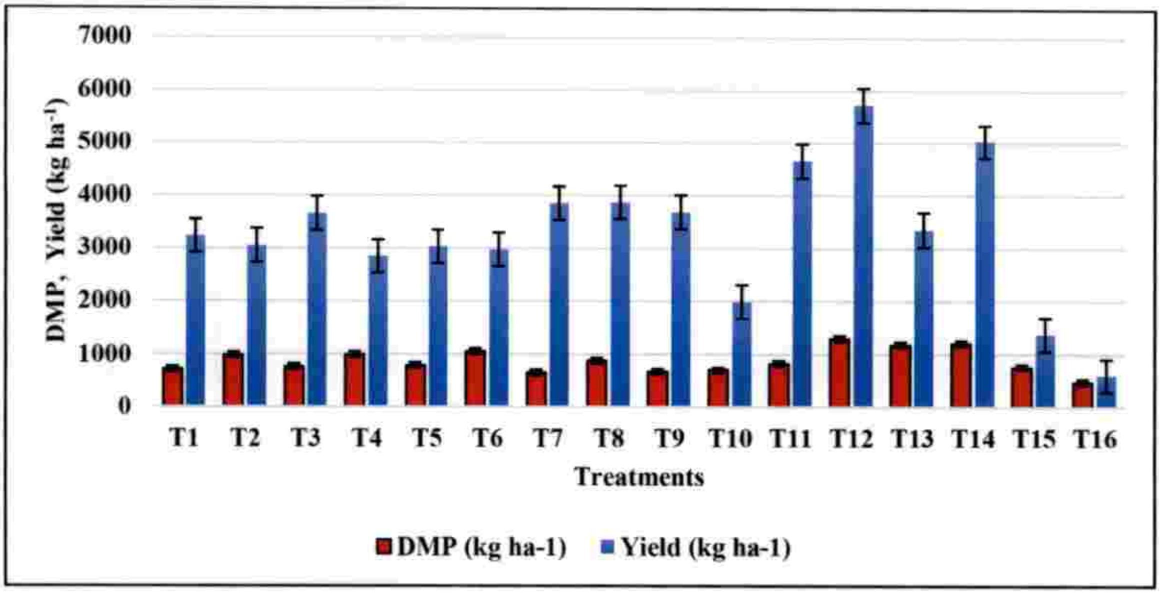
Treatment which received FYM along with soil application of nano NPK 12.5 kg ha^{-1} and foliar application of nano NPK 0.4 per cent during both direct test crops significantly influenced the dry matter production and yield of both residual test crop (Fig 37 a and b). This might be due to the residual effect of organic nano NPK formulations and FYM of the preceding crop due to the slow release pattern. Dry weight of plant increased due to the residual effect of organic manure and organic nano NPK formulations applied to the first direct test crop by the production of humic substances present in the granular nano NPK formulation resulted in improved plant growth. Adigbo (2009) stated that amaranthus is considered as the better utilizer of the residual nutrients applied for the preceding crop.

5.4.2 Quality parameters of amaranthus

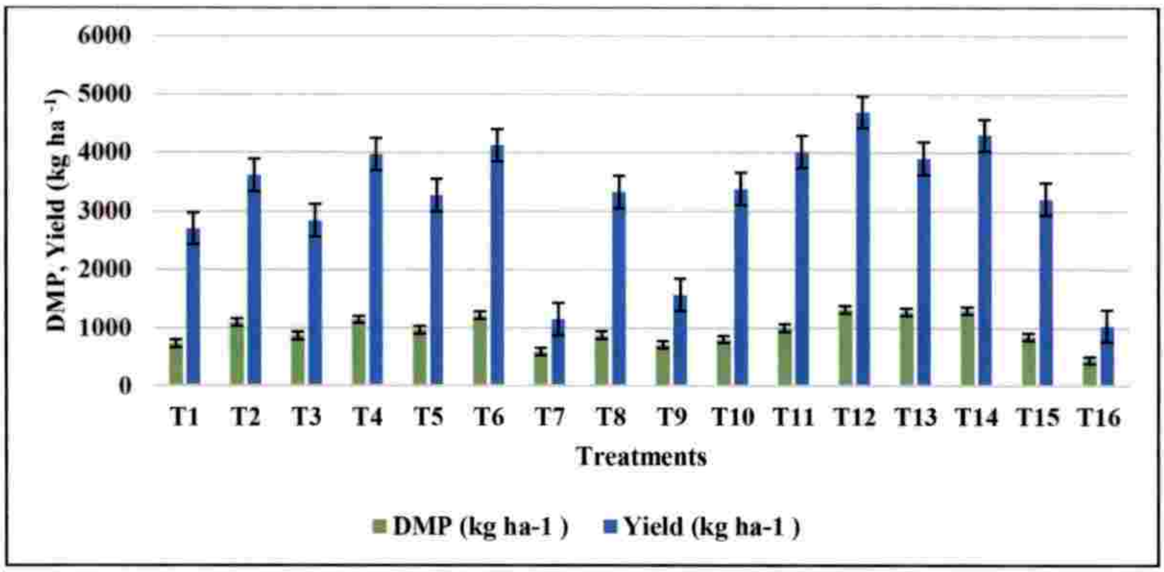
The residual effect of nano NPK formulations resulted significant variation in quality parameters of amaranthus and are presented in table 46.

5.4.2.1 β carotene, Oxalate and nitrate

Among the different treatments applied to both direct test crop, residual effect was highest for T_{15} which recorded the highest β carotene, oxalate and nitrate content of both residual test crops. This might be due to increased application of urea as nitrogen source to the main crop. Treatment T_{12} was noticed with lowest β carotene, oxalate and nitrate content. The above findings corroborate with the findings of Scharrer and Burke (1953) reported that the increased level of nitrogen supply could



a. DMP and yield of amaranthus, kg ha^{-1} (Experiment No: II)



b. DMP and yield of amaranthus, kg ha^{-1} (Experiment No: IV)

Fig. 37. Residual effect of organic nano NPK formulations on dry matter production and yield of amaranthus

able to enhance the carotene content in plants. Organic farming is considered for safe food production by the exclusion of chemical fertilizers from farming practices thereby able to produce safe food, especially in leafy vegetables.

5.4.2.2 Vitamin C

The maximum vitamin C content was obtained in T_{12} for both residual test crop and was comparable with T_6, T_{14}, T_5, T_{11}, T_8, T_1, T_9, T_{13} and T_2 for the first residual crop. For the confirmatory residual crop T_{12} and was on par with T_{14}, T_6, T_{11} and T_5. This might be due to the increased availability of K in the post harvest stage of main crop which resulted in increased vitamin C content. Majumdar *et al.* (2000) reported that application of organic and inorganic fertilizers resulted in high carbohydrate metabolism in plant that leads to enhanced ascorbic acid content.

5.4.3 Physical properties of soil

Both residual crop treatments did not show any significant influence on the soil physical properties. Any carbon rich material when it is added to the soil which provides favourable soil physical properties and in the present investigation the organic carbon content of organic nano NPK formulation was 2.25 per cent.

