EFFECT OF SOIL APPLICATION OF ORGANIC NANO NPK FORMULATION ON GROWTH AND YIELD OF SESAME (*Sesamum indicum*) IN ONATTUKARA (AEU 3)

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by

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KERALA, INDIA

2022

DECLARATION

I, hereby declare that this thesis entitled **"EFFECT OF SOIL APPLICATION OF ORGANIC NANO NPK FORMULATION ON GROWTH AND YIELD OF SESAME (*Sesamum indicum*) IN ONATTUKARA (AEU 3)"** 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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Abbreviation/ symbols	**Expansion**
%	Per cent
° C	Degree celcius
° N	Degree North
° S	Degree South
AAS	Atomic Absorption Spectrophotometer
AEU	Agro Ecological Unit
ANOVA	Analysis of Variance
B	Boron
B:C	Benefit- Cost
BET	Brunaver, Emmett and Teller
Ca	Calcium
CD (0.05)	Critical Difference at 5 % level
CeO_2	Cerium di oxide
cm	Centi meter
cm^2	Square centi meter
CMC	Carboxy- Methyl Cellulose
CNT	Carbon Nano Tubes
CRD	Completely Randomized Design
Cu	Copper
DAS	Days After Sowing
$dS\ m^{-1}$	Deci Siemens per meter
EC	Electrical Conductivity
et al.	And others
Fe	Iron
FeS_2	Iron disulphide
Fig.	Figure
FYM	Farm Yard Manure

g	Gram
g m^{-2}	Gram per square meter
GRAPES	General R-shiny based Analysis Platform Empowered by Statistics
H_2SO_4	Sulphuric Acid
HA	Humic Acid
ha	Hectare
$HClO_4$	Perchloric acid
HNO_3	Nitric acid
hrs	Hours
NS	Not Significant
IAA	Indole Acetic Acid
K	Potassium
KAU	Kerala Agricultural University
K_2O	Potassium Oxide
kg ha^{-1}	Kilo gram per hectare
KH_2PO_4	Potassium dihydrogen phosphate
Mg	Magnesium
Mg m^{-3}	Mega gram per cubic meter
mg kg^{-1}	Milli gram per kilogram
mg L^{-1}	Milli gram per litre
mg mL^{-1}	Milli gram per millilitre
MgO	Magnesium oxide
ml	Milli litre
mm	Milli meter
Mn	Manganese
N	Nitrogen
NaOH	Sodium hydroxide
nm	Nanometer
NP_s	Nano Particles

$nTiO_2$	Nano titianium dioxide
ORARS	Onattukara Regional Agricultural Research Station
P	Phosphorus
pH	Potential of Hydrogen
PO_4^{3-}	Phosphate
RBD	Randomized Block Design
RDF	Recommended Dose of Fertilizers
RH	Relative Humidity
S	Sulphur
SiO_2	Silicon dioxide
SMZ	Surfactant Modified Zeolite
t ha^{-1}	Tonnes per hectare
UN	United Nations
VAM	Vesicular Arbuscular Mycorrhizae
viz.,	Namely
Zn	Zinc
ZnO	Zinc oxide
$ZnSO_4$	Zinc sulphate
μm	Micrometer

Introduction

1. INTRODUCTION

The need to use nanotechnology in agriculture stems from the fact that the human population is rising exponentially, which demands the production of more food. The global population is predicted to exceed 9 billion by 2050 (UN, 2015). Current agricultural practices cannot meet the growing demand for food without the extensive application of fertilizers. However, conventional fertilizers are inherently limited by their low nutrient use efficiency. By necessity, low nutrient use efficiency leads to higher input of conventional fertilizers to maintain good agricultural output. The energy and materials associated with this strategy increase the economic burden on farmers and impede the development of sustainable agriculture, particularly in developing countries.

Inorganic fertilizers have been widely practiced over past decades and it massively increased the agricultural output. However, its indiscriminate use will cause soil mineral imbalances, deplete the soil fertility and subsequently overall ecosystem, which will cause serious impacts in the long term. Nano fertilizers can be adopted as the best alternative for chemical fertilizers by alleviating the nutrient deficiencies through improved nutrient use efficiency and protecting the environment from the chronic problems of environmental pollution (Shukla *et al.*, 2019). Nano fertilizers are produced by physical, chemical or biological methods by improving their properties which will boost the crop production (Singh *et al.*, 2017). Nano particles have particle size less than 100 nm which promote its higher penetration into the plant system from applied surfaces (Qureshi *et al.*, 2018). The nano fertilizers can release nutrients slowly into the targeted sites thereby reducing the adverse effect on environment. Thus nanotechnology appears to be the potential tool to transform the field of agriculture (Dimpka and Bindraban, 2016).

Nanotechnology can reduce the adverse effects associated with fertilizer over dosage and nutrient toxicity in soil. The dose and frequency of application of nano fertilizers are much lower than other fertilizers, thereby reducing labour and cultivation costs. Nano fertilizers are advantageous over conventional fertilizers due to their high nutrient use efficiency, reduced quantity of application, slow and sustained release of nutrients and the lower impact on environment. Higher surface area to volume ratio of nano particles make them more reactive and facilitates faster absorption by plant.

"TAG NANO NPK" is a commercial organic nano NPK formulation which contains proteino-lacto-gluconate based NPK in nano form. It is produced by combining the gluconated fertilizers with ICAR's 4G nano micronutrient technology. It is a complete nutritional fertilizer with chelated major and micronutrients. It also contains amino acids, vitamins and organic matter fractions. So it can act as a better replacement for chemical fertilizers and can improve the soil quality.

Sesame is an important oil seed crop grown in sandy tracts of Onattukara which is raised in garden lands as well as in summer rice fallows. Oil is the main constituent of seed and its content ranges between 44 and 60 per cent. Despite of its high proportion of polyunsaturated fatty acids, the oil is less prone to rancidity when kept open. Presence of natural antioxidants such as sesamin and sesaminol in its non-glycol fraction is responsible for the oxidative stability and antioxidant action of sesame oil (Wu, 2007). These antioxidants protect the cells from oxidative damage by preventing the formation of oxidative radicals. They are also used as dietary supplements to cure heart diseases and cancer. Apart from oil, seeds are rich in protein, vitamin B_1 and B_6.

Onattukara sandy plain (AEU 3) is the special agro ecological unit delineated for the sandy plain extending into the midlands from coast and covering 43 panchayats and 3 muncipalities with an area of 67,447 ha (KAU, 2016). Research on the effect of organic nano NPK formulation in Onattukara sandy plain has not been carried out. This study aims to investigate the effect of organic nano NPK formulation on growth, yield and quality of sesame and soil health in this soil.

Present study consists of following objectives

- To characterize organic nano NPK formulation
- To assess the nutrient release pattern under laboratory conditions
- To study the effect of soil application of organic NPK formulation on crop growth, yield, quality and soil health using sesame as a test crop in Onattukara (AEU 3).

Review of Literature

2. REVIEW OF LITERATURE

This chapter discuss the literature related to the effect of nano fertilizers on soil health and crop productivity. The review will provide information about research works carried out in the field of nano fertilizers and can be used as a future reference tool in the field of nanotechnology.

2.1 NANOTECHNOLOGY

Nanotechnology is defined as the branch of science which deals with the characterization, fabrication and manipulation of materials at nano scale (Handford *et al*., 2014). The idea of nanotechnology dates back to 1970's and has wide applications in various disciplines. The use of nano particles in agriculture have the potential to boost agricultural development. But it is still under progressive development (Gogos *et al*., 2012). Nanotechnology provides the feasibility of exploiting nano scale materials as agrochemical carriers or slow release vectors for development of smart delivery systems to improve nutrient use efficiency. It also reduces the cultivation cost while protecting the environment in long run (Chinnamuthu and Bhoopathi, 2009). Particles with at least one dimension between 1 and 100 nm is considered as "nano particles" (Thakkar *et al*., 2010).

The properties of the bulk materials will be much different at nanoscale. The smaller particle size of nano fertilizers results in higher surface area. This increased surface area will enhance various metabolic processes inside the plant system by facilitating more adsorption which subsequently results in more agricultural output. They also possess high charge density. The higher surface area and nanoscale size impart higher reactivity to the nano particles (Adhikari *et al*., 2010).

Nanotechnology provides new interdisciplinary venture into agriculture by combining engineering and science. Application of nano particles (NPs) will be a boon to agricultural production system by improving the crop output. For crop improvement, nanobiotechnology uses nano particles as the carriers for genetic manipulation of the crops. They are capable of altering the plant gene expression which subsequently results in improved growth and yield (Nair *et al*., 2010). Nanotechnology plays a significant role in precision farming, which focuses on maximizing the output through minimum chemical input. Nano sensors make possible the real-time measurement and monitoring of crop growth, nutrient imbalances in soil, soil conditions, pest and diseases which helps to assure plant and soil health. Nanotechnology has a major role in the control of pests and diseases by the advancement in the development of nano encapsulated pesticide formulations. They release the active ingredient slowly into the environment and are demonstrated to have higher specificity, solubility, stability and permeability (Bhattacharyya *et al*., 2016). Nanomaterials also finds application in developing plant stress tolerance and improving soil conditions. Thus, it could be a promising tool for enhancing crop growth and production.

2.2. NANO FERTILIZERS

Nano fertilizers are nano materials which are either nutrients themselves (micro or macro nutrients) or acting as carriers or additives for the nutrients (Kah *et al*., 2018). They have higher solubility in different solvents. Nano particles have particle size less than 100 nm which promotes its higher penetration into the plant from applied surfaces (Qureshi *et al*., 2018). Nanotechnology can provide the solutions to increase the value of agricultural products and overcome environmental problems by the application of fertilizers with nano particle size. Nano materials are able to control the release of mineral elements added as fertilizers and increase the duration of fertilizer effect (Al-Shumari *et al*., 2019).

Nano fertilizers can be used as smart fertilizers by coating it with certain materials like polymers, carbon nano tubes, mesoporous silica etc. which will regulate its nutrient release. According to Liu *et al.* (2006), organic material (polystyrene) intercalated in kaolinite clay layers binds the nano materials which makes them capable of releasing nutrients in a controlled manner. As a result, nano particles can be employed to control nutrient release through membranes.

Subramanian *et al.* (2008) opined that the nano fertilizers can limit the excess loss of nutrients from the fertilizer granules by the controlled release of nutrients which will subsequently reduce the environmental impact.

2.3 EFFECT OF NANO FERTILIZERS ON CROP GROWTH

2.3.1aPlant height, Primary branches, Leaf area and Dry matter production

Ajirloo *et al.* (2015) reported that application of K nano fertilizer @ 400 kg ha^{-1} in tomato improved the plant height and stem diameter. The application of recommended dose of fertilizers through nano fertilizers in rice increased its plant height throughout the crop period (Benzon *et al*., 2015).

Ashfaq *et al.* (2016) pointed out that Cu loaded carbon nano fibres have the capacity to increase the water uptake, germination, shoot lengths, chlorophyll and protein contents of chick pea. The soil application of green synthesized sulphur nano particles are reported to increase plant height, number of branches, number of leaves and stem diameter in *Cucurbita pepo.* This demonstrates that the successful application of sulphur nano particles (100-400 mg L^{-1}) can enhance the growth of *Cucurbita pepo* under field conditions (Salem *et al.*, 2016).

Subbaiah *et al*. (2016) reported that the nano ZnO application at 1204 mg L^{-1} Zn significantly enhanced shoot and root elongation by 35 % and 40 % respectively when compared with control, 60 % and 55 % respectively when compared to those treated with $ZnSO_4$ at a concentration of 1606 mg L^{-1} Zn. ZnO nano particles with P supplements enhanced biomass, photosynthetic pigments and proteins in cotton, indicating that they may protect against oxidative damage by enhancing antioxidant enzyme activity (Venkatachalam *et al.*, 2017).

Study conducted by Abdel-Salam (2018) on lettuce revealed that application of nano urea at the rate of 3750 mg N L^{-1} along with VAM increased the plant height upto 101 per cent and dry matter upto 155.7 per cent. Al-Juthery *et al.* (2018a) revealed that foliar spray of nano fertilizer along with the organic material new humic showed an increase of 21.11%, 29.61% and 22.29 % in plant height, length of spike and total chlorophyll. Ghassemi-Golezani and Afkhami (2018) revealed that the application of silicon nanoparticles and manganese nanoparticles in safflower improved the chlorophyll content, leaf water content and leaf area which subsequently enhanced the plant height and branches per plant under normal and water deficit conditions.

Titanium dioxide nano particles ($nTiO_2$) are reported to improve the biomass production in maize due to enhanced the nitrogen assimilation, photo reduction activities of photosystem II and electron transport chain and the scavenging of reactive oxygen species (Morteza *et al*., 2013). Tantawy *et al*. (2014) found that application of nano calcium 0.5 g L^{-1} in tomato resulted in higher chlorophyll content followed by chelated calcium. The application of glauconite nano particle in the maize plant showed maximum leaf area, plant height and nitrate reductase activity at 200 mg K_2O kg^{-1} concentration (Praveen *et al*., 2020).

Research conducted by Krutilina *et al*. (2000) in maize and barley revealed that the application of zeolite enhanced the biomass production by improving the photosynthetic rate of the crops. Application of blend of nano-TiO_2 and nano-SiO_2 improved the water uptake efficiency, fertilizer use efficiency, the antioxidant system and boosted the nitrate reductase enzyme activity, which could be a better source for the fast germination and enhanced growth in soybean (Lu *et al.*, 2002).

Hong *et al.* (2005) pointed out that at proper concentration (0.25%), application of nano-TiO_2 enhanced the rate of photosynthesis by increasing the photochemical reactions which subsequently resulted in improving the biomass of spinach. Evans (2009) reported that the iron nano particles have the ability to increase the rate of photosynthesis, thus increasing growth and dry matter production. Afify *et al*. (2019) reported that the application of potassium nanofertilizer significantly improved the dry weight of the plant, root length and leaf chlorophyll content of groundnut.

Carbon Nano Tubes (CNTs) are reported to penetrate the seeds effectively which reduced the germination time to half and weight was increased more than twice compared to control plants (Khodakovskaya *et al.*, 2009). Srinivasan and Saraswathi (2010) reported that CNTs can result in increased biomass, rapid germination and rapid growth rates, which subsequently increase the agricultural production over short period of time.

The influence of Zn nano fertilizer on bajra (*Pennisetum americanum* L.) was studied by Tarafdar *et al*. (2014). In six weeks old plants grown in field conditions, they found significant gains in phenological growth and plant biomass (12.50 per cent) compared to control plants. Miranda-Villagomez *et al.* (2019) reported that application of nano-KH_2PO_4 in rice promoted higher physiological efficiency for phosphorus in shoots and roots which finally resulted higher biomass accumulation.

2.3.2 Effect of nano fertilizers on root characters

Pandey *et al.* (2010) synthesized ZnO NPs by hydrothermal method and found that its application in chick pea increased the level of Indole Acetic Acid (IAA) in roots which further improved the germination and root activity. Jayarambabu *et al.* (2014) reported that application of 20 mg zinc nano particles can increase the root length of mung bean.

Liu and Lal (2014) revealed that the application of hydroxyapatite nano particle as P fertilizer in soybean resulted in 41 per cent increase in root biomass compared to the ordinary P fertilizer. The application of phosphorus and MgO nano particles improved the root characters like root length, root volume and root biomass in maize (Adhikari, 2019).

2.4 EFFECT OF NANO FERTILIZER ON YIELD AND YIELD ATTRIBUTES

Experiment conducted by Liu *et al.* (2007) on rice revealed that the application of nano carbon incorporated slow release fertilizer is capable of increasing the crop yield and nitrogen use efficiency. Liu *et al.* (2008) reported that carbon based nanomaterials can increase the yield and quality of winter crops and thus reduce the application rate of nitrogen fertilizers.

An experiment conducted by Liu *et al.* (2009) revealed that the application of nanomaterials along with conventional fertilizers can increase the crop yield in rice (10.29 %), spring maize (10.93 %), soybean (16.74 %), winter wheat (28.81 %) and vegetables (12.34 % - 19.76 %). Qian *et al*. (2010) found that the application of nano scale carbon together with fertilizers in rice increased the number of glume flowers per ear and the grain yield.

Das (2011) found that the application of nano-rock phosphate was more advantageous than micro-sized rock phosphate for improving the grain yield in maize. Foliar application of ZnO nano particles at a dose which is 15 times lower than the dose of chelated $ZnSO_4$, yielded 29.5 percent more groundnut pods than the chelated $ZnSO_4$ (Prasad *et al*., 2012).

With the use of nano-K Fertilizer, Sirisena *et al*. (2013) were able to increase rice grain production. Study conducted by Harsini *et al.* (2014) found that the application of nano chelated iron in wheat improved its spike number, thousand grain weight, number of grains per spike, grain yield and harvest index of wheat.

The use of carboxy-methyl cellulose (CMC) stabilized hydroxyapatite nano particles in soybean are able to enhance the phenological growth rate by 33 per cent and yield by 18 per cent compared to conventional fertilizers (Liu and Lal, 2014). The grain yield of pearl millet was increased by 37.7 per cent when the Zn nano fertilizer was applied foliarly (Tarafdar *et al.* 2014).

Ajirloo *et al.* (2015) found that the use of 300 kg ha^{-1} K nano fertilizer on tomato provided the highest number of fruits per plant, fruit weight, fruit diameter and fruit yield. Amin and Mohammad (2015) suggested that the nano zinc application can enhance the yield and yield attributes of maize grown in water deficit conditions.

Application of a P nano fertilizer (water - phosphorite suspension) of size 60-120 nm showed promising results after seed treatment. They improved morphometric indices of corn plants and increased the corn yield by 24.1 percent (Sharonova *et al.*, 2015). When NPK loaded chitosan nano particles (chitosan-NPK NPs) were applied on the wheat leaves, it accelerated the growth and yield of wheat (Abdel-Aziz *et al*., 2016).

Janmohammadi *et al*. (2016) found that the nano scale ZnO and ferric oxide application can result in considerable improvements in yield attributes like grains per spike, grain weight, length of the spike and grain yield of barley in semiarid regions. They also increased the days to flowering and maturity. Kottegoda *et al.* (2017) revealed that the application of urea- hydroxyapatite nano particles reduced the use of urea by half to produce higher yield in rice.

Singh and Kumar (2017) reported that the application of nano ZnS 500 mg kg^{-1} at 50 DAS can improve the seed yield of sunflower. Experiment conducted by Das *et al.* (2018) showed that in rice plants, seed dressing with nano pyrite (FeS_2) without any addition of NPK fertilizer resulted in comparable yield as obtained by following standard fertilizer application which indicates that, nano pyrite seed pre-treatment can come up as a NPK equivalent strategy for rice production.

Jafar *et al*. (2018) reported a significant improvement in sesame seed yield from 123 g m^{-2} to 186 g m^{-2} by the application of nano magnesium fertilizer. Application of multi nutrient nano fertilizer on safflower improved its yield and productivity by the simultaneous release of macro and micronutrients (Janmohammadi *et al.,* 2018).

Nibin (2019) found that soil application of granular organic nano NPK and biweekly spraying of 0.4 percent liquid organic nano NPK can replace the traditional fertilizers to maximize the output of bhindi. When nano chitosan nitrogen fertilizer was applied in maize, it resulted in increased silking date, ear length, seeds per row, ear weight, thousand seed weight and the yield (El- Gewely, 2020).

Kumar *et al*. (2020) reported that the foliar application of nano nitrogen produced an additional seed yield of 129 kg ha^{-1} over farmer’s fertilizer practice in mustard. Yusefi-Tanha et al. (2020) found that ZnO nanoparticle can improve the crop yield of soyabean with lower amount of application.

Yield test conducted in durum wheat with doped urea and potassium in calcium apatite nano particles recorded comparable yield with much lower N quantity (reduction of 40 per cent weight) than that supplied by conventional fertilizers (Ramirez – Rodriguez *et al*., 2020). Zarei *et al*. (2020) found that the crop yield can be optimised by the application of phosphorus nano chelate or its combination with chitosan.