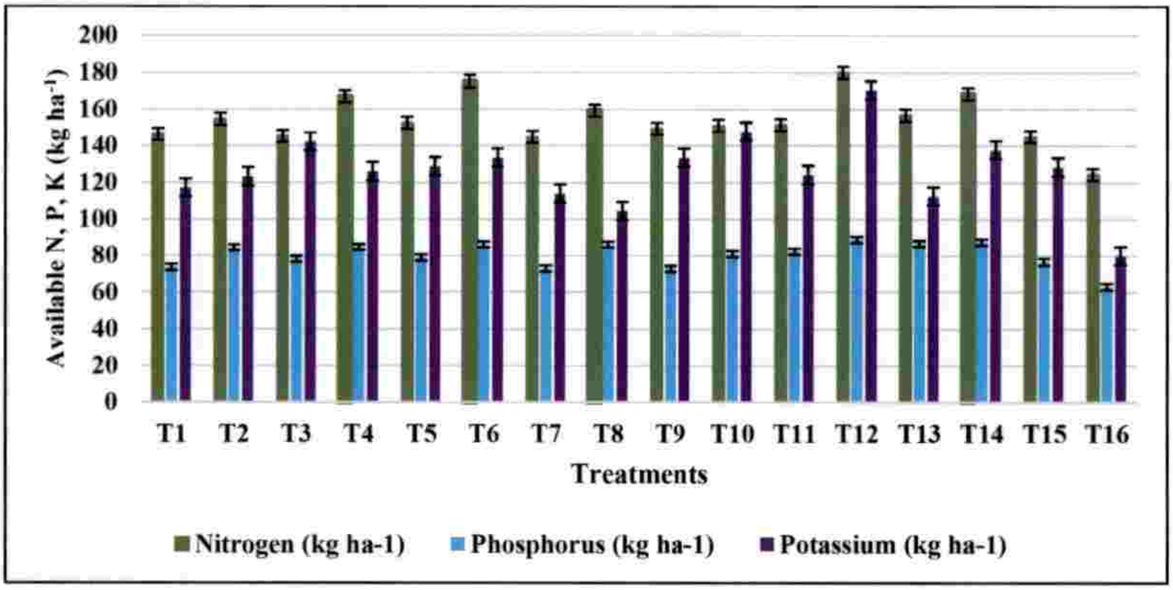
5.4.4 Chemical properties of soil

Residual effect of organic nano NPK formulations showed significant influence on the chemical properties of soil (Table 48). The residual treatment effect of T_{12} recorded higher pH, organic carbon and labile carbon for both the residual crops. For both residual crops T_1 recorded the highest EC. Incorporation of granular nano NPK formulation to soil in combination with FYM and foliar spray of nano NPK formulation resulted in increased pH than that of control treatment. From the characterization study it was revealed that pH of nano NPK formulation was in neutral in reaction. Addition of FYM to direct test crop facilitated the mineralization of nutrients and faster release of soluble salts. Increased organic carbon and labile carbon might be due to the application of FYM together with organic nano NPK formulations which resulted in increased mineralization of nutrients. Increased EC was observed during the incubation period and this might be the reason for increase in EC even after both residual test crops and also due to the quicker release of bases and soluble fractions to the soil by the process of mineralization.

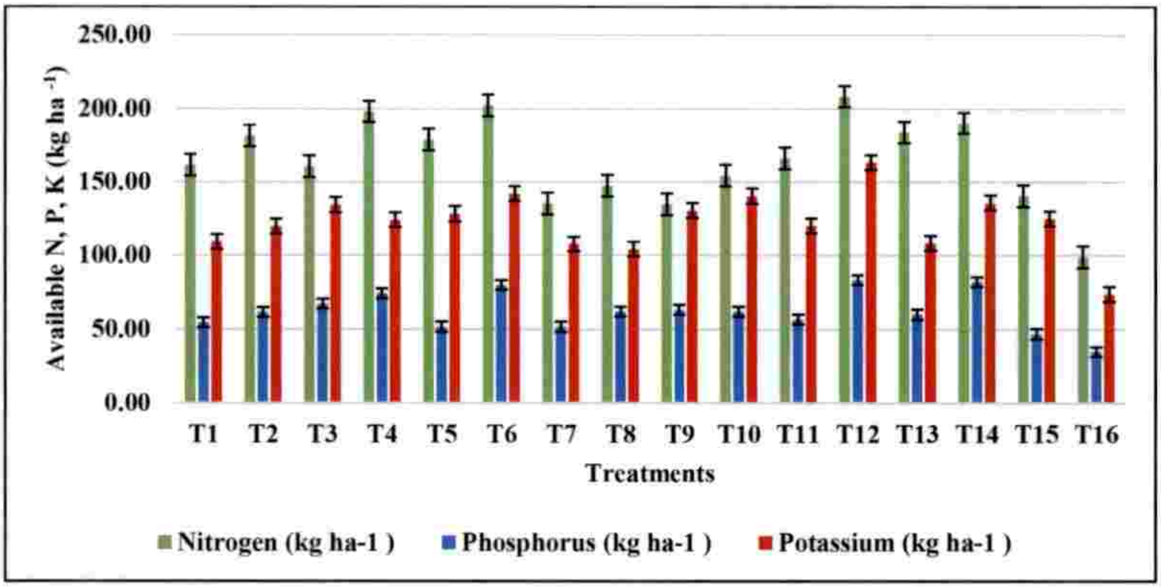
Nitrogen, phosphorous and potassium were considered as the most important nutrient elements in plant nutrition. The behavior and dynamics of soil as influenced by the residual effect of the soil and foliar applications of organic nano NPK formulations in combination with FYM were represented in fig. 38 a and b. T_{12} recorded higher N, P and K content in the soil after both residual crops. The higher availability of primary nutrients from organic nano NPK formulations in combination with FYM even at the later stages as evidenced from the incubation study might have contributed to the residual crop also.

The residual treatment effect was significant with the availability of Ca, Mg and S in the soil (Table 50). The highest Ca and Mg content was noticed in T_{12} in both residual crops. Application of FYM along with soil application of nano NPK 25 kg ha^{-1} (T_4) during the direct test crop resulted in maximum available sulphur for both residual crops. The increased concentration of Ca and Mg might be due to the faster release of basic cations during the mineralization of organic materials (Ammal and Muthiah, 1994). From the incubation study, it was revealed that Mg was released slowly throughout the period which resulted in increased availability of Mg after the residual crops.

Available Fe, Mn, Zn and Cu showed an increased trend in the post harvest soil after the residual crop when compared to that of absolute control plot (Table 51). Availability of Fe and Zn of the post harvest soil of both residual test crop was influenced by T_{12} which received application of FYM along with soil application of



a. Available N, P and K status, kg ha^{-1} (Experiment No: II)



b. Available N, P and K status, kg ha^{-1} (Experiment No: IV)

Fig. 38. Residual effect of organic nano NPK formulations on available N, P and K status of the post harvest soil, kg ha^{-1}

nano NPK 12.5 kg ha^{-1} and foliar application of nano NPK 0.4 per cent during first and second direct test crop. For available Mn, T_4 showed the highest availability for both residual crop while T_{14} recorded the highest available Cu for first and second residual crop. This might be due to the addition of organic manure to direct test crop improved the availability of native macro, secondary and micronutrients is essential for plant growth. Hence its higher availability improved the growth, yield and yield attributes. Organic materials which act as chelating agent helped in maintaining the solubility and steady availability of micronutrient availability slowly to the crops (Das, 2000).

5.4.5 Biochemical properties

Soil enzymes plays an integral role in biochemical processes of soil and can be used as the indicators of microbial communities. Soil enzymes *viz.,* dehydrogenase, urease, acid and alkaline phosphatase had significantly influenced by the treatments (Table 52 a and b). The enzyme dehydrogenase indicates the overall oxidative activities of the soil micro flora. Urease activity in the soil directly relate the hydrolysis of urea. The main role of phosphatase in soil is to convert organic P to inorganic phosphatase. Treatment which received FYM along with soil application of nano (12.5 kg ha^{-1}) and foliar application of nano (0.4%) for both direct test crop also influenced the dehydrogenase, urease and acid phosphatase activities of both residual crops. This might be due to the application of organic nano NPK fomulations which could be able to favour more microbial activity and leads to enhanced enzyme activity. Enzymes are required for the decomposition of organic matter. Dehydrogenase activity can be attributed to the readily available organic carbon substrates in the soil (Fraser, 1994). Dehydrogenase activity promote biochemical activities in the soil which are essential for maintaining soil fertility (Joachima *et al.*, 2008). According to Rai and Yadav (2011) application of organic and inorganic sources resulted in higher value for soil urease activity even after 60 days of incubation. High organic P content of FYM and nano NPK formulations might have triggered the microorganisms to produce more phosphatase enzyme in the soil.

5.4.6 Biological properties

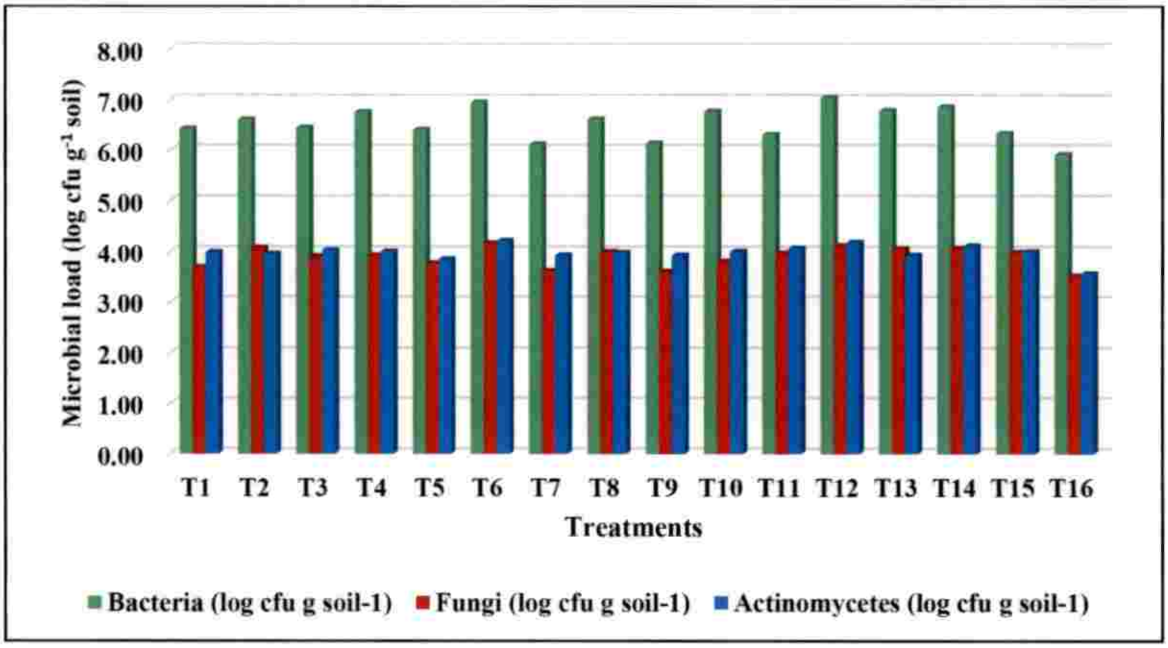
Soil biological properties were influenced by the residual effect of organic nano NPK formulations after the first and confirmatory residual crop (Fig. 39 a and b).

Maximum bacterial count was noticed in T_{12} in both the residual crops. The highest fungal and actinomycetes count were recorded by T_6. Increased microbial activity might be due to increased availability of nutrients and enhanced the rhizosphere activity. This could be due to the enhanced organic carbon content of the soil because of the addition of FYM during the direct test crop as compared to inorganic fertilizers. In addition to that, application of FYM and nano NPK formulations during the direct test crop resulted in increased primary, secondary and micronutrient status of the soil that might have resulted in increased microbial population. Addition of organic manure could be able to significantly serve as the greater input of organic carbon, which resulted in increased bacterial population (Fraser, 1994). Similar results were also reported by Kukraja *et al.* (1991), Lal *et al.* (2002) and Gaind and Nain (2010).

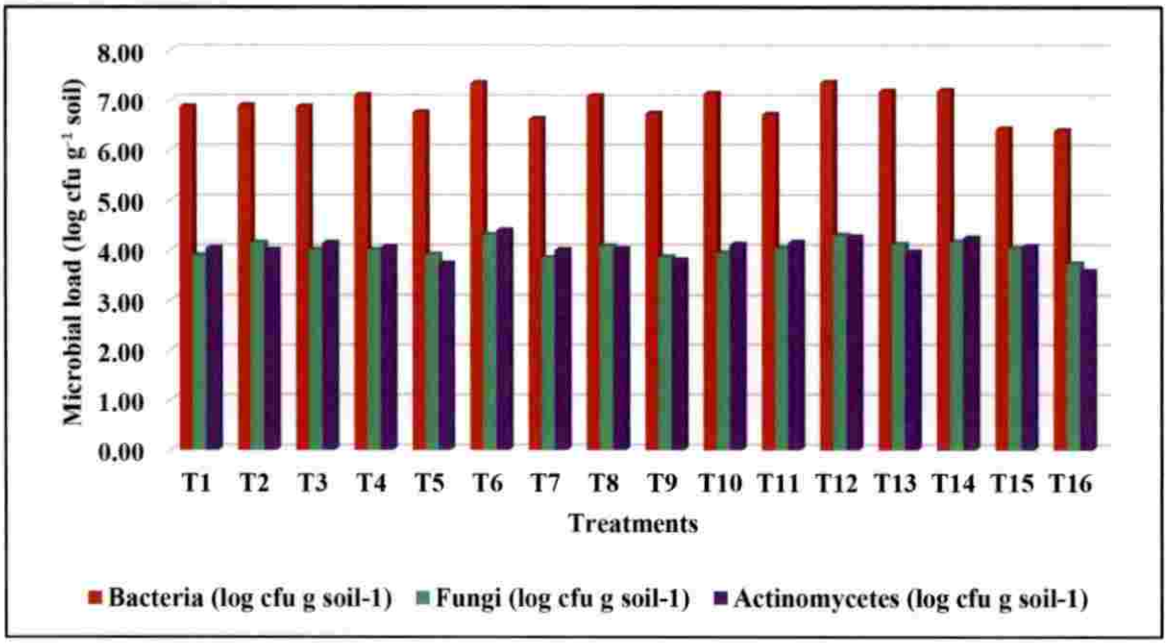
5.4.7 Nutrient uptake by the residual crop

Data presented in Fig. 40 a and b, revealed uptake of nutrients by the residual crop was significantly influenced by the treatments.

Uptake of N, P and K was maximum in T_{14}. While for the confirmatory residual crop T_{14} was on par with T_{12} in the case of N uptake. P uptake was comparable with treatment T_{12} for the first residual crop while for K uptake in the first residual crop, T_{14} was on par with T_{13}, T_{12} and T_4. For the confirmatory residual crop, T_{14} was on par with T_{12}. This might be due to the slow and steady release of organic nano NPK

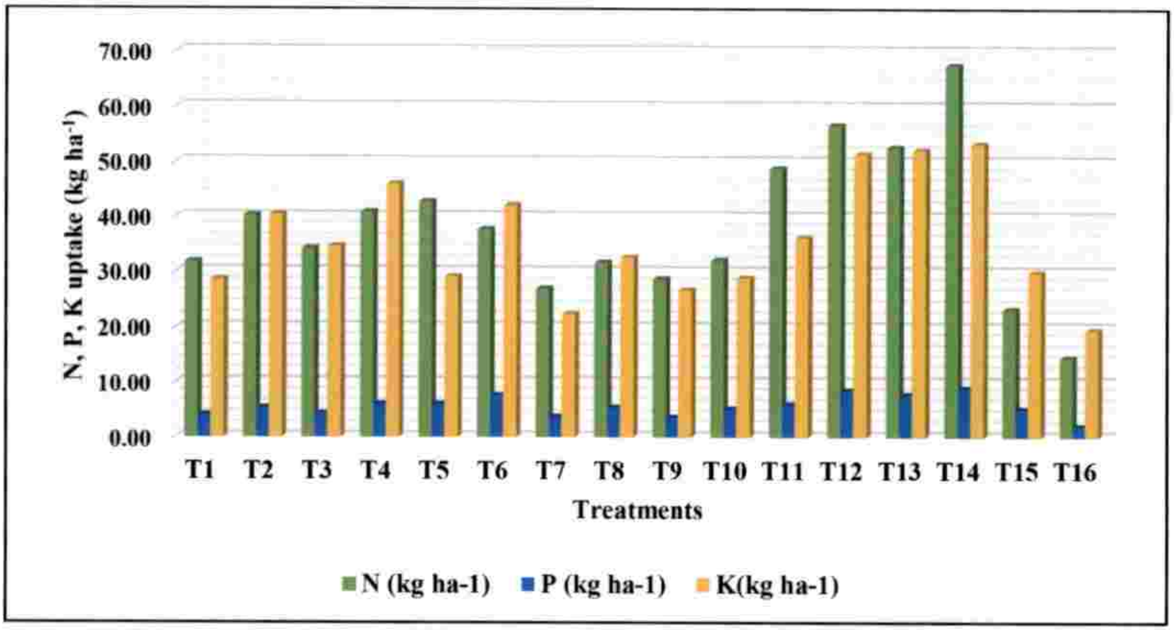


a. Soil microbial population, log cfu g^{-1} soil (Experiment No: II)