2.5 EFFECT OF NANOFERTILIZERS ON QUALITY PARAMETERS

2.5.1 Protein content

Application of nano calcium in peanut is reported to increase the protein content in aerial parts of the plant (Liu *et al.,* 2005). The study conducted by Schmidt and Szakal (2007) revealed that the protein content of the winter wheat was significantly improved by the application of zinc zeolite rather than with copper zeolite. Xiao *et al.* (2008) found that application of slow release fertilizer coated with nano material improved the grain protein content of wheat compared to the NPK chemical fertilizer. Foliar application of nano iron fertilizer is reported to enhance the crop growth, crude protein and soluble carbohydrates (Peyvandi *et al.,* 2011; Sharifi *et al.,* 2016)

Abdel-Aziz *et al*. (2016) revealed that the foliar nutrition of nano fertilizers in crops can result in improved protein content by altering the gene responsible for protein synthesis. Experiment conducted by Al-Juthery *et al*. (2018a) reported that the foliar application of complete nano fertilizer and an organic material new humic in wheat yielded more protein (14.26 %) than control (12.44%).

2.5.2 Oil content

Chelated nano iron is reported to increase the oleic and linoleic acid in the soyabean oil (Monica and Cremonini, 2009). Boghra *et al*. (2015) observed that application of nano fertilizers significantly increased the oil content in sesame.

A study carried out by Mohammadghasemi *et al*. (2020) on dragon head revealed that winter sown plants treated with NPK, nano NPK and chelated nano Fe acquired highest palmitic acid content (7.94 per cent). Varamin *et al*. (2020) reported that the co-application of nano-Mg and 4.8 g L^{-1} chitosan increased the seed yield and oil content of sesame grown in arid and semiarid region.

2.6 INCIDENCE OF PEST AND DISEASE

Rouhani *et al.* (2012) found that the silver nanoparticles can be effectively used as an effective pest control tool against *Aphis nerii* and observed the highest insect mortality rate by the application of nano particles at 700 mg mL^{-1} and imidacloprid at 1 $\mu L\ mL^{-1}$. Rao and Paria (2013) reported that the application of green synthesized sulphur nanoparticles of very small size (35 nm) are reported to be effective control against the fungal pathogens *Fusarium solani* and *Venturia inequalis.*

El-Sayed *et al.* (2020) revealed that application of compost and nano NPK fertilizer significantly reduced the incidence of pre and post emergent damping off and root rot per cent compared to the untreated plants.

2.7 EFFECT OF NANO FERTILIZERS ON PLANT NUTRIENT UPTAKE

2.7.1 Primary nutrient uptake

Jinghua (2004) showed that the application of nano composite which contains primary nutrients, micronutrients, amino acids and mannose have the capacity to increase the nutrient utilization by the grain crops. Ahmed *et al.* (2010) found that the application of zeolite along with inorganic fertilizers increased the primary nutrient uptake in stem, leaf and root of maize (*Zea mays*). Foliar application of complete nano fertilizer and organic material new humic in wheat increased N, P and K content of plants by 71.17 %, 106.66 % and 71.71 % respectively (Al-Juthery *et al*., 2018a).

Abdel-Salam (2018) reported that application of nano urea at the rate of 3750 mg N L^{-1} along with VAM resulted in maximum nitrogen uptake (357.30 %) in lettuce compared to conventional urea.

Raliya and Tarafdar (2013) found that foliar nutrition of nano ZnO in cluster bean enhanced the phosphatase and phytase enzyme activity in the soil which in turn increased P uptake by 11 per cent without supplementing with external P fertilizer. Similar results were obtained by Raliya *et al.* (2016) on mung bean. P uptake was increased to 10.8 per cent compared to the control by the application of biosynthesized ZnO nano particle.

Experiment conducted by Adhikari *et al.* (2014) revealed that the crop uptake of nano rock phosphate was comparable to that of single super phosphate in vertisol and inceptisol, suggesting the feasibility of nano rock phosphate as an effective P fertilizer for the growth of the crops. Montalvo *et al*. (2015) found that application of nano hydroxyapatite increased the P uptake by the wheat plants than the bulk hydroxyapatite.

Lettuce plants treated with nano hydroxyapatite showed increased P uptake due to the higher penetration of nano fertilizers into the plant (Taskin *et al.,* 2018). Fakharzadeh, *et al.* (2020) found that the P and K uptake in rice plants were increased by 43 and 41 per cent respectively by the application of nano chelated iron fertilizer.

2.7.2 Secondary nutrient uptake

According to Supapron *et al*. (2002), zeolite can slowly release calcium and magnesium into the soil which can improve its availability in soil. Li and Zhang (2010) conducted batch and column leaching experiment to check the suitability of surfactant modified zeolite (SMZ) as a sulphate carrier and found much reduction in sulphate leaching by the application of SMZ and it prolonged the duration of sulphur availability.

2.7.3 Micronutrient uptake

Lee *et al.* (2008) revealed that nano sized copper was significantly absorbed by mung bean and wheat. Ashfaq *et al.* (2016) observed that the more copper uptake was found in leaf than roots and shoots of *Cicer arietinum* by the application of copper nano particle grown carbon nanofiber, which confers the higher translocation capacity of nano particles.

An experiment carried out by Subbaiah *et al*. (2016) on maize found that application of ZnO nano particles resulted in 15 per cent higher zinc level in plants.

2.8 EFFECT OF NANO FERTILIZERS ON SOIL QUALITIES

2.8.1 Physical properties

The porous structure of nano zeolites can absorb more moisture and can provide water to the plants in dry areas (Ramesh *et al.*, 2010).

Lab studies conducted by Lateef *et al*. (2016) reported that nano composites had shown a considerable increase in water retention capacity, water absorbency and equilibrium water content.

Kubavat *et al*. (2020) reported that application of chitosan nano particles incorporated with K showed enhanced porosity, higher water conductivity and enhanced friability which could act as a better medium for plant growth.

2.8.2 Chemical properties

2.8.2.1 pH

El-Ghamry *et al.* (2018) suggested that use of nano fertilizers in soil can improve the soil pH which can further reflect in organic matter content and biological activity.

El-Sayed *et al.* (2020) found that when compost was applied along with nano NPK fertilizer, it decreased the pH of soil by the production of organic acids from the microbial degradation of residual organic compounds.

2.8.2.2 EC

Tantawy *et al.* (2014) concluded that the adverse effects of salinity can be reduced by applying calcium in nanoform. Hojjat and Kamyab (2017) pointed out that application of silver nano particle caused better salinity tolerance in fenugreek grown under salinity stress and suggested that application of 30 g L^{-1} silver nano particles can be practised to improve fenugreek germination under salinity stress.

El-Sayed *et al*. (2020) reported that electrical conductivity values decreased at a higher rate when compost and nano NPK fertilizer were applied together due to the increased activity of microbes which reduced salinity.

2.8.2.3 Available primary nutrients

When zeolite was coupled with nitrogen, phosphorus and potassium compounds, it improved the nutrient availability in various crops (Dwairi, 1998). Lateef *et al*. (2016) reported that the nanocomposite containing zeolite impregnated with macro and micronutrients showed a slow release of nutrients over time.

Application of ammonium sulphate loaded in clinoptilolite zeolite improved the nitrogen use efficiency by reducing nitrate leaching in crops grown in sandy soil compared to the application of ammonium sulphate alone (Huang and Petrovic, 1994). Application of 6.25 per cent zeolite in urea is reported to reduce 50 per cent ammonia loss from the nitrogenous fertilizer and improved the nitrogen status of the soil (Lefcourt and Meisinger, 2001).

Ming and Allen (2001) reported that the application of natural zeolites to the soluble N fertilizers like ammonia and urea can increase the fertilizer use efficiency. Rahale (2010) conducted a study on the nutrient release pattern of various nitrogen-containing nano fertilizer formulations. It revealed that the nitrogen availability was found to be longer (>1000 hrs) in nano-clay based fertilizer formulations (zeolite and montmorillonite of dimension 30-40 nm) compared to the conventional fertilizers (500 hrs).

Combining urea and zeolite along with sago waste water was found to be more advantageous than urea alone since it produced both ammonium and available nitrate content rather than ammonium. The mixture also improved the soil's ability to retain exchangeable ammonium and available nitrate (Latifah *et al.*, 2011). Kottegoda *et al.* (2017) revealed that the nitrogen release was reduced to 12 times when the urea loaded hydroxyapatite was used instead of the conventional urea.

Wang *et al.* (2012) found a significant reduction in P fixation in the soil by the application of nano hydroxyapatite and humic acid. Bansiwal *et al.* (2006) studied the P release pattern from fertilizer-loaded unmodified zeolite, surface modified zeolite (SMZ) and solid KH_2PO_4 and found that the P was available for more than 1080 hours of continuous percolation from fertilizer loaded SMZ against 264 hrs from KH_2PO_4.

Rahale (2010) investigated the PO_4^{3-} release pattern of several nano clays and zeolite modified surfaces using a percolation reactor. Nano-formulations have been demonstrated to release phosphate over 40-50 days, whereas traditional fertilizers only released minerals for 10-12 days. Preetha and Balakrishnan (2017) reviewed that the surface modification of fertilizers with natural clays and zeolite can extent the release of phosphorus.

2.8.2.4 Available secondary nutrients

Li and Zhang (2010) used surfactant modified zeolite as a fertilizer additive to control the release of sulphur and suggested that it could be used as a good carrier for sulphate and can improve the sulphur availability in the soil.

Supapron *et al.* (2002) revealed that the zeolite released Ca and Mg slowly into the soil and increased their availability.

2.8.2.5 Available micronutrients

Sheta *et al.* (2003) studied the sorption and release pattern of zinc and iron from five natural zeolites and bentonite. Their findings revealed that natural zeolites, especially chabazite and bentonite minerals showed higher sorption and slower release pattern so it can be used as a potential slow release fertilizer.

Broos *et al.* (2007) pointed out that the zeolite can reduce the zinc release due to its low solubility and sequestration, which will inturn improve the plant nutrient uptake.

2.8.2.6 Biological and biochemical properties

Tarafdar *et al.* (2014) found out that nano ZnO application can significantly improve the rhizosphere enzymes like acid phosphatase (61.70 per cent), alkaline phosphatase (76.90 per cent), phytase (322.20 per cent) and dehydrogenase (21 per cent) over control, which suggest the enhanced microbial activity and their population.

Yadav *et al*. (2014) also reported that soil microbial population, dehydrogenase activity and enzyme activity was enhanced by the application of zinc oxide nano particles. The ZnO application in maize plants improved the root phytase and phosphatase activity in P deficient soils (Adhikari *et al.*, 2016).

Some nano particles are reported to have adverse effects on soil health. Brandeburova *et al*. (2017) found that application of CeO_2 nano particle reduced the nitrogen fixation rate by inhibiting the growth of nitrogen fixing bacteria in the root nodules of soybean.

2.9 EFFECT OF NANOFERTILIZERS ON ECONOMICS OF CULTIVATION

Supapron *et al.* (2002) suggested that the use of chemical fertilizers along with zeolite can produce higher net profits than the chemical alone.

Spruogis *et al*. (2013) pointed out that the application of universal bio organic nano fertilizer along with NPK was found economically beneficial in spring barley.

Foliar spray of nano NPK fertilizer 50 per cent in potato resulted in higher productivity and benefit-cost ratio in potato cultivation (El-Azeim *et al*., 2020).

Materials and Methods

3. MATERIALS AND METHODS

The research experiment was conducted at Onattukara Regional Agricultural Research Station, Kayamkulam and College of Agriculture, Vellayani during the period from December 2020 to April 2021. The experiment aimed to study effect of organic nano NPK formulation on growth and yield of sesame. Objectives of the study include characterization of organic nano NPK formulation, elucidation of nutrient release pattern under laboratory condition and a field study to assess the effect of soil application of organic nano NPK formulation on crop growth, yield, quality and soil health using sesame as a test crop in Onattukara (AEU 3). The study consisted of three parts

PART I: Characterization of granular organic nano NPK formulation

PART II: Laboratory incubation study to assess the nutrient release pattern of organic nano NPK formulation.

PART III: Field experiment to study the effect of soil application of organic nano NPK formulation on crop growth, yield, quality and soil health.

A brief account of the materials used and methodology adopted in this study are described in this chapter.

PART I

3.1 CHARACTERIZATION OF ORGANIC NANO NPK FORMULATION

Characterization of organic nano NPK formulation was done to determine the physical, physico-chemical, chemical and biochemical properties as per standard procedures (Table 1).

3.1.1 Particle size analysis

Particle size of granular organic nano NPK formulation was analysed using particle size analyzer. Particle size ranging 0.3 nm – 8 μm could be determined using this instrument.

Table 1. Methods for analysis of granular organic nano NPK formulation

Sl. No	Parameter	Method	Reference
1	Particle size analysis	Zeta sizer analyzer	Asadi *et al.* (2009)
2	Surface area	Surface area analyzer	Wang *et al.* (2012)
3	Ph	pH meter method	Jackson (1973)
4	EC	Conductivity meter method	Jackson (1973)
5	Organic carbon	Walkley and Black's rapid titration method	Walkley and Black (1934)
6	Total nitrogen	Microkjedahl digestion and distillation	Jackson (1973)
7	Total phosphorus	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using spectrophotometer	Jackson (1973)
8	Total potassium	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using flame photometer	Jackson (1973)
9	Total calcium and magnesium	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using Versenate titration method	Hesse (1971)
10	Total sulphur	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and turbidimetry	Massoumi and Cornfield (1963)
11	Total micronutrients Fe, Mn, Zn, Cu	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using AAS	Jackson (1973)
12	Total boron	Dry ashing at 550 $^{\circ}$C 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)

One gram of the powdered sample is dispersed in 10 ml of ethanol. To break the powder agglomerates into fine, colloidal particles and for complete dispersion in ethanol, the suspension was stirred with mechanical stirrer for 10 minutes. A portion of the sample was filled in the disposable cuvette and measured using the instrument. (Asadi *et al.,* 2009).

3.1.2 Surface area

Surface area of nano NPK formulation was analysed using surface area analyzer (Wang *et al.,* 2012). Brunauer, Emmett and Teller (BET), was the most common method used to describe surface area. 25 mg of sample was taken and it was degassed for 16 hours to ensure that unwanted vapours and gases are removed from the surface of sample before analysis.

3.1.3 Zeta potential analysis

The zeta potential of the sample was analysed using zeta potential analyzer. 25 mg of the sample was taken for analysis. Sonication of the sample was done for 20 minutes using ultrasonicator and the supernatant of the solution was analysed for the zeta potential.

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

Organic matter is separated into fractions of humic acid, fulvic acid and humin done by alkaline extraction (McBride, 1994). Here 0.5 N NaOH was used as extractant.

200 ml of 0.5 N NaOH was added to 20 gram of the sample and shaken for 1 hour and left to stand for 18 hours. Then it was filtered. The residue was insoluble humin and the filtrate contain humic acid and fulvic acid. The humic acid extracted was quantified gravimetrically. The acid soluble fraction collected during the separation of humic acid was evaporated and estimated as fulvic acid.

3.1.5 Total amino acid

100 mg of the sample was weighed and homogenized well with mortar and pestle after adding 5 ml of 80 per cent ethanol for 10-15 minutes. Then it was filtered. The filtrate was taken. The extraction was repeated twice with residue and pool all the supernatants. 0.1 ml of extract was pipetted out for estimation and 1 ml of 2 per cent

ninhydrin reagent was added. The volume was made to 2 ml with distilled water. Then it was heated in boiling water bath for 20 minutes. After cooling, 5 ml of water – isopropanol mixture (1:1) was added and measured the absorbance at 570 nm after 15 minutes (Sadasivam and Manickam, 1992).

PART II

3.2 LABORATORY INCUBATION STUDY

An incubation study was conducted under laboratory condition for a period of 90 days from 18-01-2021 to 17-04-2021 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 90^{th} day of incubation.

3.2.1 Collection and preparation of soil sample for incubation study

Soil sample for incubation study was collected from Onattukara Regional Agricultural Research Station (ORARS), Kayamkulam. Collected soil was thoroughly mixed, air dried under shade and sieved through 2 mm sieve. The pots were filled with 10 kg soil and treatments were given as per technical programme. Field capacity was maintained throughout the study period.

3.2.2 Design and layout of the experiment

Design : CRD

Treatments : 9

Replications : 3

3.2.3 Treatment details

T_1: Soil application of organic nano NPK formulation (25 kg ha^{-1})

T_2: Soil application of organic nano NPK formulation (25 kg ha^{-1}) + FYM (5 t ha^{-1})

T_3: Soil application of organic nano NPK formulation (25 kg ha^{-1}) + 50 per cent of recommended dose of NPK

T_4: Soil application of organic nano NPK formulation (25 kg ha^{-1}) + FYM (5 t ha^{-1}) +50 per cent of recommended dose of NPK

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

T_6: Soil application of organic nano NPK formulation (50 kg ha^{-1}) + FYM (5 t ha^{-1})

T_7: Soil application of organic nano NPK formulation (50 kg ha^{-1}) + 50 per cent of recommended dose of NPK

T_8: Soil application of organic nano NPK formulation (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent of recommended dose of NPK

T_9: Absolute control

* Recommended dose of NPK- 30:15:30 kg NPK ha^{-1}

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

3.2.4 Soil sampling

Samples were drawn at 0th, 7th, 15th, 30th, 45th, 60th and 90th day of incubation and analysis was done.

3.2.5 Analysis of the samples

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

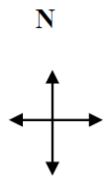
3.2.6 Statistical analysis

Statistical analysis was carried out by applying the analysis of variance (ANOVA) technique for CRD by using GRAPES statistical software developed by Department of Agricultural Statistics, College of Agriculture, Vellayani (GRAPES, 2020).

PART III

FIELD EXPERIMENT

Field experiment was conducted at Onattukara Regional Agricultural Research Station, Kayamkulam from 15-12-2020 to 19-03-2021 to study the effect of organic nano NPK formulation on crop growth, yield, quality and soil health using sesame as the test crop.



R_1	R_2	R_3
R_1T_5	R_2T_7	R_3T_3
R_1T_1	R_2T_9	R_3T_6
R_1T_8	R_2T_4	R_3T_2
R_1T_3	R_2T_8	R_3T_5
R_1T_6	R_2T_2	R_3T_4
R_1T_4	R_2T_3	R_3T_9
R_1T_2	R_2T_5	R_3T_1
R_1T_9	R_2T_6	R_3T_7
R_1T_7	R_2T_1	R_3T_8

Fig. 1. Layout of the incubation study

Plate 1. General view of the incubation study

3.3 EXPERIMENTAL SITE

3.3.1 Location

Field experiment was conducted at Onattukara Regional Agricultural Research Station, Kayamkulam. This site is located at 9.17713° N latitude and 76.51784° E longitude.

3.3.2 Climate and season

Field experiment was conducted from December 2020 to March 2021.

3.3.3 Weather parameters

Weather data was collected from Onattukara Regional Agricultural Research Station, Kayamkulam. The weekly weather data is presented in the Fig. 2 and Appendix 1.

3.3.4 Soil

Soil of the experiment site comes under the taxonomic family of Loamy Skeletal Kaolinitic Isohyperthermic Ustic Quartzi *Psamments*.

3.4 MATERIALS

3.4.1 Crop and variety used

Sesame variety Thilak was used for the study purpose. Thilak is a pureline selection from Malappuram local suited for summer rice fallows of Onattukara. The seeds were purchased from Onattukara Regional Agricultural Research Station, Kayamkulam.

3.4.2 Manures and fertilizers

FYM, organic nano NPK formulation, and chemical fertilizers *viz.*, urea, rajphos and muriate of potash were used as per treatments. ‘TAG NANO NPK’ is the commercial granular organic nano NPK formulation used and it is marketed by Tropical Agrosystem (P) Ltd.

3.5 METHODS

Different methods of soil analysis and plant sample analysis is given in Table 2 and 3.