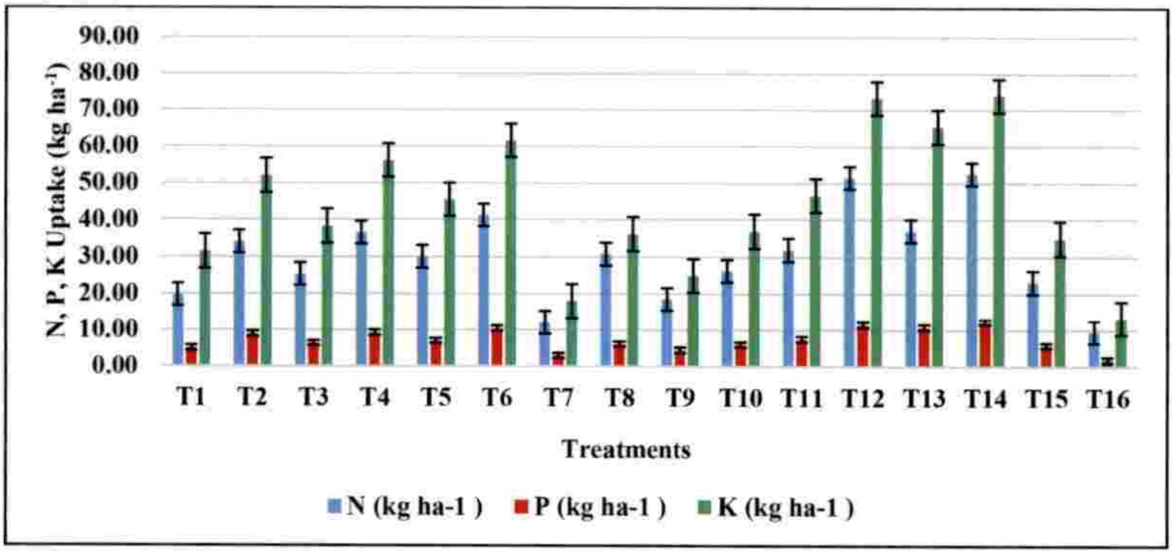


b. Soil microbial population, log cfu g^{-1} soil (Experiment No: IV)

Fig. 39. Residual effect of organic nano NPK formulations on microbial population of post harvest soil, log cfu g^{-1} soil



a. N, P and K uptake by amaranthus, kg ha^{-1} (Experiment No: II)



b. N, P and K uptake by amaranthus, kg ha^{-1} (Experiment No: IV)

Fig. 40. Residual effect of organic nano NPK formulations on N, P and K uptake by amaranthus plant

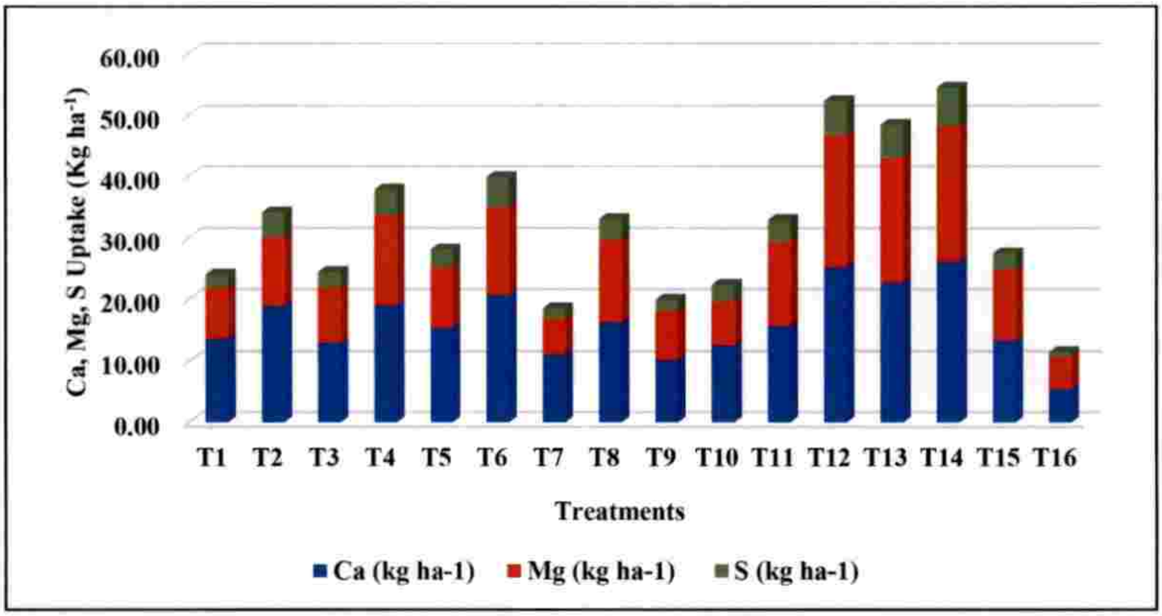
formulations along with FYM which resulted in higher uptake of nutrients by the residual crop even after the main crop.

Uptake of secondary nutrients were significantly influenced due to the residual effect of organic nano NPK formulations (Fig. 41 a and b). The highest Ca, Mg and S uptake were recorded by T_{14} for both residual crops while for Ca uptake by the first residual crop, T_{14} was on par with T_{12} and T_{13}. Mg uptake was comparable with T_{12} and T_{13} for the first residual crop and for the confirmatory residual crop, it was on par with T_{12} and T_{13}. For the S uptake T_{14} was on par with T_{12}. The better plant growth might have resulted in increased uptake of secondary nutrients released slowly and steadily from organic nano NPK formulations and also due to residual effect of FYM.

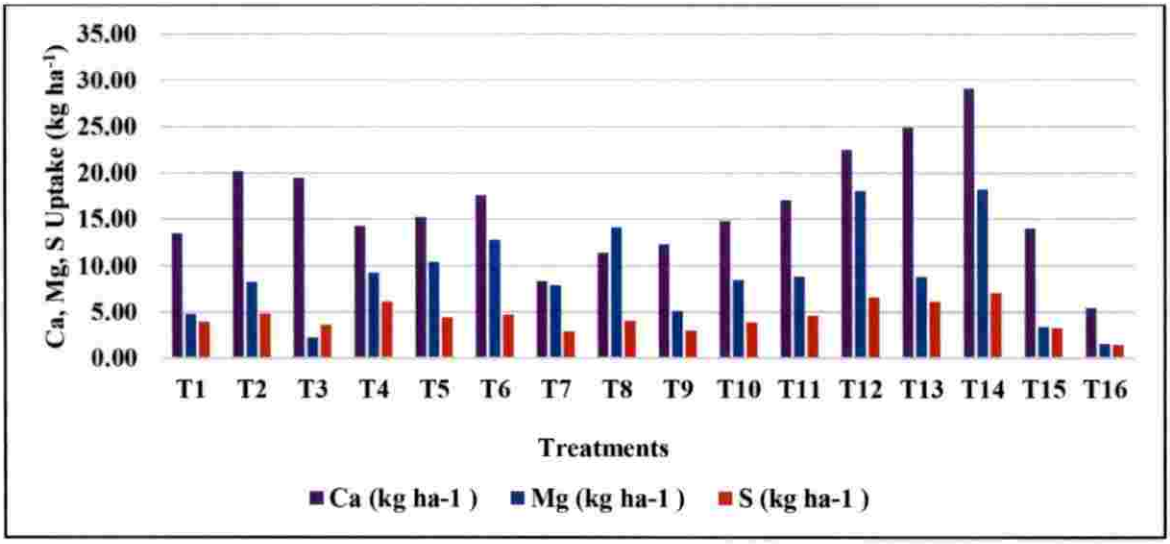
Micronutrient uptake by both residual crops were significantly influenced by the treatments (Table 56). The highest uptake of Fe, Mn and Zn by the plants were recorded by T_{14} for both residual crop but for the confirmatory crop, in the case of Fe uptake T_{14} was on par with T_{12}. For Cu uptake treatment which received FYM along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK (0.4%) utilized the remaining nutrients by both residual crops. The higher micronutrient uptake by the plant might be due to slow and steady relaease of micronutrients from organic nano NPK formulations and also due to the residual effect of FYM applied for the direct test crops. In general, organic materials can provide chelating agents and improve the solubility of micronutrients and thereby enhanced the micronutrient uptake by the plants (Tisdale *et al.,* 1997).

5.4.8 Economic analysis

Economic analysis revealed that residual effect of the treatment which received FYM along with soil application of nano NPK (12.5 kg ha^{-1}) and foliar application of nano NPK (0.4%) gave the best performance with respect to B:C ratio for both residual test crops. The higher B:C ratio might be due to the residual nutrients utilized by these crop which inturn resulted in higher yield for the residual crops.



a. Plant uptake of secondary nutrients, kg ha^{-1} (Experiment No: II)



b. Plant uptake of secondary nutrients, kg ha^{-1} (Experiment No: IV)

Fig. 41. Residual effect of organic nano NPK formulations on plant uptake of secondary nutrients

Summary

6. SUMMARY

The salient findings attained from the study on "Organic nano NPK formulations for enhancing soil health and productivity" were summarized in this chapter. The study was undertaken during July 2017 to February 2019 at College of Agriculture, Vellayani. The main objective of the investigation was to characterize organic nano NPK formulations, to assess the nutrient release pattern under laboratory conditions and to study the effect of soil and foliar applications of organic nano NPK formulations on crop growth, yield, quality and soil health using okra as direct test crop and amaranthus as residual test crop.

The study comprised of three parts. The first part of the investigation was the characterization of organic nano NPK formulations (granular and liquid). Laboratory incubation study, the second part was conducted to assess the nutrient release pattern of granular nano NPK formulation. The laboratory incubation study consisted of eight treatments with three replications *viz.*, Soil alone (T_1), Soil + FYM (12 t ha^{-1}) (T_2), Soil + nano NPK (12.5 kg ha^{-1}) (T_3), Soil + FYM (12 t ha^{-1}) + nano NPK (12.5 kg ha^{-1}) (T_4), Soil + nano NPK (25 kg ha^{-1}) (T_5), Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1}) (T_6), Soil + nano NPK (50 kg ha^{-1}) (T_7) and Soil + FYM (12 t ha^{-1}) + nano NPK (50 kg ha^{-1}) (T_8).

Field experiment was carried as the third part of the investigation to study the effect of soil and foliar applications of organic nano NPK formulations on crop growth, yield, quality and soil health using okra as the direct test crop and amaranthus as residual test crop. The field experiment was laid out in lattice design with three replications and sixteen treatments. Treatments consisted of soil application of granular nano NPK at 3 levels (12.5 kg ha^{-1}, 25 kg ha^{-1} and 50 kg ha^{-1}) with and without FYM, foliar application of liquid nano NPK at 2 levels (0.2% and 0.4%) with and without FYM and combined application of granular and liquid nano NPK formulations with and without FYM. The field experiment using okra as direct test crop followed by amaranthus as residual test crop were repeated for confirmatory results. The key findings of the research program are summarized below:

PART 1

Characterization of organic nano NPK formulations

- The particle size of granular and liquid organic nano NPK formulations were 83.20 nm and 71.79 nm, respectively. The zeta potential of the granular nano NPK formulation was -14.4 mV which indicated the stability of granular organic nano NPK formulation.
- By using SEM images, it was revealed that the granular nano NPK formulation was circular to irregular in shape.
- Granular organic nano NPK formulation recorded the neutral pH (7.68) and with EC value of 0.141 dS m^{-1} whereas, liquid nano NPK formulation recorded the pH of 6.55 and EC of 0.184 dS m^{-1}.
- The organic carbon content of granular nano NPK formulation was 2.25 per cent.
- Organic matter fractions present in the granular nano NPK formulation *viz.,* Fulvic acid, humic acid and humin contents were 29.86 per cent, 16.73 per cent and 5.90 per cent, respectively.
- Regarding primary nutrients, the granular organic nano NPK formulation had N, P and K content of 1.96 per cent, 1.76 per cent and 2.75 per cent, respectively whereas the liquid nano NPK formulation had N, P and K content of 1.82 per cent, 1.89 per cent and 3.53 per cent, respectively.
- The secondary nutrients *viz.,* Ca, Mg and S contained in the granular organic nano NPK formulation were 0.37 per cent, 0.30 per cent and 0.59 per cent,

respectively. In the case of liquid nano NPK formulation, the contents were 0.21 per cent, 0.09 per cent and 0.75 per cent with respect to Ca, Mg and S.

- Regarding micronutrient contents of organic nano NPK formulations, the granular nano NPK formulation recorded Cu content of 104.0 mg kg^{-1}, Fe content of 465.7 mg kg^{-1}, Mn content of 662.5 mg kg^{-1}, Zn content of 398.3 mg kg^{-1} and B content of 47.54 mg kg^{-1}, whereas, liquid nano NPK formulation had Cu, Fe, Mn, Zn and B content of 3.10 mg kg^{-1}, 152.8 mg kg^{-1}, 41.77 mg kg^{-1}, 318.1 mg kg^{-1} and 9.37 mg kg^{-1}, respectively.
- All the heavy metal content of granular and liquid organic nano NPK formulations was under the permissible limit. Pb, As and Cd content were not even detected, but Ni and Cr were detected in granular nano NPK formulation. In the case liquid nano NPK formulation As and Cd content were not even detected, but Pb, Ni and Cr were detected.

- Total amino acid content present in the granular and liquid organic nano NPK formulations were found to be 270 mg kg^{-1} and 370 mg kg^{-1}, respectively.

PART 2

Laboratory incubation study

- pH and EC of the incubated soil showed an increasing trend on advancement of incubation period when compared to their initial values.
- In case of organic carbon content during the incubation period, increased trend was noticed throughout the incubation.
- In case of available N and P, increased trend was noticed upto 45^{th} day of incubation and thereafter showed a declined trend.
- Available K_2O of the incubated soil increased progressively upto 60^{th} day of incubation.

- In the case of secondary nutrients, the nutrient release was increased upto 45th day of incubation thereafter showed a declining tendency. During the 75th day of incubation Ca content reduced drastically.
- There was steady increase in the release of available Fe, Mn and Cu upto 45th day of incubation and thereafter decreased.
- In the case of Zn the nutrient content showed an increasing trend in all the treatments when compared with their initial values. Combined application of FYM and granular nano NPK formulation recorded higher nutrient release than application of granular nano NPK formulation alone.

PART 3

Field experiment No: I and III using okra as direct test crop

- In case of first field experiment the highest plant height, LAI and DMP were found in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)). With respect to second direct test crop, the highest plant height was recorded by T_{12} and was on par with T_{11}, T_9, T_{13} and T_{14}. The highest LAI and DMP was noticed in T_{12}.
- Regarding first field experiment maximum number of branches per plant was observed in T_4 (FYM + soil application of nano NPK 25 kg ha^{-1}) and was on par with T_6, T_9 and T_{12}. Maximum number of branches was noticed by T_4 and was on par with T_9 in the case of third field experiment.
- With respect to root length and root volume of first direct test crop, T_4 (FYM + soil application of nano NPK 25 kg ha^{-1}) recorded the highest root length and was comparable with T_{14}. The highest root volume was observed in T_{12} and was on par with T_9 and T_{13}. Similarly, in the case of second direct test crop maximum root length was recorded by T_4 and was on par with T_{14}, T_6 and T_9. Root volume was found to be maximum in T_{12} which was comparable with T_{14}.

- Physiological parameters of the crop *viz.,* chlorophyll a, chlorophyll b and total chlorophyll content during the first field experiment were observed maximum in T_{12}. For chlorophyll a T_{12} was comparable with T_{13}, T_{10}, T_6, T_2, T_{15}, T_4, T_{11}, T_3, T_9, T_7, T_5 and T_1. For chlorophyll b and total chlorophyll content T_{12} was found to be on par with T_6, T_8, T_5, T_2 and T_{15}. In case of second direct test crop the highest chlorophyll a content was noticed in T_{13} and was on par with T_6, T_{15}, T_3, T_5, T_7, T_8, T_{14} and T_2. Chlorophyll b and total chlorophyll content were observed in T_{12} and was comparable with T_{10} and T_{11}.

- Regarding the first direct test crop, the least days taken for first flowering was T_9 and was on par with T_3, T_5, T_{14}, T_{12}, T_2, T_{15}, T_6 and T_7. The lowest days required by the treatment to take 50 per cent flowering was T_{12} and was on par with T_{14}, T_9, T_6, T_2, T_3, T_{13}, T_{11} and T_1. T_{12} recorded the highest crop period and was on par with T_{14}. With respect to second direct test crop, the lowest days taken for first flowering was recorded by T_6 and was on par with T_3, T_{10}, T_9, T_{12}, T_8, T_5, T_4, T_{13}, T_1, T_{14} and T_{11}. The least number of days taken for 50% flowering was noticed in T_{12} and was comparable with T_3, T_4, T_{14}, T_5, T_{13}, T_8, T_{10} and T_6. The highest crop period was observed by T_{12} and was on par with T_{14}.