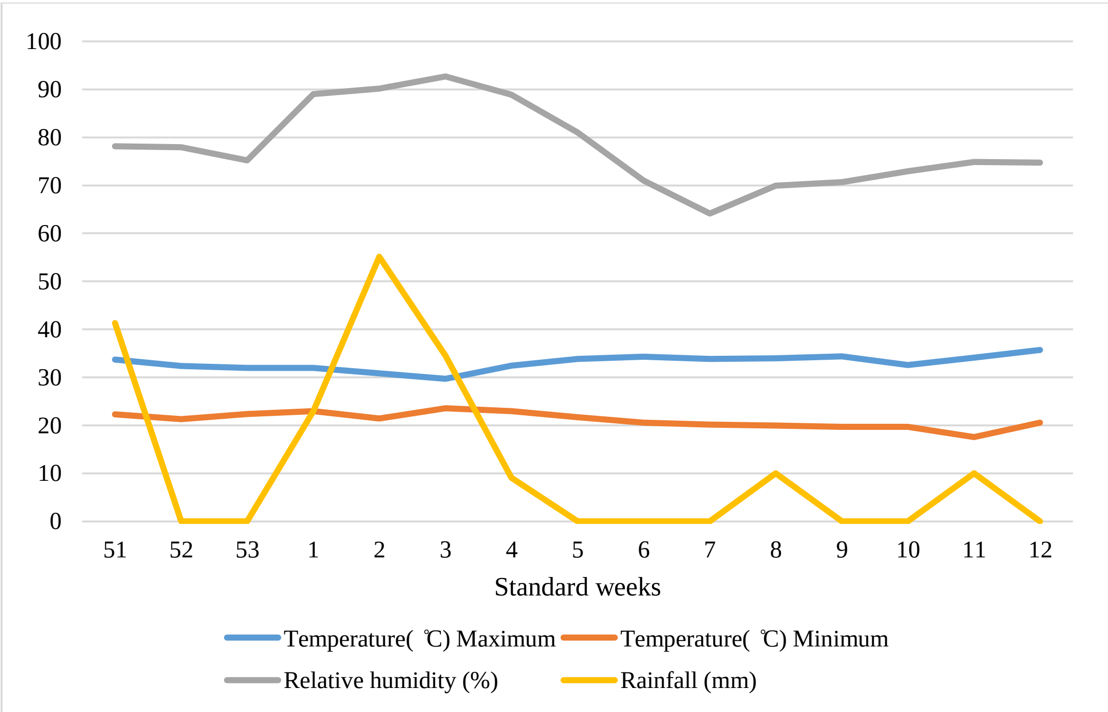


Fig. 2. Weather parameters during the cropping period (Dec 2020- Mar 2021)

Plate 2. General view of the experimental field

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

Sl. No.	Parameter	Method	Reference
1	Texture	International pipette method	Piper (1966)
2	Bulk density	Core method	Gupta and Dakshinamoorthi (1980)
3	pH	pH meter	Jackson (1958)
4	EC	Conductivity meter	Jackson (1958)
5	Organic carbon	Walkley and Black rapid titration method	Walkley and Black (1934)
6	Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
7	Available P	Bray No.1 extraction and estimation using spectrophotometer at 660 nm.	Bray and Kurtz (1945)
8	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
9	Exchangeable Ca and Mg	Versenate titration method	Hesse (1971)
10	Available S	$CaCl_2$ extraction and estimation using spectrophotometer	Massoumi and Cornfield (1963)
11	Available Micronutrients Fe, Mn, Zn and Cu	0.1 N HCl extraction and estimation using AAS	Sims and Johnson (1991)
12	Available Boron	Hot water extraction and estimation using spectrophotometer	Gupta (1972)
13	Dehydrogenase assay	Spectrophotometric method	Casida *et al.* (1964)
14	Microbial biomass carbon	Chloroform Fumigation Incubation method	Jenkinson and Powlson (1976)

Table 3. Analytical procedures followed in plant analysis of the experiment

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 Versenate 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)
7	Boron	Dry ashing at 550˚ C 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)

3.5.1 Details of field experiment

Design : Randomized Block Design

Crop : Sesame

Variety : Thilak

Spacing : 25 × 15 cm

Plot size : 20 sq. m

Treatments : 10

Replication : 3

Treatment details

T_1: Soil application of organic nano NPK formulation (25 kg ha^{-1})

T_2: Soil application of organic nano NPK formulation (25 kg ha^{-1}) + FYM (5 t ha^{-1})

T_3: Soil application of organic nano NPK formulation (25 kg ha^{-1}) + 50 per cent of recommended dose of NPK

T_4: Soil application of organic nano NPK formulation (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent of recommended dose of NPK

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

T_6: Soil application of organic nano NPK formulation (50 kg ha^{-1}) + FYM (5 t ha^{-1})

T_7: Soil application of organic nano NPK formulation (50 kg ha^{-1}) + 50 per cent of recommended dose of NPK

T_8: Soil application of organic nano NPK formulation (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent of recommended dose of NPK

T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})

T_{10}: Absolute control

* Recommended dose of NPK- 30:15:30 kg NPK ha^{-1}

3.5.2 Land preparation, sowing and fertilizer application

The experimental area was ploughed to fine tilth. Field was laid out into plots of size 20 m^2 (5x4 cm) with a spacing of 30 cm between the plots. Individual plots were levelled. Seeds were dibbled at a spacing of 25x15 cm. Organic nano NPK, FYM and inorganic fertilizers were applied as basal dose.

3.5.3 Intercultural operations

A uniform plant population was maintained by thinning. Irrigation and weeding was done as per requirement. The field was hoed after weeding.

3.5.4 Plant protection

As a prophylactic measure against pest, neem oil garlic chilli emulsion was sprayed.

3.5.5 Harvesting

Harvesting was done by pulling out the plant. Base of the plants were cut and stalked for 2 days and were dried under sun. The shed seeds were collected.

3.6 BIOMETRIC OBSERVATIONS TAKEN FOR FIELD EXPERIMENT

Biometric observations were taken at 30 DAS, 60 DAS and at harvest. Fifteen plants were randomly selected from the field and tagged. Five plants each were used to take observation at 30 DAS, 60 DAS and at harvest.

3.6.1 Growth parameters

3.6.1.1 Plant height

Height of the plant was measured from ground level to the growing tip of the plants and expressed in cm.

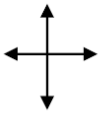
3.6.1.2 Height upto first capsule

Height of the plant from ground level to the point where first capsule appeared is measured and expressed in cm.

3.6.1.3 Primary branches per plant

Branches formed from the main stem of the crop were counted from tagged plants and the mean was worked out.

N



R_I	R_2	R_3
R_1T_6	R_2T_2	R_3T_5
R_1T_3	R_2T_9	R_3T_8
R_1T_9	R_2T_5	R_3T_3
R_1T_4	R_2T_3	R_3T_4
R_1T_5	R_2T_{10}	R_3T_9
R_1T_2	R_2T_8	R_3T_7
R_1T_{10}	R_2T_1	R_3T_2
R_1T_8	R_2T_7	R_3T_{10}
R_1T_1	R_2T_6	R_3T_1
R_1T_7	R_2T_4	R_3T_6

Fig.3 Layout of the field experiment

3.6.1.4 Leaf area per plant

The leaf area was estimated on weight basis. The total leaf area was calculated by the formula given below and expressed in cm^2 (Sreepriya, 2017).

$$L2 = (L1/W1) \times W2$$

L1 - single leaf area W1 - weight of single leaf

L2 - whole leaf area W2- weight of all leaves

3.6.1.5 Root spread

The roots were placed on a hard surface. Root spread was measured as the lateral spread of the outermost root from the taproot and expressed in cm.

3.6.1.6 Root volume

Root volume was measured by noting the volume of water displaced by the root when immersed in a measuring cylinder containing known volume of water and is expressed in cm^3.

3.6.1.7 Dry matter production

Tagged plants were pulled out during each observation and dried until constant weight was obtained. The dry matter production is expressed in kg ha^{-1}.

3.6.2 Yield parameters

3.6.2.1 Days to first flowering

Number of days to reach first flowering were counted from the date of dibbling to date at which the first flower in a plot was observed.

3.6.2.2 Days to fifty per cent flowering

Number of days needed for fifty percent of the plants to flower in a plot were counted from date of dibbling.

3.6.2.3 Days to maturity

Yellowing and defoliation occurs in sesame prior to harvest. At this stage, plants were considered as mature and the number of days taken to mature in each plot were counted.

3.6.2.4 Number of capsules per plant

Total number of capsules present in the tagged plants were counted at harvest and their average is worked out.

3.6.2.5 Number of seeds per capsule

Number of seeds in each capsule was counted at harvest from ten pods of each plot and the mean was estimated.

3.6.2.6 Thousand seed weight

One thousand seeds obtained from each plot were counted and their weight was recorded in grams.

3.6.2.7 Seed yield per plot

Seed yield obtained from each plot is recorded in grams.

3.6.2.8 Bhusa yield

Weight of the plants in a plot was measured at harvest and seed yield per plot is subtracted from this. Bhusa yield is expressed in kg ha^{-1}.

3.6.3 Quality parameters

3.6.3.1 Oil content

Oil content of oven dry seeds were estimated by cold percolation method suggested by Kartha and Sethi (1957). It is expressed in per cent.

3.6.3.2 Grain protein content

Seed protein content was worked out by multiplying seed nitrogen value by the factor 6.25 (Simpson *et al*., 1965), where nitrogen is estimated by Microkjeldahl digestion in H_2SO_4 and distillation (Jackson, 1973). It is expressed in per cent.

3.6.4 Incidence of pest and diseases

Mild infestation of leaf and pod caterpillars were observed. Single spray of 0.6 per cent neem oil garlic chilli emulsion controlled the pest.

3.6.5 Plant uptake

Representative samples were collected at harvest from each plot. Samples were oven dried at 70 ˚C until constant weight was obtained. Dried samples were ground and analysed for N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B as per the methods given in Table 3.

Nutrient uptake is calculated from the given formula given below and expressed in kg ha^{-1}.

$$\text{Nutrient uptake} = \frac{\text{Nutrient content (\%) x Drymatter production (kg ha}^{-1}\text{)}}{100}$$

3.7 SOIL SAMPLING AND ANALYSIS

Initial soil samples were collected from the surface (0-15 cm depth) and analyzed as per standard procedures (Table 1). After harvest, soil samples were collected from the surface (0-15 cm depth) of all treatment plots. The collected soil samples were shade dried and sieved through 2 mm sieve. These samples were analysed for pH, EC, organic carbon, available nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B), dehydrogenase activity and microbial biomass carbon. Undisturbed samples were collected to measure the bulk density of the soil.

3.8 ECONOMIC ANALYSIS

Economics of cultivation was found out using the cost of cultivation and existing market price of sesame.

Benefit - Cost ratio was calculated as follows.

Benefit - Cost ratio = Gross income / Total expenditure

3.9 STATISTICAL ANALYSIS

Statistical analysis was carried out based on Analysis of Variance technique for RBD and done by using GRAPES statistical software developed by Department of Agricultural Statistics, College of Agriculture, Vellayani (GRAPES, 2020).

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Results

4. RESULTS

The current study “Effect of soil application of organic nano NPK formulation on growth and yield of sesame (*Sesamum indicum*) in Onattukara (AEU 3)” was conducted at Onattukara Regional Agricultural Research Station, Kayamkulam and College of Agriculture, Vellayani from December 2020 to April 2021. The research was phased out in three sections. The first part of the study was the of characterization of organic nano NPK formulation. In this, the physical, physico-chemical, chemical and bio-chemical properties of the formulation were assessed. Second part of the study was the laboratory incubation study, where the nutrient release pattern of the formulation was elucidated. The third part was the of field experiment, in which the effect of soil application of organic nano NPK on growth and yield of sesame was studied. The data generated from these investigations are presented in this chapter.

PART I

4.1 CHARACTERIZATION OF ORGANIC NANO NPK FORMULATION

The physical, physico-chemical, chemical and biochemical properties of the organic nano NPK formulation is given in the Table 4.

4.1.1 Physical properties

Important physical properties such as particle size, surface area and zeta potential of the organic nano NPK formulation were analyzed. The particle size of organic nano NPK formulation was found to be 70.44 nm (Fig. 4, Table 4). The organic nano NPK recorded a surface area of 140.31 m^2 g^{-1} (Fig. 5, Table 4) and a stable zeta potential of -64.10 mV (Fig. 6, Table 4),

4.1.2 Physico-chemical properties

pH and EC of organic nano NPK formulation was found to be 7.81 and 0.13 dS m^{-1} respectively (Table 4).

4.1.3 Chemical properties

Organic nano NPK formulation had an organic carbon content of 2.34 per cent. Primary nutrient content of organic nano NPK was 1.96 per cent nitrogen, 1.81 per cent phosphorus and 2.96 per cent potassium. Secondary nutrient contents were 0.32 per cent calcium, 0.29 per cent magnesium and 0.61 per cent sulphur. Fe, Mn, Zn, Cu and B contents of organic nano NPK were 398, 528, 352, 98.86 and 33.4 mg kg^{-1} respectively (Table 4).

4.1.4 Biochemical properties

The organic matter fraction of organic nano NPK formulation contains 5.80 per cent humin, 19.18 per cent humic acid and 31.54 per cent fulvic acid. Total amino acid content recorded was 248 mg kg^{-1} (Table 4).

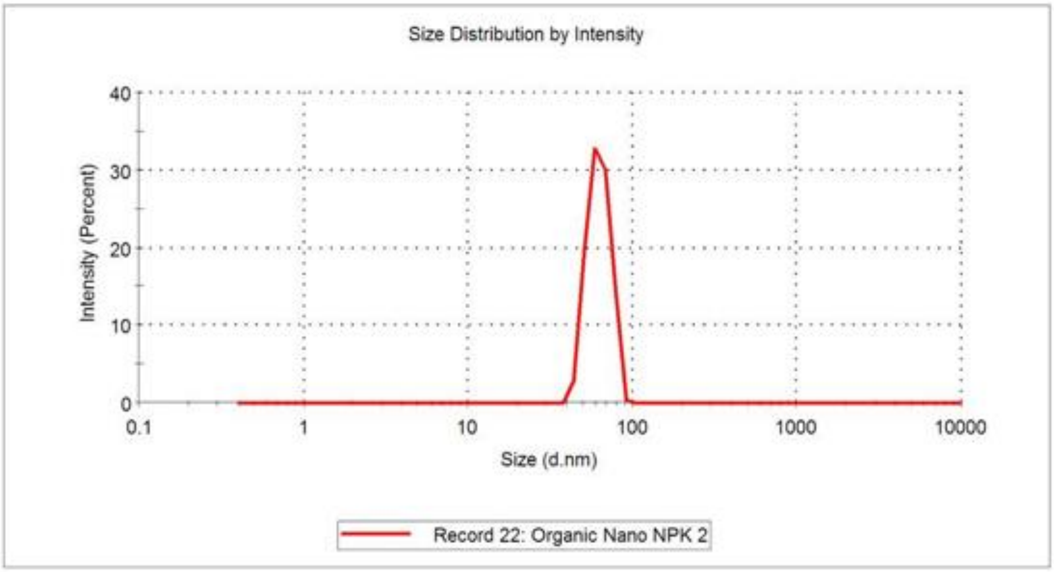

Fig. 4. Particle size of organic nano NPK formulation

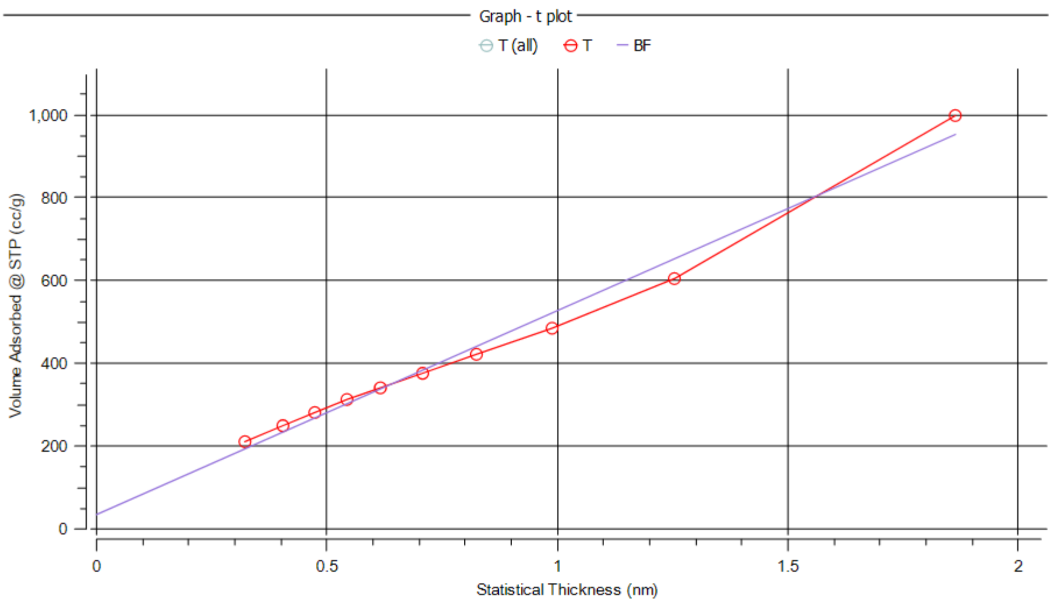

Fig. 5. Surface area of organic nano NPK formulation

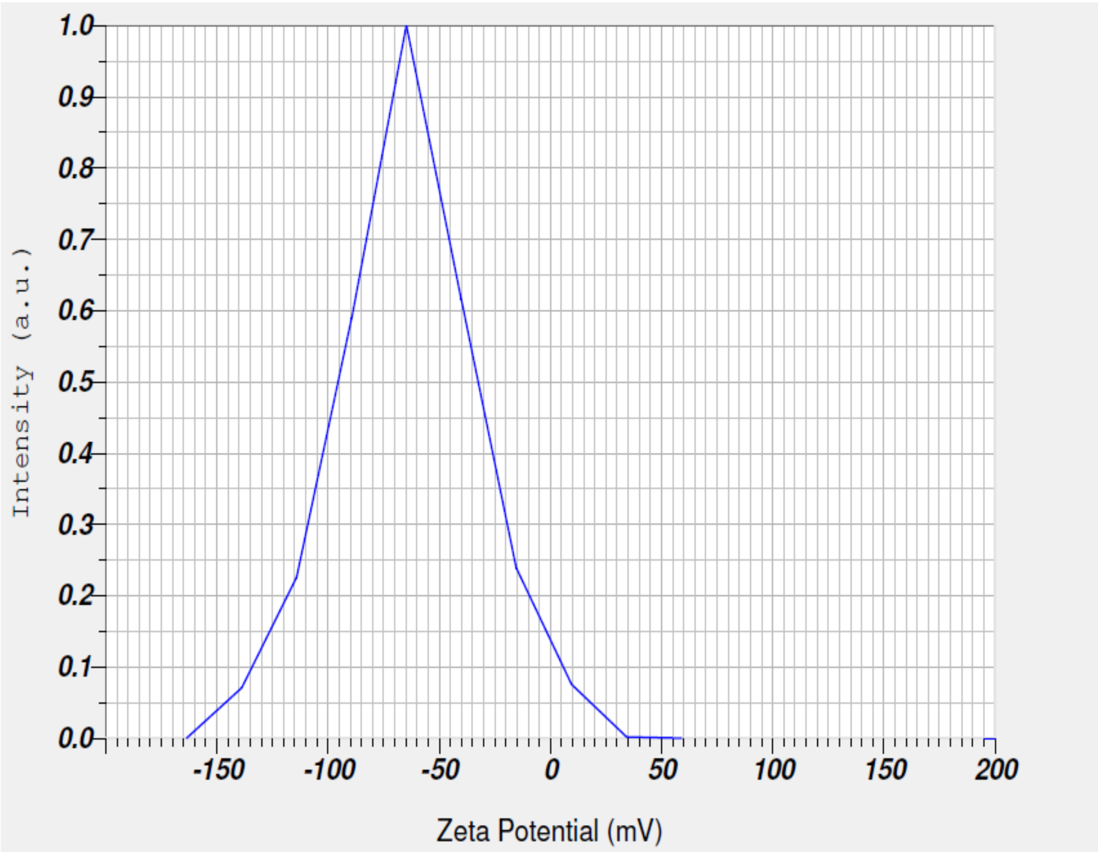

Fig. 6. Zeta potential of organic nano NPK formulation

Table 4. Characterization of organic nano NPK formulation

Sl. No.	Parameter		Value
1.	Particle size (nm)		70.44
2.	Surface area (m^2 g^{-1})		140.31
3.	Zeta potential (mV)		-64.10
4.	pH (1:5)		7.81
5.	EC (1:5) dS m^{-1}		0.13
6.	Organic carbon (per cent)		2.34
7.	N (per cent)		1.96
8.	P (per cent)		1.81
9.	K (per cent)		2.96
10.	Ca (per cent)		0.32
11.	Mg (per cent)		0.29
12.	S (per cent)		0.61
13.	Fe (mg kg^{-1})		398.00
14.	Mn (mg kg^{-1})		528.00
15.	Zn (mg kg^{-1})		352.00
16.	Cu (mg kg^{-1})		98.86
17.	B (mg kg^{-1})		33.40
18.	Total amino acid (mg kg^{-1})		248.00
19.	Organic matter fraction (per cent)	Humin	5.80
		Humic acid	19.18
		Fulvic acid	31.54

PART II

4.2. LABORATORY INCUBATION STUDY

A laboratory incubation study was set up to find out the nutrient release pattern from the organic nano NPK formulation. Samples were drawn at periodic intervals at 0^{th}, 7^{th}, 15^{th}, 30^{th}, 45^{th}, 60^{th} and 90^{th} day of incubation and the results are given in the Tables 5 to 18.