- In the first okra crop (Expt No. I), maximum fruit length was recorded in T_{12} and was comparable with T_{14} and T_6. The highest fruit girth was recorded in T_{12} and was followed by T_{13}, T_9, T_5, T_{14}, T_8 and T_{11}. Regarding the second okra crop (Expt No. III), T_{12} recorded the highest fruit length and was on par with T_{14}. The highest fruit girth was noticed in T_{12}.

- Highest number of fruits per plant, average fruit weight and total fruit yield were recorded by T_{12} in field experiment No. I. In confirmatory test crop, the highest number of fruits per plant, average fruit weight and total fruit yield were recorded by T_{12}.

- During the first field experiment, the highest crude protein was recorded by T_{12} and was on par with T_{13}, T_7 and T_3. Lowest crude fibre content was recorded by T_{14}. The highest ascorbic acid content in bhindi fruit was found in T_{14} and was on par with T_6, T_{12}, T_{10}, T_{13} and T_{11}. Regarding third field experiment, the highest crude protein was recorded by T_{12} and was on par with T_{13}, T_{10}, T_7 and T_3. The lowest crude fibre was found in T_{14}. The highest ascorbic acid content was noticed by T_{12} and was comparable with T_{14}, T_6, T_{13} and T_{10}. Combined application of granular and liquid nano NPK formulations were found to be very effective with respect to highest crude protein content, highest ascorbic acid and lowest crude fibre content.

- After the first field experiment, the highest WHC value of 29.35 per cent was recorded in the treatment T_4 and was found to be on par with T_{11}, T_1, T_{15}, T_{14}, T_8, T_{12}, T_5, T_7, T_6, T_{13}, T_3 and T_2. The highest water holding capacity was noticed in T_4 and was on par with T_9, T_{15}, T_{13}, T_{10} and T_6 in the case of second direct test crop.

- The analysis of post harvest soil after the first direct test crop revealed that maximum pH was observed in T_{12} and was on par with T_5, T_3, T_7, T_{10}, T_6, T_2, T_{13} and T_{14}. The highest EC was recorded by T_4. After the confirmatory test crop, the highest pH and EC was recorded by T_{12}. But pH was on par with T_{10}, T_{14}, T_2, T_3, T_5, T_{13} and T_6 whereas EC was on par with T_4.

- In case of analysis of post harvest soil after the first direct test crop, the highest OC was recorded by T_{12} FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)) and was comparable with T_{10} and T_4. T_{12} also recorded the highest labile carbon content and was found to be on par with T_{13} and T_4. After the second direct test crop, T_{12} recorded the highest OC and labile carbon content in the soil. In the case of OC T_{12} was found to be on par with T_4 and T_{10}.

- Post harvest analysis of the soil after the first direct test crop, treatment T_{12} recorded the highest available N, P and K. For available N, T_{12} was on par with T_4, T_{13}, T_{10}, T_3, T_5, T_9 and T_{14}. For available K, T_{12} was on par with T_{14}. Regarding post harvest soil analysis of confirmatory crop, T_{12} recorded the highest available N and it was on par with T_4. For P, T_{12} was on par with T_{10} and for K, T_{12} was on par with T_{14}.

- With respect to analysis of post harvest soil after the first direct test crop, T_{12} recorded maximum exchangeable Ca and was on par with T_2, T_{10}, T_4, T_5, T_{14}, T_6, T_7 and T_3. T_2 recorded the highest exchangeable Mg and was comparable with T_7, T_5, T_{12} and T_{14}. The highest available S was observed in T_{14}. In case of analysis of secondary nutrients after second direct test crop, the highest exchangeable Ca was found in T_{12}. The highest exchangeable Mg was recorded by T_2 and it was comparable with T_7 and T_5. The highest mean value for available S was found in T_{14} and was on par with T_{13}, T_{12} and T_{10}.

- With respect to micronutrient analysis of post harvest soil after the first direct test crop, T_2 recorded the highest available Fe. T_{12} recorded the highest available Mn and was on par with T_5. Available Zn was highest in T_{12}. The highest available Cu content was recorded in T_5. After the second direct test crop, T_2 recorded the highest available Fe. T_{12} recorded the highest available Mn and Zn. The highest available Cu content was recorded in T_5.

- The highest nutrient use efficiency was recorded by T_{12} in first and second direct test crop.

- Regarding enzyme activities in the soil after the harvest of both direct test crops, T_{12} recorded the highest activities. After the harvest of first crop, T_{12} was on par with T_9 and T_{14} for dehydrogenase activity. The highest urease activity was recorded by T_{12} and was comparable with T_{14}, T_6, T_7 and T_{13}. In case of acid phosphatase, T_{12} was on par with T_{14}, T_6 and T_4. T_{12} recorded the highest alkaline phosphatase activity and was on par with T_2, T_4 and T_7. After the confirmatory crop, T_{12} indicated the highest value for soil enzyme activities *viz.,* dehydrogenase, acid and alkaline phosphatase. T_{12} recorded the highest urease activity and was on par with T_{14}, T_{13}, T_6, T_4 and T_2.

- In case of analysis of the post-harvest soil after the first direct test crop, maximum bacterial count was found in T_6 and was on par with T_{12}. The highest fungal count was recorded by T_6 and was on par with T_{14}, T_8, T_{11} and T_3. In case of actinomycetes, T_{14} recorded maximum count. In the post-harvest analysis of soil after second direct test crop, maximum bacterial count was recorded by T_{12}. The highest fungal count was recorded by T_6 and was on par with T_{14}, T_4, T_{11}, T_8 and T_{13}. In case of actinomycetes, T_{14} recorded the highest count and was on par with T_2.
- Regarding the uptake of primary nutrients in the first direct test crop, the highest N, P and K uptake was observed in T_{12} (FYM (12 t ha^{-1}) + Soil application of nano NPK (12.5 kg ha^{-1}) + Foliar application of nano NPK (0.4%)). With respect to uptake of primary nutrients in the second direct test crop, the highest uptake of N, P and K was also recorded by T_{12} but for N uptake it was on par with T_{14}.
- Maximum uptake of secondary nutrients was recorded by T_{12} in first and second direct test crops. In case of first direct test crop, T_{12} was significantly superior to all treatments for Ca and S but for Mg it was on par with T_{14} and T_3. Regarding second direct test crop, T_{12} recorded the highest value for Ca and was on par with T_{14}. In case of Mg uptake, T_{12} was comparable with T_{13}, T_8 and T_{14}.
- The highest micronutrient uptake was found in T_{12} for first direct test crop. In case of second direct test crop, T_{12} recorded the highest uptake of Fe, Mn, Zn and Cu. But Fe uptake was also on par with T_{14}.

- The highest benefit cost ratio was observed in T_{12} for both first and second direct test crop.

Field experiment No: II and IV using amaranthus as residual test crop

- For the first residual crop, maximum plant height, DMP and yield were recorded in T_{12}. Maximum number of branches was observed in T_9 and was on par with T_2 and T_3. Regarding second residual crop, tallest plant was noticed in T_{12}. Maximum number of branches was recorded by T_9 and was found to be on par with T_3. The highest DMP and yield were registered by T_{12} but and was on par with T_{14} and was on par with T_{14} with respect to DMP.
- Regarding the quality parameters of first residual crop, the lowest β carotene, oxalate and nitrate content was found in T_{12}. The highest vitamin C was noticed in T_{12} and was on par with T_6, T_{14}, T_5, T_{11}, T_8, T_1, T_9, T_{13} and T_2. With respect to quality parameters of second residual crop, the lowest β carotene, oxalate and nitrate content was found in T_{12}. The highest vitamin C was found in T_{12} and was on par with T_{14}, T_6, T_{11} and T_5.
- After the first residual crop, pH of the soil decreased comparatively in all the treatments. The highest pH was observed in T_{12} and was on par with T_6. Maximum electrical conductivity was noticed in T_1. In case of post-harvest analysis of soil after the second residual crop, T_{12} recorded the highest pH (5.86) and was on par with T_6, T_3, T_2 and T_9. The highest electrical conductivity was recorded by T_1.
- The post harvest analysis of soil after the first residual crop revealed that the highest OC and labile carbon content were found in T_{12} and was on par with T_4 with respect to OC content. After the second residual crop, the highest OC content and labile carbon content were recorded by T_{12} with mean values of 1.71 per cent and 988.44 mg kg^{-1}, respectively.