4.2.1 pH

Table 5 represents the change in pH of the soil during the incubation period. In general, pH showed a gradual increase throughout the experimental period. The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed highest pH of 5.98 on 90^{th} day of incubation and treatment T_9 (absolute control) showed the lowest pH throughout the incubation period.

At 0^{th} day, the maximum pH (5.70) was obtained for treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was found to be on par with T_5 (organic nano NPK 50 kg ha^{-1}) with a mean value of 5.62. At the 7^{th} day also, treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded maximum pH (5.69), and was found to be on par with T_2 (5.65), T_5 (5.63), T_1 (5.61) and T_8 (5.60). The treatment T_6 secured the highest pH in 15^{th} day (5.85), which was comparable with T_2 (5.83), T_5 (5.80) and T_1 (5.73). At 30^{th} day, the treatment T_6 recorded maximum (5.92) and was comparable with T_5 (5.84), T_2 (5.82) and T_1 (5.80). At 45^{th} day, maximum pH was showed by the treatment T_6 (5.90) and was found to be on par with T_5 (5.89), T_2 (5.86) and T_1 (5.83). The treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded highest pH (5.89) in 60^{th} day of incubation and was on par with T_6 (5.88), T_2 (5.84), T_5 (5.82) and T_1 (5.81). At 90^{th} day of incubation, treatment T_6 showed the highest value of pH (5.98) in this study and it was on par with T_2 (5.92) and T_5 (5.89).

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

Treatment	0th	7th	15th	30th	45th	60th	90th
T_1: Organic nano NPK (25 kg ha^{-1})	5.53	5.61	5.73	5.80	5.83	5.81	5.83
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	5.58	5.65	5.83	5.82	5.86	5.84	5.92
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	5.42	5.39	5.44	5.43	5.47	5.58	5.67
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	5.44	5.42	5.46	5.62	5.65	5.64	5.77
T_5: Organic nano NPK (50 kg ha^{-1})	5.62	5.63	5.80	5.84	5.89	5.82	5.89
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	5.70	5.69	5.85	5.92	5.90	5.88	5.98
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	5.49	5.40	5.48	5.48	5.53	5.63	5.73
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	5.59	5.60	5.53	5.68	5.68	5.89	5.84
T_9: Absolute control	5.39	5.37	5.42	5.38	5.42	5.48	5.63
SEm (±)	0.03	0.04	0.05	0.05	0.04	0.05	0.04
CD (0.05)	0.108	0.121	0.149	0.151	0.123	0.153	0.122

RDF- 30:15:30 kg NPK ha^{-1}

4.2.2 Electrical conductivity

The Electrical Conductivity (EC) of the soil during the incubation period is given in Table 6. The treatments had significant influence on EC of the soil. In general, the EC increased upto 30 days of incubation after which it started to decline. The highest EC was registered in the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) at 30^{th} day of incubation (0.256 dS m^{-1}). The lowest EC was recorded from the absolute control during the entire period of incubation.

At 0^{th} day of incubation, the treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded highest EC (0.087 dS m^{-1}) which was comparable with T_3 (0.086 dS m^{-1}) and T_6 (0.078 dS m^{-1}). This trend was continued upto the 7^{th} day of incubation also where, the treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded highest EC of 0.088 dS m $^{-1}$. It was found to be on par with T_3 (0.084 dS m $^{-1}$), T_6 (0.082 dS m $^{-1}$) and T_8 (0.078 dS m^{-1}). At the 15^{th} day of incubation, the treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) showed significantly higher value of EC (0.154 dS m^{-1}) among all other treatments. The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed significantly superior value (0.256 dS m^{-1}, 0.158 dS m^{-1} and 0.135 dS m^{-1}) than all other treatments on 30^{th} day, 45^{th} and 60^{th} day of incubation respectively. At 90^{th} day of incubation, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest EC with a mean value (0.094 dS m^{-1}) which was comparable with T_5 (0.090 dS m^{-1}) and T_7 (0.068 dS m^{-1}).

4.2.3 Organic carbon

Organic carbon content increased throughout the incubation period (Table 7). The highest organic carbon content was recorded in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) on the 90^{th} day of incubation (0.86%).

At 0^{th} day, the treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded the highest organic carbon content (0.56%) and was found to be on par with T_6 (0.52 %), T_7 (0.50%), T_4 (0.49%), T_5 (0.46%) and T_2 (0.45%).

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

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	90^{th}
T_1: Organic nano NPK (25 kg ha^{-1})	0.054	0.056	0.053	0.059	0.091	0.096	0.041
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	0.066	0.069	0.070	0.074	0.052	0.050	0.047
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.086	0.084	0.090	0.089	0.042	0.064	0.056
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.087	0.088	0.086	0.115	0.081	0.043	0.042
T_5: Organic nano NPK (50 kg ha^{-1})	0.057	0.061	0.062	0.134	0.085	0.098	0.090
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM(5 t ha^{-1})	0.078	0.082	0.128	0.256	0.158	0.135	0.094
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.051	0.059	0.113	0.215	0.124	0.070	0.068
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.068	0.078	0.154	0.235	0.108	0.059	0.049
T_9: Absolute control	0.045	0.046	0.030	0.056	0.040	0.048	0.030
SEm (±)	0.004	0.003	0.005	0.008	0.010	0.009	0.007
CD (0.05)	0.011	0.012	0.014	0.020	0.029	0.025	0.027

RDF- 30:15:30 kg NPK ha^{-1}

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

Treatment	0th	7th	15th	30th	45th	60th	90th
T_1: Organic nano NPK (25 kg ha^{-1})	0.38	0.44	0.53	0.59	0.62	0.65	0.75
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	0.45	0.47	0.56	0.63	0.66	0.69	0.81
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.43	0.45	0.52	0.62	0.64	0.66	0.77
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) +50 per cent recommended dose of NPK	0.49	0.53	0.59	0.66	0.65	0.70	0.84
T_5: Organic nano NPK (50 kg ha^{-1})	0.46	0.48	0.55	0.61	0.63	0.68	0.76
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	0.52	0.54	0.66	0.65	0.68	0.72	0.86
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.50	0.51	0.57	0.63	0.65	0.69	0.74
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.56	0.58	0.59	0.70	0.69	0.71	0.82
T_9: Absolute control	0.36	0.40	0.48	0.55	0.53	0.51	0.68
SEm (±)	0.04	0.02	0.02	0.02	0.01	0.01	0.02
CD (0.05)	0.112	0.054	0.054	0.077	0.028	0.054	0.052

RDF- 30:15:30 kg NPK ha^{-1}

The treatment T_8 showed highest value (0.58%) in 7th day also, which was followed by T_6 (0.54 %) and T_4 (0.53%). At 15th day, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest value (0.66%) and was significantly superior than all other treatments. The treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) showed highest value (0.70 %) at 30th day which was on par with T_4 (0.66 %), T_6 (0.65%), T_2 (0.63%) and T_7 (0.63%). At 45th day of incubation, the treatment T_8 (0.69%) recorded highest organic carbon content, which was comparable with treatment T_6 (0.68%). At 60th day of incubation, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest organic carbon (0.72%) and was on par with T_8 (0.71 %), T_4 (0.70%), T_2 (0.69%), T_7 (0.69 %) and T_5 (0.68%). And at 90th day also, the treatment T_6 (0.86%) showed higher organic carbon content which were comparable with T_4 (0.84%), T_8 (0.82%) and T_2 (0.81%).

4.2.4 Available nitrogen

Table 8 depicts the nitrogen availability during this period. In general, the availability of nitrogen increased upto 45th day of incubation. The maximum nitrogen availability (363.78 kg ha^{-1}) was registered by treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) on 45th day of incubation and the lowest availability was for soil which received no treatments (T_9) throughout the period of incubation.

At 0th day and 7th day of incubation, the nitrogen availability in treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) was found significantly higher than all other treatments (250.88 kg ha^{-1} and 288.51 kg ha^{-1} respectively). At 15th day of incubation, treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} +50 per cent recommended dose of NPK) recorded highest N availability (301.06 kg ha^{-1}) which was on par with T_8 (288.51 kg ha^{-1}). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest availability in 30th day of incubation (313.60 kg ha^{-1}) which was found on par with T_8 (301.06 kg ha^{-1}). The N availability from treatment T_6 (363.78 kg ha^{-1}) was significantly higher than all other treatments on 45th day of incubation.

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

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	90^{th}
T_1: Organic nano NPK (25 kg ha^{-1})	137.98	150.53	175.62	163.07	225.79	188.16	213.25
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	200.70	213.23	238.34	288.51	326.14	250.88	263.42
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	163.07	188.16	213.25	263.42	200.70	225.79	213.25
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	225.79	250.88	301.06	275.97	288.51	313.60	294.78
T_5: Organic nano NPK (50 kg ha^{-1})	150.53	175.12	200.7	238.34	225.79	238.34	213.25
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	213.25	238.34	263.42	313.60	363.78	326.14	338.69
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	188.16	200.70	225.79	213.25	219.52	206.98	200.70
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	250.88	288.51	288.51	301.06	338.69	288.51	326.14
T_9: Absolute control	125.44	137.98	150.53	125.44	137.98	137.98	150.53
SEm (±)	7.24	7.26	7.24	6.95	6.93	6.93	6.93
CD (0.05)	21.512	21.564	21.523	21.476	20.604	20.651	20.603

RDF- 30:15:30 kg NPK ha^{-1}

On 60^{th} day of incubation, treatment T_6 (326.14 kg ha^{-1}) showed highest availability and was comparable with treatment T_4 (313.60 kg ha^{-1}). The treatment T_6 (338.69 kg ha^{-1}) showed the higher N availability in 90^{th} day of incubation and was on par with T_8 (326.14 kg ha^{-1}).

4.2.5 Available phosphorus

In general P availability increased upto 45^{th} day of incubation and then started to decrease (Table 9). The highest available P content was obtained for the treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) at 30^{th} day of incubation (103.58 kg ha^{-1}). From 45^{th} day onwards till 90^{th} day of incubation, the treatment T_6 (Organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}) was found to release higher available P contents. The lowest P availability was recorded by the absolute control (T_9) throughout the study and the details of P availability are given in Table 9.

The highest P availability was recorded by the treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) at 0^{th} day (96.81 kg ha^{-1}), 7^{th} day (98.28 kg ha^{-1}), 15^{th} day (101.58 kg ha^{-1}) and 30^{th} day (103.58 kg ha^{-1}) of incubation. It was found to be on par with T_4 (92.38 kg ha^{-1}, 94.84 kg ha^{-1}, 96.31 kg ha^{-1} and 98.23 kg ha^{-1} at 0^{th} ,7^{th} ,15^{th} and 30^{th} day respectively). At 45^{th} day, treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed highest P availability (97.36 kg ha^{-1}) which was on par with T_8 (96.48 kg ha^{-1}), T_4 (94.32 kg ha^{-1}) and T_2 (92.51 kg ha^{-1}). The treatment T_6 (101.32 kg ha^{-1}) showed highest P availability in 60^{th} day of incubation which was found on par with T_8 (98.39 kg ha^{-1}). At 90^{th} day also, treatment T_6 recorded highest value (90.21 kg ha^{-1}) and was found on par with T_8 (88.21 kg ha^{-1}), T_2 (87.31 kg ha^{-1}) and T_4 (86.48 kg ha^{-1}).

4.2.6 Available potassium

Generally, availability of K increased upto 45^{th} day of incubation (Table 10). The highest K availability (234.75 kg ha^{-1}) was found in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) on 45^{th} day of incubation followed by the treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) with a mean value of 231.53 kg ha^{-1} at 30^{th} day of incubation.

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

Treatment	0th	7th	15th	30th	45th	60th	90th
T_1: Organic nano NPK (25 kg ha^{-1})	58.47	60.84	63.28	66.37	70.38	64.2	62.83
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	73.92	80.23	79.08	82.51	92.51	90.85	87.31
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	64.59	65.24	68.55	75.29	80.83	78.35	75.96
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	92.38	94.84	96.31	98.23	94.32	93.98	86.48
T_5: Organic nano NPK (50 kg ha^{-1})	61.83	63.41	64.32	69.18	78.56	73.84	68.32
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	82.58	84.39	89.21	93.29	97.36	101.32	90.21
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	70.08	73.97	76.87	79.38	87.5	83.85	79.53
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	96.81	98.28	101.58	103.58	96.48	98.39	88.21
T_9: Absolute control	42.32	48.61	51.39	43.21	59.78	53.28	54.78
SEm (±)	2.51	2.56	2.61	2.54	2.70	2.40	2.98
CD (0.05)	7.523	7.691	7.842	7.626	8.098	7.194	8.929

RDF- 30:15:30 kg NPK ha^{-1}

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

Treatment	0th	7th	15th	30th	45th	60th	90th
T_1: Organic nano NPK (25 kg ha^{-1})	164.42	169.89	179.11	183.18	190.35	187.82	168.65
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	172.63	188.96	206.54	204.38	216.54	199.68	188.21
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	175.95	182.56	198.53	203.62	212.58	194.53	175.83
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	183.68	200.13	208.76	211.43	223.83	212.53	201.76
T_5: Organic nano NPK (50 kg ha^{-1})	173.60	176.51	183.75	188.32	194.33	191.56	180.05
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	189.70	215.60	220.73	224.93	234.75	231.28	219.38
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	177.65	196.79	208.77	213.18	219.82	218.54	206.72
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	192.29	218.68	228.14	231.53	228.36	223.18	218.08
T_9: Absolute control	134.7	137.65	148.14	153.5	150.43	161.38	158.33
SEm (±)	8.11	6.66	8.77	6.93	6.22	6.22	7.56
CD (0.05)	12.081	19.804	26.028	20.581	18.484	18.497	22.454

RDF- 30:15:30 kg NPK ha^{-1}

At 0^{th} day, highest K availability (192.29 kg ha^{-1}) was found in treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) which was on par with treatments T_6 (189.70 kg ha^{-1}) and T_4 (183.68 kg ha^{-1}). The treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) showed highest K availability (218.68 kg ha^{-1}) on 7^{th} day also, which was on par with treatments T_6 (215.60 kg ha^{-1}) and T_4 (200.13 kg ha^{-1}). At 15^{th} day of incubation, treatment T_8 (228.14 kg ha^{-1}) recorded highest K availability which was comparable with treatments T_6 (220.73 kg ha^{-1}), T_7 (208.77 kg ha^{-1}), T_4 (208.76 kg ha^{-1}) and T_2 (206.54 kg ha^{-1}). The treatment T_8 (231.53 kg ha^{-1}) showed highest K availability on 30^{th} day of incubation which was on par with T_6 (224.93 kg ha^{-1}), T_7 (213.8 kg ha^{-1}) and T_4 (211.43 kg ha^{-1}). At 45^{th} day, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed highest K availability (234.75 kg ha^{-1}) and was comparable with T_8 (228.36 kg ha^{-1}), T_4 (223.83 kg ha^{-1}), T_7 (219.82 kg ha^{-1}) and T_2 (216.54 kg ha^{-1}). At 60^{th} day also, treatment T_6 (231.28 kg ha^{-1}) recorded the highest K availability which was on par with T_8 (223.18 kg ha^{-1}) and T_7 (218.54 kg ha^{-1}). The treatment T_6 (219.38 kg ha^{-1}) recorded the maximum K availability on 90^{th} day which was comparable with T_8 (218.08 kg ha^{-1}), T_7 (206.72 kg ha^{-1}) and T_4 (201.76 kg ha^{-1}).

4.2.7 Exchangeable calcium

The Ca availability during the incubation period is furnished in Table 11. In general, Ca availability increased upto 45^{th} day of incubation. The highest exchangeable Ca (394.12 mg kg^{-1}) was recorded for the soil which is treated with T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) on 45^{th} day of incubation. The lowest calcium availability was recorded by the absolute control (T_9).

The treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) showed highest Ca availability (199.64 mg kg^{-1}) on 0^{th} day of incubation which was on par with T_4 (198.63 mg kg^{-1}) and T_7 (193.7 mg kg^{-1}). Same trend was observed in 7^{th} day also. On 15^{th} day, treatment T_8 (277.35 mg kg^{-1}) showed highest Ca availability which was on par with treatment T_4 (268.87mg kg^{-1}). The treatment T_8 (348.34 mg kg^{-1}) showed significantly higher values than other treatments in 30^{th} day of incubation also. At 45^{th} day of incubation, the treatment T_8 (394.12 mg kg^{-1}) showed highest Ca availability which was comparable with T_4 (389.92 mg kg^{-1}).

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

Treatment	0th	7th	15th	30th	45th	60th	90th
T_1: Organic nano NPK (25 kg ha^{-1})	156.86	168.25	179.48	209.87	258.49	291.42	101.92
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	173.26	188.77	194.26	240.58	282.46	270.14	132.27
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	182.06	203.28	207.63	254.51	362.65	228.50	135.52
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	198.63	212.80	268.87	336.41	389.92	298.54	133.95
T_5: Organic nano NPK (50 kg ha^{-1})	171.08	187.76	196.43	238.56	301.82	283.36	113.56
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	179.87	197.85	201.50	243.52	333.59	352.91	168.69
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	193.70	206.70	213.80	279.45	372.35	268.35	140.54
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	199.64	214.20	277.35	348.34	394.12	348.59	152.85
T_9: Absolute control	101.69	102.36	118.53	148.20	135.80	123.60	81.65
SEm (±)	2.94	2.77	3.59	3.41	3.98	3.24	4.30
CD (0.05)	8.812	8.314	10.780	10.234	11.968	9.723	12.907

RDF- 30:15:30 kg NPK ha^{-1}

The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest Ca availability (352.91 mg kg^{-1}) on 60th day of incubation which was found to be on par with T_8 (348.59 mg kg^{-1}). The treatment T_6 (168.69 mg kg^{-1}) registered higher Ca availability on 90th day of incubation.

4.2.8 Exchangeable magnesium

Mg availability increased upto 30th day of incubation. The highest Mg availability (18.55 mg kg^{-1}) was recorded by treatment T_6 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}) on 15th day of incubation. The result of exchangeable Mg during the incubation period is given in the Table 12.

Treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed the highest Mg availability (13.53 mg kg^{-1}) at 0th day of incubation which was on par with T_8 (13.09 mg kg^{-1}). At 7th day of incubation highest Mg availability (14.31 mg kg^{-1}) was found in treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) which was on par with T_7 (14.07 mg kg^{-1}), T_4 (13.96 mg kg^{-1}), T_2 (13.95 mg kg^{-1}) and T_6 (13.72 mg kg^{-1}). The treatment T_6 (18.55 mg kg^{-1}), showed significantly superior results compared to other treatments on 15th day of incubation. At 30th day, the treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) resulted higher Mg availability (15.62 mg kg^{-1}) which was comparable with T_4 (15.25 mg kg^{-1}). The treatment T_8 (16.84 mg kg^{-1}) showed significantly superior Mg availability compared to other treatments at 45th day of incubation. The highest Mg availability on 60th day was by treatment T_6 (13.25 mg kg^{-1}) which was found on par with T_5 (13.16 mg kg^{-1}), T_2 (12.94 mg kg^{-1}) and T_8 (12.94 mg kg^{-1}). On the final day of incubation, treatment T_6 (12.38 mg kg^{-1}) was found to be significantly superior to all treatments.

4.2.9 Available sulphur

The data regarding the availability of sulphur during the incubation period is given in the Table 13. Sulphur availability was increased upto 30th day of incubation. Later a decreasing trend was noted. The highest amount of available S (5.91 mg kg^{-1}) was recorded by the treatment T_8 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) on 45th day of incubation.

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

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	90^{th}
T_1: Organic nano NPK (25 kg ha^{-1})	11.54	12.51	13.17	13.28	11.38	10.53	10.45
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	11.87	13.95	13.22	14.26	12.31	12.94	10.78
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	10.83	12.48	15.38	14.13	12.04	11.06	10.35
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	10.25	13.96	16.53	15.25	15.78	12.58	11.24
T_5: Organic nano NPK (50 kg ha^{-1})	12.03	12.49	13.08	13.96	14.83	13.16	11.07
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	13.53	13.72	18.55	14.38	12.47	13.25	12.38
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	11.08	14.07	13.99	14.01	11.98	12.01	11.43
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	13.09	14.31	17.34	15.62	16.84	12.94	10.87
T_9: Absolute control	7.75	8.16	12.08	12.82	9.36	8.94	7.56
SEm (±)	0.34	0.30	0.14	0.15	0.09	0.11	0.09
CD (0.05)	1.023	0.901	0.475	0.498	0.264	0.348	0.281

RDF- 30:15:30 kg NPK ha^{-1}

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

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	90^{th}
T_1: Organic nano NPK (25 kg ha^{-1})	1.98	2.16	2.59	3.19	2.91	3.08	2.19
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	3.03	3.29	3.10	4.15	3.92	3.38	2.46
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	2.02	2.38	3.05	3.95	2.63	2.91	2.25
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	2.54	3.08	4.38	4.31	3.08	3.32	2.79
T_5: Organic nano NPK (50 kg ha^{-1})	2.10	2.84	3.19	3.34	2.98	3.16	2.38
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	3.24	3.38	4.94	4.28	5.82	3.69	2.43
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	2.41	2.37	3.13	3.81	3.54	2.73	2.21
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	2.82	3.21	5.63	4.24	5.91	3.43	2.98
T_9: Absolute control	1.21	1.68	1.91	2.98	2.01	2.43	1.35
SEm (±)	0.08	0.06	0.08	0.07	0.07	0.09	0.09
CD (0.05)	0.252	0.181	0.235	0.224	0.209	0.275	0.268

RDF- 30:15:30 kg NPK ha^{-1}

The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded the highest S availability (3.24 mg kg^{-1}) on 0^{th} day of incubation which was on par with T_2 (3.03 mg kg^{-1}). On 7^{th} day also, highest S availability was recorded by treatment T_6 (3.38 mg kg^{-1}) which was comparable with T_2 (3.29 mg kg^{-1}) and T_8 (3.21 mg kg^{-1}). The treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) recorded significantly superior value (5.63 mg kg^{-1}) on 15^{th} day of incubation. On 30^{th} day of incubation, highest S availability (4.31 mg kg^{-1}) was found in the treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK), which were comparable with T_6 (4.28 mg kg^{-1}), T_8 (4.24 mg kg^{-1}) and T_2 (4.15 mg kg^{-1}). The treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded highest S availability (5.91 mg kg^{-1}) on 45^{th} day of incubation which was on par with T_6 (5.82 mg kg^{-1}). On 60^{th} day of incubation, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed highest S availability (3.69 mg kg^{-1}) which was comparable with T_8 (3.43 mg kg^{-1}). The treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) recorded highest S availability (2.98 mg kg^{-1}) at 90^{th} day of incubation which was comparable with T_4 (2.79 mg kg^{-1}).

4.2.10 Available iron

Fe content increased upto 30 days of incubation study. The highest availability of Fe (132.52 mg kg^{-1}) was recorded in the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) on 30^{th} day of incubation. The result of Fe availability in the incubation study is presented in the Table 14.

At 0^{th} day of incubation, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed superior Fe accumulation (43.59 mg kg^{-1}) than all other treatments. The highest Fe availability (86.89 mg kg^{-1}) was registered in treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) on 7^{th} day of incubation which was on par with T_8 (85.94 mg kg^{-1}), T_6 (84.58 mg kg^{-1}), T_2 (83.90 mg kg^{-1}) and T_1 (83.49 mg kg^{-1}). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) had showed significantly highest Fe availability in 15^{th} day (130.20 mg kg^{-1}), 30^{th} day (132.52 mg kg^{-1}) and 45^{th} day (122.13 mg kg^{-1}) of incubation which was on par with T_4 (128.48 mg kg^{-1}) on 30^{th} day of incubation.

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

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	90^{th}
T_1: Organic nano NPK (25 kg ha^{-1})	33.32	83.49	107.17	115.32	112.37	60.80	25.32
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	39.93	83.90	109.65	119.48	116.48	62.54	27.17
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	29.96	80.29	92.46	107.45	97.32	56.62	26.91
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	34.02	86.89	124.32	128.48	110.32	64.74	28.48
T_5: Organic nano NPK (50 kg ha^{-1})	34.25	82.72	122.81	124.79	114.59	62.78	28.39
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	43.59	84.58	130.20	132.52	122.13	61.38	32.25
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	34.24	77.19	110.43	117.12	109.26	58.63	27.45
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	34.70	85.94	108.29	120.26	103.37	65.93	36.73
T_9: Absolute control	27.68	74.09	84.39	95.39	89.25	48.69	29.35
SEm (±)	1.14	1.27	1.52	1.54	1.42	1.79	1.52
CD (0.05)	3.435	3.802	4.576	4.634	4.271	5.360	4.564

RDF- 30:15:30 kg NPK ha^{-1}

At 60th day of of incubation, the treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) released highest amount of Fe (65.93 mg kg^{-1}) which was on par with T_4 (64.74 mg kg^{-1}), T_5 (62.78 mg kg^{-1}), T_2 (62.54 mg kg^{-1}), T_6 (61.38 mg kg^{-1}) and T_1 (60.8 mg kg^{-1}). On the 90th day of incubation, treatment T_8 (36.73 mg kg^{-1}) recorded the highest Fe availability which was comparable with T_6 (32.25 mg kg^{-1}).

4.2.11 Available manganese

The Mn availability generally increased upto 45th day of incubation. The highest Mn availability (8.40 mg kg^{-1}) was recorded by the treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) on 60th day of incubation. The data regarding manganese availability is furnished in the Table 15.

At 0th day of incubation, the treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) showed highest Mn availability (1.70 mg kg^{-1}) which was on par with T_6 (1.62 mg kg^{-1}) and T_8 (1.57 mg kg^{-1}). The treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) recorded highest Mn availability (1.87 mg kg^{-1}) on 7th day of incubation which was comparable with treatment T_4 (1.85 mg kg^{-1}). At 15th day of incubation, treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest Mn availability (2.33 mg kg^{-1}) which was comparable with T_5 (2.30 mg kg^{-1}), T_8 (2.27 mg kg^{-1}) and T_1 (2.24 mg kg^{-1}). Treatment T_6 (5.38 mg kg^{-1}) recorded highest Mn availability at 30th day of incubation which was on par with T_8 (5.34 mg kg^{-1}). At 45th day incubation, the treatment T_6 (8.39 mg kg^{-1}) recorded highest Mn availability which was on par with T_7 (8.28 mg kg^{-1}) and T_8 (8.26 mg kg^{-1}). The treatment T_8(organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) recorded significantly highest value (8.40 mg kg^{-1}) among all treatments in 60th day of incubation. At 90th day of incubation, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest Mn availability (4.39 mg kg^{-1}) which was on par with T_8 (4.38 mg kg^{-1}).

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

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	90^{th}
T_1: Organic nano NPK (25 kg ha^{-1})	1.05	1.32	2.24	4.41	6.48	5.66	4.02
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	1.12	1.41	2.21	4.59	6.52	6.18	4.18
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.36	1.28	2.01	4.35	6.34	5.83	3.91
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.70	1.85	2.20	4.92	6.47	6.92	4.09
T_5: Organic nano NPK (50 kg ha^{-1})	1.53	1.52	2.30	4.61	6.37	5.84	4.21
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	1.62	1.54	2.33	5.38	8.39	7.95	4.39
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.31	1.27	2.19	4.96	8.28	7.82	3.78
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.57	1.87	2.27	5.34	8.26	8.40	4.38
T_9: Absolute control	0.82	1.15	1.92	3.82	5.92	5.30	2.98
SEm (±)	0.06	0.05	0.04	0.06	0.05	0.05	0.05
CD (0.05)	0.162	0.148	0.112	0.187	0.154	0.146	0.144

RDF- 30:15:30 kg NPK ha^{-1}

4.2.12 Available zinc

Zinc availability increased upto the 45th day of incubation. The highest Zn availability (4.65 mg kg^{-1}) was recorded in treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) on 45th day of incubation. Table 16 shows the release pattern of zinc during the incubation study.

At 0th day, the Zn availability was significantly the highest (4.09 mg kg^{-1}) in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and was comparable with treatment T_8 (4.01). The treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) registered highest Zn availability (3.87 mg kg^{-1}) on 7th day of incubation which was comparable with T_6 (3.78 mg kg^{-1}). At 15th day also, treatment T_4 (4.32 mg kg^{-1}) showed higher nutrient availability which was on par with T_6 (4.23 mg kg^{-1}). On 30th day and 45th day of incubation, treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) showed significantly higher values (4.48 and 4.65 mg kg^{-1} respectively) which was on par with T_6 (4.33 and 4.52 mg kg^{-1} respectively). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed highest Zn availability (4.28 mg kg^{-1}) in 60th day of incubation which was on par with T_8 (4.19 mg kg^{-1}). At 90th day, treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) showed significantly higher value (3.82 mg kg^{-1}) compared to other treatments.

4.2.13 Available copper

In general, Cu availability increased upto 45th day of incubation. The highest Cu availability (6.30 mg kg^{-1}) was recorded by the treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) at 45th day of incubation. Absolute control (T_9) recorded the lowest value throughout the incubation period. The analytical results obtained on copper availability is given in the Table 17.

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

Treatment	0th	7th	15th	30th	45th	60th	90th
T_1: Organic nano NPK (25 kg ha^{-1})	2.87	2.98	4.14	3.28	3.56	3.68	3.01
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	3.85	3.70	3.84	3.89	4.09	3.70	3.21
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	3.71	3.19	3.51	3.62	3.95	3.75	3.14
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	3.78	3.87	4.32	4.29	4.48	4.15	3.18
T_5: Organic nano NPK (50 kg ha^{-1})	2.94	3.08	4.08	3.47	3.61	3.81	3.42
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	4.09	3.78	4.23	4.33	4.52	4.28	3.38
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	3.68	3.52	3.88	3.97	4.11	4.16	3.54
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	4.01	3.61	4.11	4.48	4.65	4.19	3.82
T_9: Absolute control	2.05	2.56	2.48	2.89	2.94	2.68	2.72
SEm (±)	0.04	0.04	0.04	0.05	0.04	0.04	0.05
CD (0.05)	0.122	0.113	0.135	0.152	0.136	0.114	0.158

RDF- 30:15:30 kg NPK ha^{-1}

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

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	90^{th}
T_1: Organic nano NPK (25 kg ha^{-1})	3.34	3.42	6.01	5.81	5.91	2.48	1.05
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	3.81	4.66	6.10	6.01	6.12	2.53	1.12
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	3.56	4.53	6.07	5.98	6.11	2.58	0.77
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	4.36	4.39	6.08	6.02	6.17	2.69	1.28
T_5: Organic nano NPK (50 kg ha^{-1})	3.71	3.97	6.15	6.21	6.21	2.51	1.25
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	3.78	4.37	6.18	6.23	6.25	2.84	1.22
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	3.67	4.06	6.12	6.15	6.12	2.81	0.86
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	4.56	4.76	6.14	6.27	6.30	2.79	1.19
T_9: Absolute control	3.16	2.75	5.98	5.62	5.81	2.10	0.60
SEm (±)	0.04	0.04	0.04	0.42	0.05	0.04	0.04
CD (0.05)	0.132	0.114	0.112	0.128	0.163	0.116	0.120

RDF- 30:15:30 kg NPK ha^{-1}

At 0th day and 7th day, the treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded significantly higher Cu availability (4.56 and 4.76 mg kg^{-1} respectively). At 7th day, treatment T_8 was found to be on par with T_2 (4.66 mg kg^{-1}). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed highest Cu availability (6.18 mg kg^{-1}) on 15th day of incubation, which was on par with T_5 (6.15 mg kg^{-1}), T_8 (6.14 mg kg^{-1}), T_7 (6.12 mg kg^{-1}), T_2 (6.10 mg kg^{-1}), T_4 (6.08 mg kg^{-1}) and T_3 (6.07 mg kg^{-1}). At 30th day of incubation, the treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) showed higher Cu availability (6.27 mg kg^{-1}) which was comparable with T_6 (6.23 mg kg^{-1}) , T_5 (6.21 mg kg^{-1}) and T_7 (6.15 mg kg^{-1}).The treatment T_8 (6.30 mg kg^{-1}) recorded highest Cu availability on 45th day of incubation which was on par with T_6 (6.25 mg kg^{-1}), T_5 (6.21 mg kg^{-1}) and T_4 (6.17 mg kg^{-1}).On 60th day of incubation, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest Cu availability (2.84 mg kg^{-1}), which was found to be comparable with T_7 (2.81 mg kg^{-1}) and T_8 (2.79 mg kg^{-1}). The treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded highest Cu availability (1.28 mg kg^{-1}) on 90th day of incubation which was comparable with T_5 (1.25 mg kg^{-1}), T_6 (1.22 mg kg^{-1}) and T_8 (1.19 mg kg^{-1}).

4.2.14 Available boron

Availability of boron increased upto 45th day of incubation and later it declined. The highest B content (0.79 mg kg^{-1}) was recorded by the treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) on 45th day of incubation. The result of boron availability is presented in the Table 18.

At 0th day of incubation, highest B availability (0.25 mg kg^{-1}) was recorded by the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was on par with T_8 (0.23 mg kg^{-1}), T_5 (0.22 mg kg^{-1}), T_7 (0.21 mg kg^{-1}) and T_4 (0.20 mg kg^{-1}). The treatment T_6 (0.28 mg kg^{-1}) recorded highest B availability on 7th day of incubation, which was comparable with T_8 (0.26 mg kg^{-1}), T_4 (0.25 mg kg^{-1}) and T_7 (0.24 mg kg^{-1}). At 15th day of incubation, treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) resulted in highest B availability (0.47 mg kg^{-1}) which was on par with T_8 (0.46 mg kg^{-1}), T_2 (0.46 mg kg^{-1}), T_6 (0.45 mg kg^{-1}), T_5 (0.43 mg kg^{-1}) and T_1 (0.42 mg kg^{-1}).

Table 18. Available B content (mg kg^{-1}) of soil during the period of incubation

Treatment	0^{th}	7^{th}	15^{th}	30^{th}	45^{th}	60^{th}	90^{th}
T_1: Organic nano NPK (25 kg ha^{-1})	0.14	0.16	0.42	0.51	0.68	0.34	0.15
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	0.17	0.19	0.46	0.66	0.74	0.33	0.18
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.16	0.21	0.41	0.74	0.76	0.29	0.09
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.20	0.25	0.47	0.76	0.71	0.36	0.14
T_5: Organic nano NPK (50 kg ha^{-1})	0.22	0.17	0.43	0.68	0.70	0.35	0.11
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	0.25	0.28	0.45	0.65	0.78	0.38	0.19
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.21	0.24	0.33	0.41	0.73	0.32	0.14
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.23	0.26	0.46	0.67	0.79	0.40	0.16
T_9: Absolute control	0.12	0.14	0.29	0.36	0.49	0.25	0.08
SEm (±)	0.02	0.02	0.02	0.02	0.03	0.02	0.02
CD (0.05)	0.062	0.060	0.058	0.063	0.085	0.065	0.064

RDF- 30:15:30 kg NPK ha^{-1}

The treatment T_4 (0.76 mg kg^{-1}) resulted in highest B availability in 30th day of incubation, which was comparable with T_3 (0.74 mg kg^{-1}). On 45th day of incubation, treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) resulted in higher B availability (0.79 mg kg^{-1}), which was on par with T_6 (0.78 mg kg^{-1}), T_3 (0.76 mg kg^{-1}), T_2 (0.74 mg kg^{-1}), T_7 (0.73 mg kg^{-1}) and T_4 (0.71 mg kg^{-1}). The treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) released highest B (0.40 mg kg^{-1}) on 60th day of incubation study, which was comparable with treatments T_6 (0.38 mg kg^{-1}), T_4 (0.36 mg kg^{-1}), T_5 (0.35 mg kg^{-1}) and T_1 (0.34 mg kg^{-1}). At 90th day, the treatment T_6 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}) released highest B (0.19 mg kg^{-1}) which was on par with T_2 (0.18 mg kg^{-1}), T_8 (0.16 mg kg^{-1}), T_1 (0.15 mg kg^{-1}), T_4 (0.14 mg kg^{-1}) and T_7 (0.14 mg kg^{-1}). The lowest B content was recorded in the absolute control (T_9) throughout the incubation period.

PART III

4.3 FIELD EXPERIMENT

The field experiment was conducted at ORARS, Kayamkulam to find out the effect of the organic nano NPK formulation on plant growth, yield and soil biochemical parameters using sesame as the test crop. Plant growth observations were taken at 30th DAS, 60th DAS and at harvest.