- The highest value for available soil primary nutrients were recorded by T_{12} after the first residual crop but for nitrogen, T_{12} was on par with T_6, T_{14}, T_4 and T_8. The post harvest analysis of soil after the second residual crop revealed that the highest value for available soil primary nutrients were recorded by T_{12}. For N it was comparable with T_6, T_4, T_{14} and T_{13}. In case of P, T_{12} was on par with T_{14}.

- In case of soil analysis after first residual crop for available secondary nutrients, highest exchangeable Ca was recorded by T_{12} and was on par with T_3, T_{14}, T_6, T_7, T_1, T_4, T_2, T_5, T_{15}, T_{11}, T_9 and T_{10}. The highest exchangeable Mg and available S was recorded by T_{12} and T_4 respectively. With respect to secondary nutrient analysis of soil after the second residual crop, the highest exchangeable Ca was recorded by T_{12} and was on par with T_6, T_8, T_2, T_4 and T_{13}. The highest exchangeable Mg was observed by T_{12} and was found to be on par with T_6, T_{14}, T_4 and T_2. Available S was found to be highest in T_4.

- Regarding micronutrient analysis of soil after the first residual crop, the highest available Fe and Zn was noticed in T_{12}. Maximum available Mn and Cu were found in T_4 and T_{14} respectively. After second residual crop, Treatment T_{12} recorded the highest available Fe and Zn content. T_4 recorded the highest available Mn and T_{14} recorded the highest available Cu.

- Enzyme activities of post harvest soil after first and second residual test crop were estimated and found that T_{12} recorded the highest values for dehydrogenase, urease and acid phosphatase. For alkaline phosphatase, T_{14} recorded the highest value and was on par with T_{12}, T_6, T_{13} and T_{11}. In the case of second residual crop T_{12} was on par with T_{14} and T_4 with respect to dehydrogenase activity. In case of urease activity, T_{12} was on par with T_6, T_{14}, T_2 and T_4. The highest alkaline phosphatase was recorded by T_{14} in the case second residual test crop also.

- Microbial count of the post harvest soil of the first residual test crop revealed that maximum bacterial count was noticed in T_{12} and was on par with T_6. The highest fungal count was found in T_6 and was comparable with T_{12}, T_2, T_{14} and T_{13}. In the case of actinomycetes T_6 recorded maximum count and was on par with T_{12}, T_{14} and T_{11}. After the second residual test crop, maximum bacterial count was noticed in T_{12} and was on par with T_6 and T_{13}. The highest fungal count was found in T_6 and was comparable with T_{12}, T_{14}, T_2 and T_{13}. T_6 recorded maximum count of actinomycetes.

- Regarding the uptake of primary nutrients by the first residual test crop, the highest N, P and K uptake were noticed in T_{14}. For P uptake it was also on par with T_{12} and for K uptake T_{14} was on par with T_{13}, T_{12} and T_4. With respect to second residual crop, the highest N, P and K uptake were noticed in T_{14}. For N and K uptake it was on par with T_{12}.

- With respect to first residual crop, the highest uptake of secondary nutrients were observed by T_{14}, for Ca and Mg it was on par with T_{12}, T_{13} and T_6 while for Mg T_{14} was on par with T_{12} and T_{13}. For S T_{14} was comparable with T_{12}. Regarding the uptake of nutrients in second residual test crop, maximum uptake of secondary nutrients was recorded by T_{14}. In case of Mg, T_{14} was on par with T_{12} and T_8.

- In case of first residual crop, the highest uptake of Fe, Mn and Zn were noticed in T_{14} and for Cu it was in T_{12}. For second residual crop, the highest uptake of Cu was recorded by T_{12} and the highest Fe, Mn and Zn uptake was noticed in T_{14}. For Fe uptake it was on par with T_{13}.

- T_{12} recorded the highest benefit cost ratio for both residual crops.

From the characterization study of both granular and liquid nano NPK formulations it was concluded that these formulations satisfied nano specifications having particle size less than 100 nm and high surface area. Nano NPK formulations contained primary, secondary, micronutrients, organic carbon, amino acid, humic acid etc. From the laboratory incubation study, it was revealed that in general, granular nano NPK formulation was found to be capable of releasing nutrients slowly for a period of 45 days and thereafter showed declining trend. Treatment which received Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1}) was superior with respect to nutrient release. Among the different treatments, application of FYM (12 t ha^{-1}) + granular nano NPK (12.5 kg ha^{-1}) + liquid nano NPK (0.4%) was found to be the best resulting in highest growth, yield and yield attributes of okra as direct test crop. Hence combined application of organic nano NPK formulations at the rate of 12.5 kg ha^{-1} with 0.4 per cent foliar application of liquid nano NPK at biweekly intervals along with 12 t ha^{-1} of FYM as basal dose improved the physical, chemical, biological and biochemical properties of the soil and enhanced the yield, yield attributes and nutrient uptake by the crops thereby improved the crop productivity and soil health.Similar trend was observed with respect to residual crop (amaranthus) also. But for the nutrient uptake of the residual crop, FYM (12 t ha^{-1}) + granular nano NPK (25 kg ha^{-1}) + liquid nano NPK (0.2% as foliar application) showed the highest uptake. From the study it was concluded that combined application of granular organic nano NPK at 12.5 kg ha^{-1} with foliar application of liquid nano NPK 0.4 per cent at biweekly intervals can substitute conventional fertilizers for sustainable crop production and healthy environment. Organic nano NPK formulations are ecofriendly and organically certified which can totally substitute conventional fertilizers and are considered as a boon for organic farming.

FUTURE LINE OF WORK

- Integrated use of nano and conventional fertilizers in crops need to be studied.
- Standardization of dose of application of organic nano formulations with respect to major crops in different agro ecological zones to be conducted.

- There is a need to unveil the penetration mechanism of nanoparticle inside the plants and plant cells as well as their transformation and movement through the vascular system.
- Other type or kind of nanofertilizers and their combinations available in market need to be considered and studied for field application.

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Appendices

Appendix I

I a. Weather data for the field experiment No: I

Standard week	Temperature (° C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
40	31.7	25.1	85.21	63.20
41	31.4	24.8	89.43	68.60
42	30.7	24.6	92.36	48.10
43	31.0	24.9	90.50	21.70
44	30.6	24.8	90.71	21.00
45	30.6	24.4	90.86	104.4
46	31.6	24.1	84.21	0.00
47	31.1	23.9	87.36	45.30
48	29.5	22.5	94.57	205.9
49	31.3	23.2	86.29	9.40
50	31.4	24.1	87.00	0.90
51	32.3	23.8	84.21	0.00
52	32.6	23.7	83.71	0.00
01	31.80	22.14	83.29	0.00

I b. Weather data for the field experiment No: II

Standard week	Temperature (° C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
3	32.23	21.63	83.50	0.0
4	31.66	21.51	82.43	0.0
5	31.66	22.80	82.64	0.0
6	32.37	24.17	84.50	0.0
7	32.63	23.66	84.71	0.0
8	32.49	23.09	85.00	0.0

I c. Weather data for the field experiment No: III

Standard week	Temperature (° C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
20	32.17	24.83	82.14	109.2
21	32.20	24.83	86.29	64.10
22	31.54	25.11	86.93	68.00
23	30.60	24.69	91.17	126.6
24	31.17	25.06	87.24	63.50
25	31.00	24.57	88.07	57.00
26	31.46	24.40	85.21	25.20
27	31.56	24.69	81.00	10.20
28	29.63	23.00	89.64	69.30
29	30.41	23.54	85.14	56.30
30	31.41	23.57	81.29	13.10
31	29.49	23.91	85.64	136.2
32	30.29	23.33	88.07	107.3
33	29.09	22.57	92.36	205.2

I d. Weather data for the field experiment No: IV

Standard week	Temperature (° C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
35	31.97	24.46	80.50	0.00
36	32.17	24.06	79.57	0.00
37	33.00	24.07	78.00	0.00
38	32.00	24.23	80.21	9.30
39	32.54	24.60	85.79	57.70
40	31.46	24.73	88.71	48.30

Appendix II

Composition of media for microbial enumeration

1. Enumeration of Bacteria

Media: Nutrient Agar

Composition:

1. Peptone - 5 g
2. NaCl - 5 g
3. Beef Extract - 3 g
4. Agar - 20 g
5. pH - 7.0
6. Distilled water - 1000 ml

2. Enumeration of fungi

Media: Rose Bengal Agar

Composition:

1. Glucose - 3.0 g
2. $MgSO_4$ - 0.2 g
3. KH_2PO_4 - 0.9g
4. Rose Bengal - 0.5 g
5. Streptomycin - 0.25 g
6. Agar - 20 g
7. Distilled water - 1000 ml

3. Enumeration of Actinomycetes

Media: Kenknight's Agar

Composition:

1. Dextrose - 1.0 g
2. KH_2PO_4 - 0.1 g
3. $NaNO_3$ - 0.1 g
4. KCl - 0.1 g
5. $MgSO_4$ - 0.1 g
6. Agar - 15 g
7. Distilled water - 1000 ml

ORGANIC NANO NPK FORMULATIONS FOR ENHANCING SOIL HEALTH AND PRODUCTIVITY

By

NIBIN. P. M

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ABSTRACT

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DOCTOR OF PHILOSOPHY IN AGRICULTURE

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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM

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ABSTRACT

The present investigation entitled "Organic nano NPK formulations for enhancing soil health and productivity" was carried out from July 2017 to February 2019 in the Model Organic Farm under the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. The objectives of the study were to characterize organic nano NPK formulations, assess the nutrient release pattern under laboratory conditions and study the effect of soil and foliar applications of organic nano NPK formulations on crop growth, yield, quality and soil health using okra as direct test crop and amaranthus as residual test crop.

The first part of the experiment comprised characterization of granular and liquid nano NPK formulations. During characterization study physical, physico-chemical and biochemical properties of nano NPK formulations were estimated. The particle size of granular and liquid nano NPK formulations were 83.20 nm and 71.79 nm, respectively. The surface area of granular nano NPK formulation was 138.95 $m^2\ g^{-1}$. The pH of granular nano NPK was neutral and that of liquid nano NPK was slightly acidic. Primary, secondary and micro nutrient contents (Cu, Zn, Fe, Mn and B) in both granular and liquid nano NPK formulations were analysed. Heavy metals such as As and Cd were not detected in the nano NPK formulations and Pb, Ni and Cr detected were below the permissible limit. Organic carbon, total amino acid and organic matter fractions of granular nano NPK were also determined.

The second part of the experiment was a laboratory incubation study, conducted to assess the nutrient release pattern of granular nano NPK formulation for a period of 75 days. The study comprised of 8 treatments with 3 replications. Treatments included Soil alone (T_1), Soil + FYM (12 t ha^{-1}) (T_2), Soil + nano NPK 12.5 kg ha^{-1} (T_3), Soil + FYM (12 t ha^{-1}) + nano NPK 12.5 kg ha^{-1} (T_4), Soil + nano NPK 25 kg ha^{-1} (T_5), Soil + FYM (12 t ha^{-1}) + nano NPK 25 kg ha^{-1} (T_6), Soil + nano NPK 50 kg ha^{-1} (T_7) and

Soil + FYM (12 t ha^{-1}) + nano NPK.50 kg ha^{-1} (T_8). In general, pH, EC and organic carbon content of incubated soil significantly increased throughout the incubation period. There was a significant difference in the available nutrient status of primary, secondary and micronutrients throughout the period of incubation. In general all the available nutrients increased upto 45th day of incubation and thereafter showed a decreasing trend except for K, where K showed an increasing trend upto 60th day and thereafter declined on 75th day. In the case of available Fe, Mn and Cu, the nutrient release increased upto 45th day of incubation and then declined. Zn showed a varying pattern of release. T_1 (Soil alone treatment) recorded the least nutrient release pattern throughout the incubation period.

The third part of the study consisted of four field experiments to study the efficacy of organic nano NPK formulations on crop growth, yield, quality and soil health using okra as the direct test crop and amaranthus as residual test crop. The field experiment on okra followed by amaranthus was repeated once again for confirmatory results. The field studies were carried out in a lattice design with 16 treatments and 3 replications. Treatments consisted of soil application of granular nano NPK at 3 levels (12.5 kg ha^{-1}, 25 kg ha^{-1} and 50 kg ha^{-1}) with and without FYM, foliar application of liquid nano NPK at 2 levels (0.2% and 0.4%) with and without FYM and combined application of granular and liquid nano NPK formulations with and without FYM.

Growth, physiological and yield attributes of okra (direct test crop of first and third field experiment) *viz.,* plant height, LAI, DMP, chlorophyll content, days to 50 % flowering, fruit length, fruit girth, number of fruits per plant, average fruit weight and total fruit yield were significantly influenced by the soil and foliar applications of organic nano NPK formulations. Treatment that received FYM + soil application of granular nano NPK formulation 12.5 kg ha^{-1} along with foliar application of liquid nano NPK formulation 0.4 per cent was found to be the best with respect to yield and yield attributes. Quality parameters of the fruit *viz.,* crude protein, crude fibre and ascorbic acid contents were influenced by the application of organic nano NPK formulations.

Post harvest analysis of soil for physical, chemical, biological and biochemical properties after the first and third experiments was done and was found to be significantly influenced by the treatments except for the bulk density of the soil. Highest NUE of 30.81 % and 31.38 % was recorded by the treatment T_{12} for the first and second direct crop, respectively. In general, microbial load *viz.*, bacteria, fungi and actinomycetes were significantly influenced by the application of organic nano NPK formulations. With respect to nutrient uptake by the plants, T_{12} recorded the highest uptake of N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu for first and second direct test crop (okra). The highest B:C ratio of 2.27 was also recorded by T_{12} for both the okra crops.

The residual effect of nano NPK formulations on growth, yield, quality and soil health was studied by raising amaranthus as test crop in the same field after the harvest of the direct test crops (okra). Highest plant height, DMP and yield were recorded in T_{12} in both residual crops. Quality parameters of residual crop were analysed and T_{12} registered the lowest oxalate and nitrate content. The highest vitamin C was recorded by T_{12}. Post harvest analysis of soil revealed that pH, OC, labile carbon, available N, P, K, Ca, Mg, micronutrients and enzymatic activities were significantly influenced due to the residual effect of organic nano NPK formulations by soil and foliar application. Regarding the uptake of nutrients, T_{14} (FYM (12 t ha^{-1}) + soil nano (25 kg ha^{-1}) + foliar nano NPK (0.2%)) recorded the highest uptake of N, P, K, Ca, Mg, S and micronutrients (Fe, Mn and Zn). The highest B: C ratio of 1.99 was registered in T_{12} in first residual experiment. Similarly B:C ratio of 1.81 was recorded in the treatment T_{12} in second residual experiment.

The present study revealed that both granular and liquid nano NPK formulations satisfied nano specifications having particle size less than 100 nm and high surface area. Organic nano NPK formulations contained primary, secondary, micronutrients, organic carbon, amino acid, humic acid etc. From the incubation study, in general, it was revealed that granular nano NPK formulation was found to be capable of releasing nutrients slowly for a period of 45 days and thereafter showed declining trend. Treatment which received Soil + FYM (12 t ha^{-1}) + nano NPK (25 kg ha^{-1}) was superior with respect to the nutrient release. Among the different treatments, application of FYM (12 t ha^{-1}) + soil nano NPK (12.5 kg ha^{-1}) + foliar nano NPK (0.4%) was found to be the best resulting in highest growth, yield and yield attributes of okra, the direct test crop. Similar trend was observed with respect to residual crop (amaranthus) also. But for the nutrient uptake of the residual crop, FYM (12 t ha^{-1}) + granular nano NPK (25 kg ha^{-1}) + foliar nano NPK (0.2%) showed a significant influence over the other treatments. From the study it was concluded that combined application of granular organic nano NPK at 12.5 kg ha^{-1} with foliar application of liquid nano NPK 0.4 per cent at biweekly intervals can substitute conventional fertilizers for sustainable crop production and healthy environment. Organic nano NPK formulations are ecofriendly and organically certified which can totally substitute conventional fertilizers and are considered as a boon for organic farming.