4.3.1 Physical, chemical and biochemical properties of the experimental site

The data regarding physical, chemical and biochemical properties of the soil is given in Table 19. The field experiment was conducted in garden lands of ORARS, Kayamkulam which has a loamy sand texture (74.35 % sand, 20 % silt and 5.65 % clay). The bulk density of the soil was found to be 1.34 Mg m^{-3}. Initial soil analysis revealed that the soil selected for field study was acidic in reaction with a pH of 5.21 and an EC of 0.081 dS m^{-1}. The organic carbon content (0.21%) was very low. The primary, secondary and micronutrient analysis in soil revealed that soil has low N (154.71 kg ha^{-1}), high P (44.60 kg ha^{-1}) and low K (125.84 kg ha^{-1}). The soil was found deficient in exchangeable Ca (80.37 mg kg^{-1}), exchangeable Mg (7.74 mg kg^{-1}) and

Table 19. Physical, chemical and biochemical properties of the soil at the experimental field

Sl. No.	Parameter	Value
	Physical properties	
1	Mechanical composition	
	Sand (Per cent) Silt (Per cent) Clay (Per cent)	74.35 20.00 5.65
2	Texture	Loamy Sand
3	Bulk density (Mg m^{-3})	1.34
	Chemical properties	
4	pH (1:2.5)	5.21
5	EC (1:2.5) dS m^{-1}	0.081
6	Organic carbon (per cent)	0.21
7	Available nitrogen (kg ha^{-1})	154.71
8	Available phosphorus (kg ha^{-1})	44.60
9	Available potassium (kg ha^{-1})	125.84
10	Exchangeable calcium (mg kg^{-1})	80.37
11	Exchangeable magnesium (mg kg^{-1})	7.74
12	Available sulphur (mg kg^{-1})	0.98
13	Available micronutrients (mg kg^{-1})	
	Fe Mn Zn Cu B	44.79 1.48 3.90 1.75 0.39
	Biochemical properties	
14	Dehydrogenase activity (µg of TPFg^{-1} soil 24 h^{-1})	10.32
15	Microbial biomass carbon (mg kg^{-1})	88.88

available sulphur (0.98 mg kg^{-1}). The micronutrients were sufficient with respect to the available nutrient status, (Fe- 44.79 mg kg^{-1}, Mn- 1.48 mg kg^{-1}, Zn- 3.90 mg kg^{-1} and Cu-1.75 mg kg^{-1}) except for boron (0.39 mg kg^{-1}). The soil showed dehydrogenase activity (10.32 μg of $TPFg^{-1}$ soil 24 h^{-1}) and microbial biomass carbon (88.88 mg kg^{-1}). In general, the soil is less fertile with low OC, N, K, Ca, Mg, S, B and microbial activity.

4.3.2 Biometric observations

The biometric observations of the field study are presented in the Table 20 to Table 28. Plant growth characters, yield characters, quality parameters and plant uptake are recorded and presented here.

4.3.2.1 Growth parameters

4.3.2.1.1 Plant height

The results of the effect of soil application of organic nano NPK formulation on plant height of sesame are presented in Table 20. Application of treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) produced significantly taller plants till harvest even though the treatment T_7 (Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK) was found to be on a par with T_6 at 30 DAS. The control plot (T_{10}) recorded the lowest plant height throughout the study.

4.3.2.1.2 Height upto first capsule

The height upto the first capsule formed was also found to be significantly influenced by the application of organic nano NPK (Table 20).

The treatment T_3 (organic nano NPK 25 kg ha^{-1} + 50 per cent recommended dose of NPK) produced capsules from the lower height (41.77 cm) which was comparable with T_2 (42.26 cm), T_8 (42.31 cm), T_5 (42.57 cm), T_9 (44.11 cm), T_4 (45.44 cm) and T_1 (46.33 cm). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) produced capsules from the higher height (57.00 cm) and was found to be on par with T_7 (53.42 cm).

Table 20. Effect of organic nano NPK on plant height and height upto first capsule of sesame, cm

Treatment	Plant height (cm)			Height upto first capsule (cm)
	30 DAS	60 DAS	At harvest	
T_1: Organic nano NPK (25 kg ha^{-1})	35.80	60.53	85.00	46.33
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	35.63	63.36	85.17	42.26
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	30.20	60.55	71.83	41.77
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	34.28	73.50	90.83	45.44
T_5: Organic nano NPK (50 kg ha^{-1})	34.98	77.17	79.94	42.57
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	43.53	90.61	103.00	57.00
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	38.93	69.28	89.67	53.42
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	32.60	78.33	92.00	42.31
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	37.45	73.50	79.67	44.11
T_{10}: Absolute control	27.86	55.46	68.12	46.67
SEm (±)	2.77	2.40	2.28	1.59
CD (0.05)	8.491	7.132	6.785	4.563

RDF- 30:15:30 kg NPK ha^{-1}

4.3.2.1.3 Primary branches per plant

Table 21 indicates the influence of organic nano NPK on primary branches per plant.

The treatment T_5 (organic nano NPK 50 kg ha^{-1}) recorded the highest number of primary branches per plant throughout the plant growth. Even though the treatment T_2 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1}) recorded the highest value with 2.86 primary branches at 30 DAS, the results were found to be on par with T_7 (2.53), T_6 (2.26) and T_5 (2.20).

4.3.2.1.4 Leaf area per plant

The data regarding influence organic nano NPK on leaf area of the plant is presented in Table 22. The leaf area was found to increase as the plants matured.

At 30 DAS, leaf area per plant was found to be significantly higher (200.11 cm^2) in T_5 (organic nano NPK 50 kg ha^{-1}). At 60 DAS and at harvest, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) registered significantly higher leaf area per plant (414.42 cm^2 and 529.61 cm^2 respectively). Absolute control (T_{10}) recorded the lowest leaf area per plant throughout the observation.

4.3.2.1.5 Root spread

Table 23 depicts the influence of application of organic nano NPK on root spread. In general, the root spread increased with crop maturity.

The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) registered highest root spread at all stages of growth of sesame. At 30 DAS, the root spread (5.93 cm) was significantly higher over other treatments. At 60 DAS, even though the highest root spread (10.78) was recorded by the treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK), it was found to be on par with T_6 (10.22 cm), T_8 (9.88 cm), T_7 (9.72 cm) and T_3 (9 cm). At harvest, significantly higher root spread was observed in treatment T_6 (14.02 cm) which was followed by T_8 (13.62 cm).

Table 21. Effect organic nano NPK on primary branches per plant of sesame

Treatment	Primary branches per plant		
	30 DAS	60 DAS	At harvest
T_1: Organic nano NPK (25 kg ha^{-1})	2.13	2.56	3.83
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	2.86	2.78	4.67
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.40	2.67	3.50
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	2.03	2.89	4.67
T_5: Organic nano NPK (50 kg ha^{-1})	2.20	3.17	5.17
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	2.26	2.28	4.50
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	2.53	2.11	3.83
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	2.06	2.33	4.75
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	1.40	2.06	4.50
T_{10}: Absolute control	1.33	1.55	3.50
SEm (±)	0.24	0.08	0.07
CD (0.05)	0.715	0.236	0.223

RDF- 30:15:30 kg NPK ha^{-1}

Table 22. Effect organic nano NPK on leaf area per plant of sesame, cm^2

Treatment	Leaf area per plant (cm^2)		
	30 DAS	60 DAS	At harvest
T_1: Organic nano NPK (25 kg ha^{-1})	130.54	149.00	216.60
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	155.54	223.50	327.54
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	134.72	180.22	212.92
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	147.04	226.67	466.76
T_5: Organic nano NPK (50 kg ha^{-1})	200.11	206.20	239.41
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	174.55	414.42	529.61
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	167.19	292.57	249.18
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	181.21	327.86	320.52
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	137.89	167.42	273.39
T_{10}: Absolute control	104.82	126.20	205.98
SEm (±)	3.27	7.13	8.06
CD (0.05)	9.174	21.182	23.956

RDF- 30:15:30 kg NPK ha^{-1}

Table 23. Effect organic nano NPK on root spread of sesame, cm

Treatment	Root spread (cm)		
	30 DAS	60 DAS	At harvest
T_1: Organic nano NPK (25 kg ha^{-1})	4.33	6.72	8.16
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	5.40	8.66	10.17
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	4.46	9.00	9.33
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	5.46	10.78	10.87
T_5: Organic nano NPK (50 kg ha^{-1})	5.42	7.06	9.25
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	5.93	10.22	14.02
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	5.40	9.72	9.96
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	5.43	9.88	13.62
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	5.17	6.66	9.20
T_{10}: Absolute control	4.13	6.50	7.57
SEm (±)	0.12	0.61	0.59
CD (0.05)	0.373	1.804	1.741

RDF- 30:15:30 kg NPK ha^{-1}

4.3.2.1.6 Root volume

The effect of organic nano NPK on root volume of sesame is presented in the Table 24.

The treatment T_4 (organic nano NPK 25 kg ha^{-1} + 50 per cent recommended dose of NPK+ FYM 5 t ha^{-1}) recorded significantly higher root volume (0.63 cm^3) at 30 DAS whereas at 60 DAS and at harvest, treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed significantly superior values (1.92 cm^3 and 5.80 cm^3 respectively). The root volume was found to be the least for absolute control (T_{10}).

4.3.2.1.6 Dry matter production

The data on dry matter production as influenced by the organic nano NPK application is presented in Table 25.

At 30th DAS, the treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded the highest dry matter production (346.67 kg ha^{-1}) which was found to be on par with T_8 (338.66 kg ha^{-1}). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded significantly higher dry matter production (3394.66 and 5191.98 kg ha^{-1}) at 60 DAS and at harvest. The lowest dry matter was recorded by T_{10} (absolute control) in all stages.

4.3.2.2 Yield and yield parameters

The results of influence of organic nano NPK on yield and yield parameters are presented in Table 26 and 27.

4.3.2.2.1 Days to first flowering

Data on the effect of soil application of organic nano NPK on days to first flowering are presented in Table 26. The results revealed that there was no significant difference between the treatments.

Table 24. Effect of organic nano NPK on root volume of sesame, cm^3

Treatment	Root volume (cm^3)		
	30 DAS	60 DAS	At harvest
T_1: Organic nano NPK (25 kg ha^{-1})	0.37	0.62	3.53
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	0.43	0.85	1.97
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.47	0.75	2.00
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.63	0.92	3.08
T_5: Organic nano NPK (50 kg ha^{-1})	0.40	1.55	2.35
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	0.37	1.92	5.80
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.30	1.24	5.00
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.43	1.47	3.50
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	0.47	0.90	1.35
T_{10}: Absolute control	0.20	0.52	0.93
SEm (±)	0.03	0.10	0.20
CD (0.05)	0.072	0.284	0.591

RDF- 30:15:30 kg NPK ha^{-1}

Table 25. Effect of organic nano NPK on dry matter production of sesame, kg ha^{-1}

Treatment	Dry matter production (kg ha^{-1})		
	30 DAS	60 DAS	At harvest
T_1: Organic nano NPK (25 kg ha^{-1})	252.00	682.66	2206.22
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	302.52	766.02	2858.66
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	293.33	746.66	2687.99
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	346.67	1162.66	4805.32
T_5: Organic nano NPK (50 kg ha^{-1})	314.12	1888.00	2532.68
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	320.00	3394.66	5191.98
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	307.00	1522.00	3367.99
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	338.66	1986.00	4085.33
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	277.39	954.66	3461.32
T_{10}: Absolute control	139.00	528.18	1746.66
SEm (±)	7.89	88.32	97.22
CD (0.05)	23.485	263.782	288.873

RDF- 30:15:30 kg NPK ha^{-1}

Table 26. Effect of organic nano NPK on yield parameters of sesame

Treatment	Days to first flowering	Days to 50 percent flowering	Days to maturity	No. of capsules per plant	No. of seeds per capsule	Thousand seed weight (g)
T_1: Organic nano NPK (25 kg ha^{-1})	33.00	39.00	90.00	36.83	46.66	3.07
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	32.67	38.00	89.67	40.17	51.11	3.33
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	31.67	37.33	91.33	33.33	47.44	3.20
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	32.00	37.00	87.67	50.17	54.22	3.37
T_5: Organic nano NPK (50 kg ha^{-1})	32.33	38.00	89.33	34.50	48.86	3.50
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	31.00	36.67	87.33	52.33	57.00	3.46
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	32.67	37.33	89.67	37.50	47.80	3.39
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	32.67	36.33	89.33	47.33	49.78	3.31
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	33.00	38.33	87.00	34.33	47.44	3.08
T_{10}: Absolute control	33.33	39.33	93.00	32.00	46.56	2.70
SEm (±)	0.92	0.88	1.05	1.51	1.17	0.04
CD (0.05)	NS	NS	3.123	4.491	3.473	0.132

RDF- 30:15:30 kg NPK ha^{-1}

4.3.2.2.2 Days to 50 per cent flowering

The treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) took only 36.33 days for 50 per cent flowering followed by the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) with 36.67 days (Table 26). But the results were not found to be significant (Table 26).

4.3.2.2.3 Days to maturity

Given treatments caused significant variation in days to maturity (Table 26). The number of days to maturity was lower (87) in treatment T_9 (Soil based recommendation of NPK + FYM 5 t ha^{-1}) which was found to be on par with T_6 (87.33), T_4 (87.67), T_5 (89.33), T_8 (89.33), T_2 (89.67), T_7 (89.66) and T_1 (90) whereas, absolute control (T_{10}) required more number of days to mature (93 days) and was found on par with T_3 (91.33 days) and T_1 (90 days).

4.3.2.2.4 Number of capsules per plant

Significant increase in number of capsules per plant was recorded due to the application of organic nano NPK (Table 26). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) produced more number of capsules in sesame (52.33) followed by treatment T_4 (50.17). The lowest value (32) was recorded by the treatment T_{10} (absolute control).

4.3.2.2.5 Number of seeds per capsule

Different treatments involving organic nano NPK had significantly influenced the no. of seeds per capsule in sesame (Table 26).

The plants that received the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) produced significantly higher number of seeds per capsule (57.00) which was found to be on par with T_4 (54.22). The lowest number of seeds was produced by absolute control (T_{10}) with 46.56 seeds.

4.3.2.2.6 Thousand seed weight

Data in Table 26 revealed that the treatments had a significant influence on thousand seed weight of sesame.

Significantly highest thousand seed weight (3.50 g) was recorded by the treatment T_5 (organic nano NPK 50 kg ha^{-1}) which was comparable with T_6 (3.46 g), T_7 (3.39 g) and T_4 (3.37 g). The lowest value (2.70 g) was recorded by the absolute control (T_{10}).

4.3.2.2.7 Seed yield

The organic nano NPK showed significant influence on the seed yield of sesame (Table 27). Among treatments, the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded significantly superior seed yield per plot (1.42 kg or 712.50 kg ha^{-1}). The treatment T_{10} (absolute control) could only produce 0.99 kg seed yield per plot (499.00 kg ha^{-1}) which was the lowest.

4.3.2.2.8 Bhusa yield

The data in Table 27 indicates that the treatments had a significant influence on bhusa yield. The treatment T_5 (organic nano NPK 50 kg ha^{-1}) yielded highest bhusa (9287.01 kg ha^{-1}) which was found to be on par with T_6 (9055.52 kg ha^{-1}). All the treatment showed significantly higher values than control (T_{10}).

4.3.2.3 Influence of organic nano NPK on quality parameters of sesame.

The Table 28 depicts the influence of organic nano NPK on quality parameters of sesame like oil and grain protein content and is expressed in percentage. Significant influence was observed on the treatments by the application of organic nano NPK.

4.3.2.3.1 Oil content

In general, application of organic nano NPK had significant influence on oil content of sesame (Table 28). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded the highest oil content (56 %) which was found to be on par with T_8 (53 %). The lowest oil content (40 %) were found in absolute control (T_{10}).

Table 27. Effect of organic nano NPK on seed yield and bhusa yield of sesame

Treatment	Seed yield (kg)		Bhusa yield (kg ha^{-1})
	Per plot*	Per hectare	
T_1: Organic nano NPK (25 kg ha^{-1})	1.12	559.05	7016.65
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	1.20	601.15	7383.31
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.18	588.20	5749.98
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.21	604.84	7447.20
T_5: Organic nano NPK (50 kg ha^{-1})	1.15	573.33	9287.01
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	1.42	712.50	9055.52
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.24	619.50	6249.98
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.34	670.50	7671.28
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	1.19	595.50	6254.60
T_{10}: Absolute control	0.99	499.00	4412.02
SEm (±)	0.02	1.95	183.48
CD (0.05)	0.071	5.793	545.342

*Plot size- 20 m^2, RDF- 30:15:30 kg NPK ha^{-1}

4.3.2.3.2 Grain protein content

The grain protein content was significantly influenced by the organic nano NPK treatments (Table 28).

The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded the highest protein content (18.40 %), and was found on par with T_8 (18.05 %) and T_7 (17.70 %). Plants in absolute control (T_{10}) yielded low grain protein content (13.85 %).

4.3.2.4 Incidence of pest and disease

Mild infestation of leaf and pod caterpilllars were observed. Single spray of 0.6 per cent neem oil garlic chilli emulsion controlled the pest.

4.3.2.5 Plant uptake

Various treatments had significant influence on the plant nutrient uptake (Table 29 to 31).

4.3.2.5.1 Primary nutrient uptake

Table 29 depicts the data on effect of organic nano NPK formulation on uptake of primary nutrients.

4.3.2.5.1.1 Nitrogen uptake

The treatments showed significant effect in nitrogen uptake (Table 29). The highest nitrogen uptake (22.35 kg ha^{-1}) was obtained from the treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK), which was found to be on par with treatment T_6 (20.35 kg ha^{-1}). The lowest N uptake was recorded by absolute control (T_{10}). The nitrogen uptake ranged between 3.91 to 22.35 kg ha^{-1}.

4.3.2.5.1.2 Phosphorus uptake

Significant response was recorded for phosphorus uptake in sesame with the application of various treatments (Table 29). The treatment T_6 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}) resulted in higher P uptake (8.38 kg ha^{-1}) which was on par with T_4 (7.15 kg ha^{-1}). Absolute control (T_{10}) recorded the lowest P uptake (1.76 kg ha^{-1}).

Table 28. Effect of organic nano NPK on quality parameters of sesame

Treatment	Oil content (per cent)	Grain protein content (per cent)
T_1: Organic nano NPK (25 kg ha^{-1})	42.00	14.20
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	51.00	14.55
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	43.00	15.95
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	49.00	16.30
T_5: Organic nano NPK (50 kg ha^{-1})	48.00	15.60
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	56.00	18.40
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	47.00	17.70
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	53.00	18.05
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	48.00	14.90
T_{10}: Absolute control	40.00	13.85
SEm (±)	1.19	0.51
CD (0.05)	3.534	1.561

RDF- 30:15:30 kg NPK ha^{-1}

Table 29. Effect of organic nano NPK on uptake of primary nutrient by sesame, kg ha^{-1}

Treatment	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1: Organic nano NPK (25 kg ha^{-1})	5.56	2.43	8.01
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	14.41	3.60	16.09
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	15.05	2.92	13.17
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	22.35	7.15	29.60
T_5: Organic nano NPK (50 kg ha^{-1})	8.50	3.50	14.23
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	20.35	8.38	33.28
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	12.25	6.13	20.24
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	18.30	6.86	25.57
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	11.63	4.50	19.79
T_{10}: Absolute control	3.91	1.76	5.41
SEm (±)	0.91	0.42	0.93
CD (0.05)	2.703	1.241	2.775

RDF- 30:15:30 kg NPK ha^{-1}

4.3.2.5.1.3 Potassium uptake

A perusal of the data revealed that there was significant difference between treatments (Table 29). Among the treatments applied, treatment T_6 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}) recorded significantly highest K uptake (33.28 kg ha^{-1}) and absolute control (T_{10}) recorded the least (5.41 kg ha^{-1}).

4.3.2.5.2 Secondary nutrient uptake

The results of the effect of organic nano NPK formulation on the uptake of secondary nutrients are presented in Table 30. As in the case of primary nutrient uptake, the application of organic nano NPK had significant influence on secondary nutrient uptake by sesame.

4.3.2.5.2.1 Calcium uptake

There was significant influence for different treatments on calcium uptake (Table 30). The treatment T_6 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}) recorded highest Ca uptake (5.18 kg ha^{-1}) and was comparable with the treatment T_4 (4.83 kg ha^{-1}). The lowest value was recorded by absolute control (T_{10}). The calcium uptake ranged between 0.71 kg ha^{-1} and 5.18 kg ha^{-1}.

4.3.2.5.2.2 Magnesium uptake

Application of organic nano NPK significantly influenced Mg uptake (Table 30). The highest Mg uptake (2.01 kg ha^{-1}) was recorded in treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) which was on par with treatment T_6 (1.98 kg ha^{-1}). The lowest Mg uptake was found in absolute control (T_{10}). The magnesium uptake ranged between 0.51 kg ha^{-1} to 2.01 kg ha^{-1}.

4.3.2.5.2.3 Sulphur uptake

Data analysis revealed that treatments had significant influence on sulphur uptake (Table 30). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest sulphur uptake (4.34 kg ha^{-1}) and was on par with T_4 (4.22 kg ha^{-1}) among various treatments and absolute control (T_{10}) recorded the least (0.46 kg ha^{-1}).

Table 30. Effect of organic nano NPK on secondary nutrient uptake by sesame, kg ha^{-1}

Treatment	Ca (kg ha^{-1})	Mg (kg ha^{-1})	S (kg ha^{-1})
T_1: Organic nano NPK (25 kg ha^{-1})	0.99	0.76	0.65
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	1.75	0.83	1.49
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.13	0.85	1.66
T_4: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	4.83	1.04	4.22
T_5: Organic nano NPK (50 kg ha^{-1})	1.66	1.27	0.98
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	5.18	1.98	4.34
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	3.34	1.56	2.13
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	4.13	2.01	4.08
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	2.42	0.87	1.65
T_{10}: Absolute control	0.71	0.51	0.46
SEm (±)	0.16	0.02	0.06
CD (0.05)	0.468	0.054	0.172

RDF- 30:15:30 kg NPK ha^{-1}

4.3.2.5.3 Micronutrient uptake

The micronutrient uptake was also enhanced by the application of organic nano NPK and the details are furnished in Table 31.

4.3.2.5.3.1 Iron uptake

Iron uptake was influenced by the application of different treatments (Table 31). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded significantly higher iron uptake (1.15 kg ha^{-1}) which was found on par withT_8 (1.13 kg ha^{-1}), T_4 (1.08 kg ha^{-1}) and T_7 (0.86 kg ha^{-1}). The least iron uptake was in absolute control (0.17 kg ha^{-1}).

4.3.2.5.3.2 Manganese uptake

Data in the Table 31 revealed that treatments had significant effect on manganese uptake. The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded significantly higher manganese uptake (0.73 kg ha^{-1}) followed by T_4 (0.67 kg ha^{-1}). Absolute control (T_{10}) recorded the lowest value (0.13 kg ha^{-1}).

4.3.2.5.3.3 Zinc uptake

The treatment effects significantly influenced the zinc uptake in sesame (Table 31). The maximum uptake (0.31 kg ha^{-1}) was recorded in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was comparable with T_8 (0.27 kg ha^{-1}) and the least uptake (0.02 kg ha^{-1}) was reported in absolute control (T_{10}).

4.3.2.5.3.4 Copper uptake

Copper uptake of sesame was influenced by the application of the organic nano NPK application (Table 31). Copper uptake was found highest in plot which received treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) with a mean value of 0.42 kg ha^{-1} and was on par with T_8 (0.37 kg ha^{-1})$^{.}$ The least copper uptake (0.07 kg ha^{-1}) was recorded by the absolute control (T_{10}).

Table 31. Effect of organic nano NPK on micronutrient uptake by sesame, kg ha^{-1}

Treatment	Fe (kg ha^{-1})	Mn (kg ha^{-1})	Zn (kg ha^{-1})	Cu (kg ha^{-1})	B (kg ha^{-1})
T_1: Organic nano NPK (25 kg ha^{-1})	0.26	0.19	0.04	0.10	0.02
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	0.37	0.35	0.09	0.12	0.03
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.48	0.31	0.08	0.11	0.03
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.08	0.67	0.21	0.28	0.05
T_5: Organic nano NPK (50 kg ha^{-1})	0.49	0.29	0.08	0.13	0.03
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	1.15	0.73	0.31	0.42	0.07
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.86	0.46	0.18	0.21	0.04
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.13	0.59	0.27	0.37	0.05
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	0.54	0.33	0.12	0.15	0.03
T_{10}: Absolute control	0.17	0.13	0.02	0.07	0.01
SEm (±)	0.10	0.03	0.02	0.02	0.01
CD (0.05)	0.302	0.091	0.053	0.058	0.026

RDF- 30:15:30 kg NPK ha^{-1}

4.3.2.5.3.5 Boron uptake

It was observed that treatments had significant influence on uptake of boron in sesame (Table 31). The highest uptake of boron (0.07 kg ha^{-1}) was registered in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was on par with T_4 (0.05 kg ha^{-1}) and T_8 (0.05 kg ha^{-1}), proving the superiority of organic nano NPK over soil test based recommendation (T_9) and absolute control (T_{10}).

4.3.3 Soil analysis after the experiment

After the plant harvest, soil samples were collected and various physical, chemical and biochemical properties were analyzed. The results showed a positive influence of organic nano NPK on soil properties (Table 32 to 37).

4.3.3.1 Physical property

4.3.3.1.1 Bulk density

Even though the soil bulk density after the experiment was found to be improved compared to the initial status of the soil (1.34 Mg m^{-3}), the treatments did not have any significant effect on bulk density (Table 32). The bulk density ranged from 1.51 to 1.61 Mg m^{-3}.

4.3.3.2 Chemical properties

4.3.3.2.1 pH

Critical appraisal of the data revealed that the treatments had influenced the pH of the soil (Table 33). In all the treatments, after the experiment the pH was found to be significantly improved. Highest pH (5.96) was recorded by treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). In absolute control plots, there was only a slight increase in soil pH after the experiment and registered the lowest value (5.38).

Table 32. Effect of organic nano NPK on soil bulk density

Treatment	Bulk density ($Mg\ m^{-3}$)
T_1: Organic nano NPK (25 kg ha^{-1})	1.55
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	1.58
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.59
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.51
T_5: Organic nano NPK (50 kg ha^{-1})	1.54
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	1.52
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.61
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.52
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	1.54
T_{10}: Absolute control	1.56
SEm (±)	16.83
CD (0.05)	NS

RDF- 30:15:30 kg NPK ha^{-1}

Table 33. Effect of organic nano NPK on soil pH and EC

Treatment	pH	EC (dS m^{-1})
T_1: Organic nano NPK (25 kg ha^{-1})	5.63	0.091
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	5.72	0.108
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	5.68	0.105
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	5.79	0.118
T_5: Organic nano NPK (50 kg ha^{-1})	5.67	0.109
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	5.96	0.120
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	5.73	0.117
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	5.83	0.121
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	5.52	0.110
T_{10}: Absolute control	5.38	0.085
SEm (±)	0.02	0.001
CD (0.05)	0.052	0.003

RDF- 30:15:30 kg NPK ha^{-1}

4.3.3.2.2 Electrical conductivity

The electrical conductivity also followed the same pattern as soil pH. The EC was found to be significantly increased compared to the initial value (0.081dS m^{-1}). The highest EC (0.121 dS m^{-1}) was registered by the treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) and found to be on par with T_6 (0.120 dS m^{-1}) and T_4 (0.118 dS m^{-1}) (Table 33). The lowest mean value was registered by the treatment T_{10} (0.085 dS m^{-1}).

4.3.3.2.3 Organic carbon

Various treatments significantly influenced the organic carbon status of the soil after the experiment (Table 34). The mean values ranged from 0.18 to 0.72%. The highest organic carbon content was recorded for the treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) with 0.72 % which was on par with the treatment T_6 (0.66 %).

4.3.3.2.4 Available nitrogen

Nitrogen availability after the experiment was significantly influenced by the application of organic nano NPK (Table 34).

Nitrogen availability was found to be significantly higher (288.51 kg ha^{-1}) in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was on par with T_8 (275.97 kg ha^{-1}) and T_4 (275.97 kg ha^{-1}). The lowest N availability (150.53 kg ha^{-1}) was recorded in the absolute control (T_{10}) plots.

4.3.3.2.5 Available phosphorus

The results revealed that applied treatments had significant effect on the available P status of the soil (Table 34).

The treatments had significant results in the available phosphorus status of the soil. The highest P content in soil (84.92 kg ha^{-1}) was recorded from treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and was significantly superior to all other treatments. The P content in soil varied between 59.81 kg ha^{-1} to 84.92 kg ha^{-1}.

Table 34. Effect of organic nano NPK on OC (%), available N, P and K content (kg ha^{-1}) of the soil

Treatment	Organic carbon (%)	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
T_1: Organic nano NPK (25 kg ha^{-1})	0.25	188.16	61.58	142.08
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	0.31	263.42	74.76	154.00
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.24	250.88	63.90	148.13
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.51	275.97	81.58	155.58
T_5: Organic nano NPK (50 kg ha^{-1})	0.29	225.79	69.17	151.19
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	0.66	288.51	84.92	168.43
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	0.38	200.70	72.58	165.37
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	0.72	275.97	78.04	173.78
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	0.23	238.35	65.21	150.04
T_{10}: Absolute control	0.18	150.53	59.81	131.09
SEm (±)	0.02	5.16	0.78	1.91
CD (0.05)	0.063	15.334	2.325	5.681

RDF- 30:15:30 kg NPK ha^{-1}

4.3.3.2.6 Available potassium

It is inferred from Table 34 that available potassium status was significantly improved due to the treatments. The highest K content (173.78 kg ha^{-1}) was recorded from the plot which received treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) and was found to be on par with treatment T_6 (168.43 kg ha^{-1}). Lowest value of 131.09 kg ha^{-1} was recorded by T_{10} (absolute control).

4.3.3.2.7 Exchangeable calcium

The results revealed that calcium content of the soil was significantly influenced by various treatments (Table 35). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed significantly highest value (168.00 mg kg^{-1}) followed by treatment T_8 (162.51 mg kg^{-1}). The absolute control (T_{10}) recorded the lowest value (84.34 mg kg^{-1}).

4.3.3.2.8 Exchangeable magnesium

Data in Table 35 revealed that there is significant difference between exchangeable magnesium content of various treatments. Significantly higher magnesium availability was achieved from treatment T_6 (9.87 mg kg^{-1}) followed by T_8 (9.28 mg kg^{-1}). The lowest magnesium availability (6.20 mg kg^{-1}) was recorded in T_{10} (absolute control).

4.3.3.2.9 Available sulphur

Organic nano NPK showed significant effect in available sulphur content of the soil (Table 35). The treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) showed significantly higher S content than all treatments with a mean value of 3.98 mg kg^{-1} and the absolute control recorded the lowest value (1.13 mg kg^{-1}).

Table 35. Effect of organic nano NPK on exchangeable Ca, Mg and available S (kg ha^{-1}) content of the soil

Treatment	Exchangeable calcium (mg kg^{-1})	Exchangeable magnesium (mg kg^{-1})	Available sulphur (kg ha^{-1})
T_1: Organic nano NPK (25 kg ha^{-1})	129.00	6.78	1.23
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	136.00	8.86	1.69
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	110.00	7.80	1.73
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	150.26	8.98	2.48
T_5: Organic nano NPK (50 kg ha^{-1})	143.12	7.91	1.71
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	168.00	9.87	3.28
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	151.26	8.15	2.98
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	162.51	9.28	3.98
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	114.86	8.08	1.71
T_{10}: Absolute control	84.34	6.20	1.13
SEm (±)	2.12	0.29	0.07
CD (0.05)	8.092	0.853	0.210

RDF- 30:15:30 kg NPK ha^{-1}

4.3.3.2.10 Available iron

The data revealed that application of various treatments caused significant effect on available iron content of the soil (Table 36). The highest iron content (94.56 mg kg^{-1}) was found in plots which received treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) followed by treatment T_8 (89.31 mg kg^{-1}). The iron content in the field ranged between 42.34 to 94.56 mg kg^{-1}. The lowest Fe content (42.34 mg kg^{-1}) was recorded by T_{10} (absolute control).

4.3.3.2.11 Available manganese

Available manganese content of the soil was not affected by the application of various treatments (Table 36). The Mn content in soil ranged between 1.58 mg kg^{-1} to 2.04 mg kg^{-1}.

4.3.3.2.12 Available zinc

The zinc content of the soil was significantly affected by the treatments (Table 36). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded the higher Zn availability (6.70 mg kg $^{-1}$) which was comparable with T_7 (6.51 mg kg^{-1}), T_4 (6.42 mg kg^{-1}) and T_8 (6.41 mg kg^{-1}). The lowest Zn availability (4.96 mg kg^{-1}) was recorded in absolute control (T_{10}).

4.3.3.2.13 Available copper

The data in Table 36 showed that the soil application of organic nano NPK formulations did not produced any significant effect in available copper content of the soil after the experiment. The copper availability ranged between 1.68 mg kg^{-1} to 2.52 mg kg^{-1}.

4.3.3.2.14 Available boron

The Table 36 depicts the available boron status of the soil after experiment. The highest boron was available from the plots which received the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) with a mean value of 0.72 mg kg^{-1} and was comparable with T_4 (0.69 mg kg^{-1}). The absolute control (T_{10}) recorded the lowest value (0.42 mg kg^{-1}).

Table 36. Effect of organic nano NPK formulation on available Fe, Mn, Zn, Cu and B content (kg ha^{-1}) of the soil

Treatment	Available Fe (mg kg^{-1})	Available Mn (mg kg^{-1})	Available Zn (mg kg^{-1})	Available Cu (mg kg^{-1})	Available B (mg kg^{-1})
T_1: Organic nano NPK (25 kg ha^{-1})	45.86	1.81	5.68	1.90	0.53
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	58.52	1.95	5.50	2.30	0.57
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	45.00	1.78	5.48	1.86	0.54
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	65.64	1.83	6.42	2.35	0.69
T_5: Organic nano NPK (50 kg ha^{-1})	84.13	2.04	5.98	2.45	0.63
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	94.56	1.82	6.70	2.52	0.72
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	79.34	1.98	6.51	2.46	0.61
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	89.31	1.77	6.41	2.43	0.64
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	43.36	1.66	5.42	1.79	0.49
T_{10}: Absolute control	42.34	1.58	4.96	1.68	0.42
SEm (±)	2.51	0.16	0.13	0.28	0.01
CD (0.05)	7.443	NS	0.381	NS	0.044

RDF- 30:15:30 kg NPK ha^{-1}

4.3.3.3 Biochemical properties of the soil

4.3.3.3.1 Dehydrogenase activity

The dehydrogenase activity of soil by the application of various treatments increased compared to the initial value (10.32 µg of TPF g^{-1} soil 24 h^{-1} from Table 19). The organic nano NPK formulation had significant influence on soil dehydrogenase activity (Table 37). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed highest dehydrogenase activity with a mean value of 17.74 µg of $TPFg^{-1}$ soil 24 h^{-1} and was comparable with T_4 (17.27 µg of $TPFg^{-1}$ soil 24 h^{-1}), T_2 (16.81 µg of $TPFg^{-1}$ soil 24 h^{-1}), T_5 (16.34 µg of $TPFg^{-1}$ soil 24 h^{-1}), T_8 (15.87 µg of TPF g^{-1} soil 24 h^{-1}) and T_1 (15.41 µg of $TPFg^{-1}$ soil 24 h^{-1}). The lowest value (10.40 µg of $TPFg^{-1}$ soil 24 h^{-1}) was recorded by the absolute control (T_{10}).

4.3.3.3.2 Microbial biomass carbon

The microbial biomass carbon increased from 88.88 mg kg^{-1} (Table 19) due to organic nano NPK application after the experiment (Table 37). Microbial biomass carbon was found high in the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) with a mean value of 311.11 mg kg^{-1} and it was significantly superior than all other treatments. Thus the microbial population increases due to treatments reveals the environmental suitability of the organic nano NPK fertilizer treatments.

4.3.4 Economics of cultivation

Table 38 depicts the economics of cultivation of sesame under different treatments with organic nano NPK. The highest B: C ratio of 1.99 was recorded by the T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). The B: C ratio of soil test based application of NPK + FYM (T_9) was 1.90 which was on par with T_7. The absolute control recorded the lowest B: C ratio (1.67).

Table 37. Effect of organic nano NPK on biochemical properties of the soil

Treatment	Dehydrogenase activity (µg of TPFg^{-1} soil 24 h^{-1})	Microbial biomass carbon (mg kg^{-1})
T_1: Organic nano NPK (25 kg ha^{-1})	15.41	111.11
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	16.81	133.33
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	12.14	111.11
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	17.27	244.44
T_5: Organic nano NPK (50 kg ha^{-1})	16.34	133.33
T_6: Organic nano NPK (50 kg ha^{-1})+ FYM (5 t ha^{-1})	17.74	311.11
T_7: Organic nano NPK (50 kg ha^{-1})+ 50 per cent recommended dose of NPK	12.14	222.22
T_8: Organic nano NPK (50 kg ha^{-1})+ FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	15.87	266.66
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	11.20	111.11
T_{10}: Absolute control	10.40	88.88
SEm (±)	1.17	8.12
CD (0.05)	2.843	24.112

RDF- 30:15:30 kg NPK ha^{-1}

Table 38. Effect of organic nano NPK on B: C ratio

Treatment	B: C ratio
T_1: Organic nano NPK (25 kg ha^{-1})	1.81
T_2: Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})	1.73
T_3: Organic nano NPK (25 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.86
T_4:Organic nano NPK (25 kg ha^{-1}) + FYM (5 t ha^{-1})+50 per cent recommended dose of NPK	1.73
T_5: Organic nano NPK (50 kg ha^{-1})	1.75
T_6: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1})	1.99
T_7: Organic nano NPK (50 kg ha^{-1}) + 50 per cent recommended dose of NPK	1.89
T_8: Organic nano NPK (50 kg ha^{-1}) + FYM (5 t ha^{-1}) + 50 per cent recommended dose of NPK	1.83
T_9: Soil test based recommendation of NPK + FYM (5 t ha^{-1})	1.90
T_{10}: Absolute control	1.67
SEm (±)	0.01
CD (0.05)	0.034

RDF- 30:15:30 kg NPK ha^{-1}

Discussion

5. DISCUSSION

This thesis entitled "Effect of soil application of organic nano NPK formulation on growth and yield of sesame (*Sesamum indicum*) in Onattukara (AEU 3) was conducted at Onattukara Regional Agricultural Research Station, Kayamkulam and College of Agriculture, Vellayani from December 2020 to April 2021. The study comprised of characterization of organic nano NPK formulation, elucidaton of nutrient release pattern under laboratory conditions and the field study to assess the effect of organic nano NPK formulation on growth and yield of test crop sesame.

Possible explanation and justification of the results obtained in this experiment are given in this chapter.

PART I

5.1 CHARACTERIZATION OF ORGANIC NANO NPK FORMULATION

5.1.1 Physical properties

5.1.1.1 Particle size analysis

Particle size of the organic nano NPK formulation was analyzed using particle size analyzer and average size of the formulation was found to be 70.44 nm (Table 4, Fig. 4). According to Thomas *et al*. (2012), particle size ranging between 1 and 100 nm can be considered as a nano particle. Hence, it can be inferred that the particle size of organic nano NPK formulation comes under the nano scale. Fundamental and physico-chemical characters of particle at nano scale vary from its bulk counterpart due to its small size (Nanjwade *et al.*, 2011) which helps to induce higher mobility and activity of the particle (Sasson *et al*., 2007). Reduction in particle size increases the rate of dissolution and makes the nutrients available to the plants and increase the root contacts (Borm *et al.*, 2006; Khasawneh and Doll, 1979; Watkinson, 1994).

5.1.1.2 Surface area

Surface area is an important parameter for adsorption of materials. Surface area increases adsorptive capacity and it increases with decrease in particle size. Surface area of organic nano NPK was measured in BET surface area analyzer and was found to be 140.31 m^2 g^{-1} (Table 4, Fig. 5). Thirunavakkarasu (2014) reported that 1 g of zeolite has surface area of 465 m^2g^{-1} at microscale whereas in nano scale surface area was increased to 885 m^2g^{-1}. Naseem *et al.* (2020) found out that urea holding capacity of zinc alumina silicate nano composite was increased over time due to the high surface area (193.07 m^2 g^{-1}).

5.1.1.3 Zeta potential

Zeta potential is based on the agglomerative capacity of nano particles. Agglomeration reduces when the zeta potential is more negative. Here the zeta potential of organic nano NPK was found to be -64.10 mV (Table 4, Fig. 6). This higher negative value confirms that the particles have higher repulsion. Hence this formulation is stable. The capping agents used in nano hydroxyapatites was found to reduce the agglomeration of the particles by increasing the negative surface charge on the particles (Leeuwenburgh *et al*., 2010; Swain *et al*., 2012).

5.1.2 Physico-chemical and chemical characters of organic nano NPK formulation.

The analytical results (Table 4) showed that the organic nano NPK had a pH of 7.81, EC of 0.13 dS m^{-1} and contained 2.34 % organic carbon. The nutrient contents were found to be N (1.96%), P (1.81 %), K (2.96 %), Ca (0.32%), Mg (0.29%), S (0.61%), Fe (398 mg kg^{-1}), Mn (528 mg kg^{-1}), Zn (352 mg kg^{-1}), Cu (98.86 mg kg^{-1}), and B (33.40 mg kg^{-1}). This implies that organic nano NPK is the source of all nutrients that are essential for plant growth. The major nutrients are present in organic form as proteino-lacto-gluconates. The micronutrients are in the organic and chelated form. Hussein *et al.* (2019) has reported that the organic components tightly bind the metal ion and prevents the release into soil and thus reduce its loss. Mordogon *et al.* (2013) suggested that citric acid chelated form of iron is the most optimum form for increasing iron content in plants. So chelation of nutrients might had resulted in longer availability of nutrients.

5.1.3 Biochemical characters of organic nano NPK formulation

The total amino acid content of organic nano NPK was found to be 248 mg kg^{-1} (Table 4). The application of nano fertilizer produced from banana peels, which contains high amount of potassium and amino acids are reported to improve the biological aspects of the soil and physiological aspects of the crops like tomato and fenugreek (Hussein *et al*., 2019). This may be due to the increased water and nutrient availability to the plants, activation of endogenous hormones by the tryptophan, increasing the tolerance against various stresses etc. (Lee *et al*., 2010; Emaga *et al*. 2007). Amino acids can act as a chelating agent which will increase the availability of micronutrients.

The organic matter fraction of organic nano NPK contained humin (5.80%), humic acid (19.18%) and fulvic acid (31.54%). The humic substances are reported to convert unavailable form of nutrients to the plant available form (Wang *et al*., 1995). Humic acid (HA), a major component of natural organic matter and ubiquitous in soils and groundwater environments, is one of the key factors governing the environmental transport and fate of colloids and especially nano particles (Wang *et al.*, 2012). HA was reported to enhance transport of nano sized C60 and carbon nano tubes in saturated porous media by decreasing electrostatic attraction and increasing steric repulsion (Hyung *et al.*, 2007; Xie *et al*., 2008).

PART II

5.2 LABORATORY INCUBATION STUDY

A laboratory incubation study was set up to assess the nutrient release pattern of organic nano NPK formulation for a period of 90 days. The results are discussed below.

5.2.1 Changes in pH

The application of organic nano NPK had caused significant changes in the pH of the soil (Fig. 7). The pH of the soil increased throughout the incubation period. In the current experiment, the treatments T_5 (organic nano NPK application 50 kg ha^{-1}) and the treatment T_6 (organic nano NPK application 50 kg ha^{-1} along with FYM 5 t ha^{-1}) showed higher pH at periodic intervals. The organic nano NPK which was used for the study had a pH of 7.81 (Table 4), which might had resulted in the increased pH of soil. The treatments which received organic nano NPK and FYM showed an increased pH compared to the sole application of organic nano NPK. This might be due to following mechanisms: consumption of protons by the functional group associated with the organic manures (Dong *et al.,* 2001), proton consumption during decarboxylation of organic anions as a part of decomposition, specific adsorption of organic molecules by ligand exchange with the release of OH^- (Hue *et al.,* 1986) or OH^- ion release during anaerobic reduction reactions (Eghball, 1999). Compounds like organic acid with carboxyl and phenolic hydroxyl group have the capacity to increase the pH of acid soil when supplemented with organic fertilizers (Whalen *et al.* 2000).

5.2.2 Changes in electrical conductivity

EC of the soil was significantly influenced by the application of organic nano NPK formulation (Fig. 8). Like pH, highest EC was recorded in the soils, which received both organic nano NPK formulation and FYM compared to organic nano formulation alone or in combination with chemical fertilizers. It was observed that soils which received treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) showed higher EC on 0^{th} and 7^{th} day of incubation. The treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded highest value in 15^{th} day and the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) resulted in higher EC for the rest of the period. This increase in EC might be due to the higher release of bases and soluble fractions by mineralization of FYM and organic nano NPK formulation. Similar results were obtained for Eghball (2002), who suggested that an increase in manure application rate can increase the EC of the soil. Rus *et al.* (2004) reported that the application of nano fertilizer can increase the EC of the soil due to its high dissolution rates.

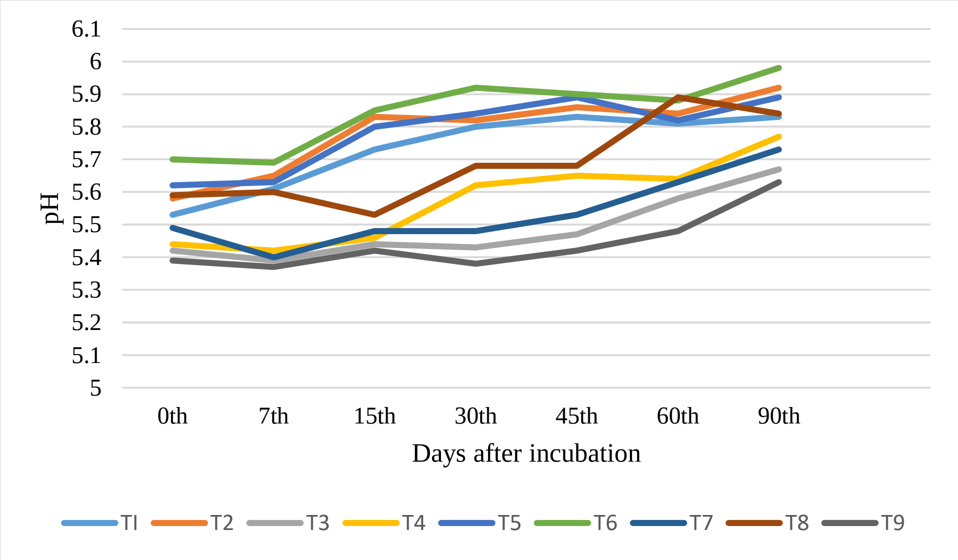

Fig. 7. Influence of organic nano NPK formulation on pH of soil during the period of incubation

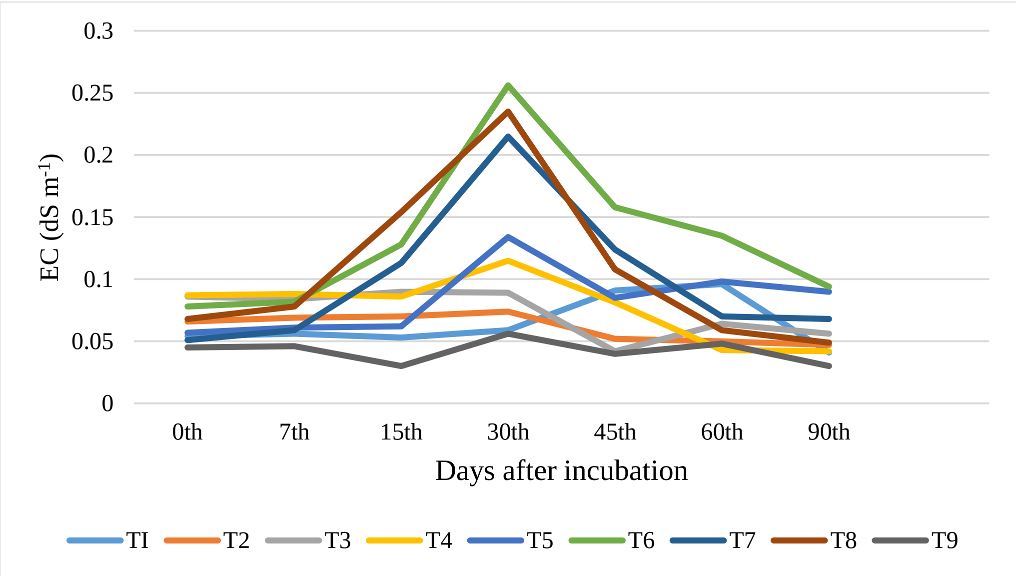

Fig. 8. Influence of organic nano NPK formulation on EC (dS m^{-1}) of soil during the period of incubation

5.2.3 Changes in organic carbon

Generally organic carbon content in all treatments increased from 0^{th} day to 90^{th} day (Fig. 9). The highest organic carbon content was obtained in the soil which received treatments as 50 kg organic nano NPK per ha and 5 t ha^{-1} of FYM (T_6). This increase in organic carbon might be due to the addition of carbon source through organic formulations. Hati *et al.* (2007) had reported that soil organic carbon could be increased by the addition of carbon source through FYM, root biomass and crop residues. Similar results were also obtained by Nibin (2019) who reported that the organic carbon availability showed an increasing trend upto 75 days of incubation due to the application of organic nano NPK formulation.

5.2.4 Changes in primary nutrients

Organic nano NPK had significantly influenced the primary nutrient content of soil (Fig.10,11 and 12). In general, N, P and K release showed an increasing trend upto 45^{th} day of incubation and after that the availability had gradually declined. Similar results were obtained by Nibin (2019). The highest available nitrogen and potassium contents were found in the soil which received 50 kg ha^{-1} organic nano NPK and FYM 5 t ha^{-1} (T_6) on the 45^{th} day of incubation whereas, available P was higher in treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) at 30^{th} day of incubation. This effect might be due to the increased nutrient content with the combined application of organic nano NPK and chemical fertilizers or by the enhancement of soil microbial activity which makes the nutrients available to the plants. The treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded highest nutrient release upto 15^{th} day for N and upto 30^{th} day for P and K. After that T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) resulted in the highest nutrient release. Meng *et al.* (2005) reported that the decrease in nutrient availability might be due to loss of some part of inorganic nitrogen by denitrification, volatilization, leaching or fixation of P and K. Similar results were also obtained by Simon and Czako (2014). Rajonee *et al*. (2016) suggested that slow release of nitrogen from zeolite might be due to the tight linkage of ammonium ions in the nano pores of zeolite.

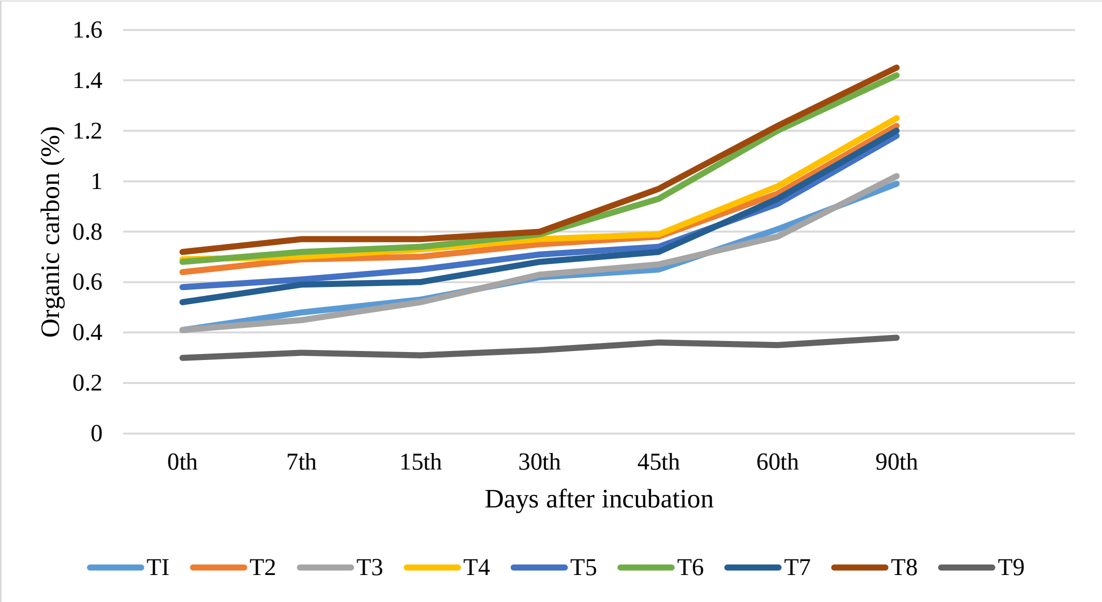

Fig. 9. Influence of organic nano NPK formulation on organic carbon (per cent) of soil during the period of incubation

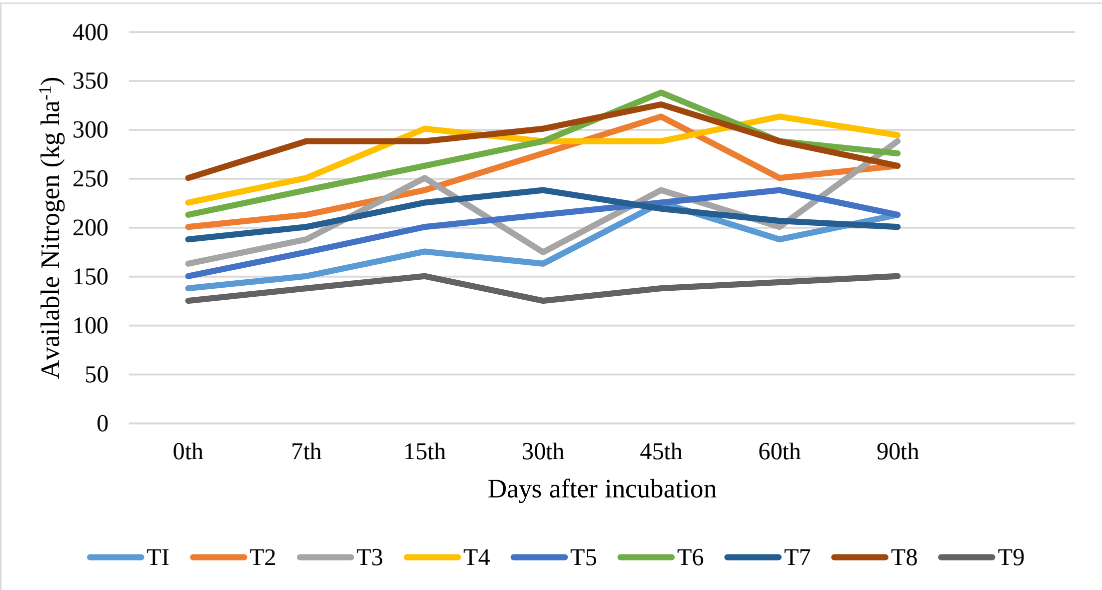

Fig. 10. Influence of organic nano NPK formulation on available N status (kg ha^{-1}) of soil during the period of incubation

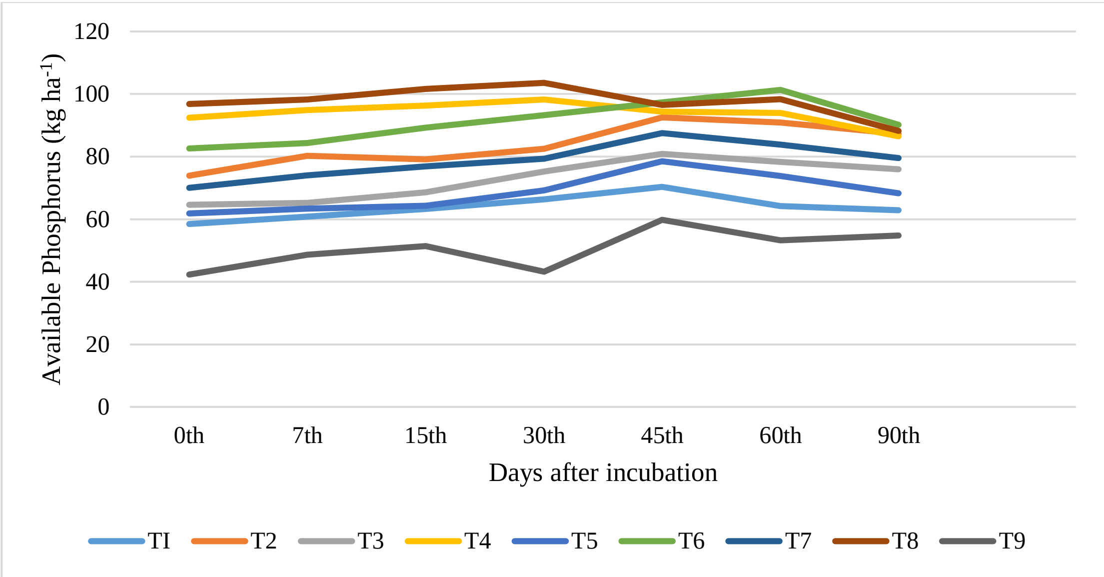

Fig. 11. Influence of organic nano NPK formulation on available P status (kg ha^{-1}) of the soil at different periods of incubation

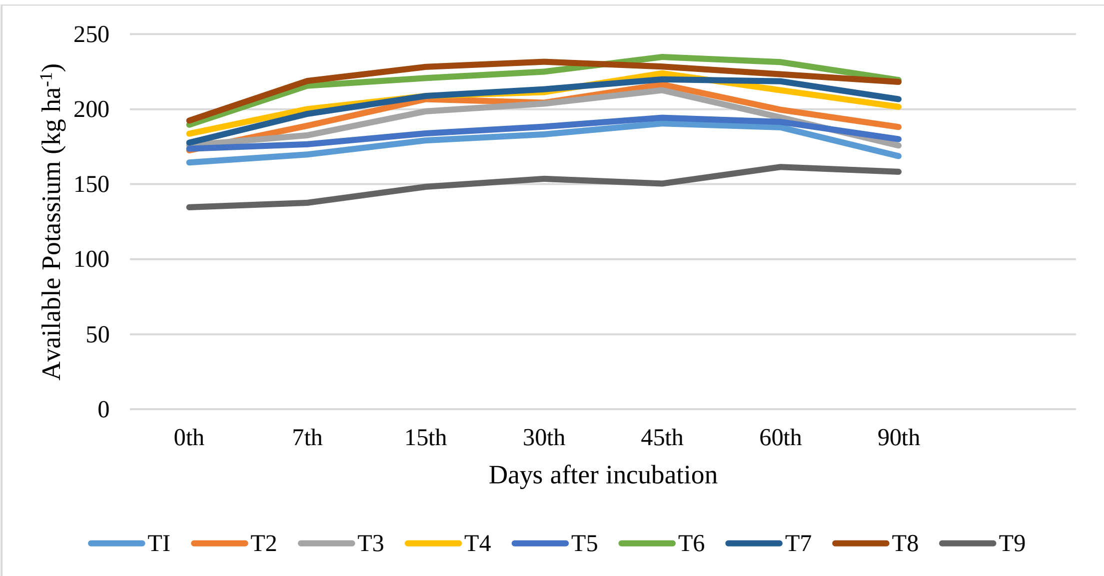

Fig. 12. Influence of organic nano NPK formulation on available K status (kg ha^{-1}) of soil during the period of incubation

Dhansil *et al.* (2018) concluded that application of nano phosphatic fertilizer increased the N and P content of the soil and reduced the use of conventional fertilizers by 40 per cent. Kottegoda *et al*. (2017) also reported that nano hybrid of urea modified hydroxyapatite released nitrogen 12 times slower than the conventional fertilizers.

5.2.5 Changes in secondary nutrients

In general, Ca content was found to be increased upto 45th day of incubation, whereas Mg and S availability declined after 30 days of incubation (Fig.13,14 and 15). The treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) resulted in highest calcium release upto 45th days of incubation. After the 45th day, highest values were recorded by the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). The treatment T_6 showed highest Mg release upto 15th day of incubation and treatment T_8 resulted in higher magnesium content at 30th and 45th day of incubation. Later highest values were showed by treatment T_6. The highest S content was recorded by the treatments T_8 (organic nano NPK 50 kg ha^{-1}+FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) and T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) during most of the intervals. From the characterization study, it was observed that organic nano NPK formulation contains 0.32 per cent calcium, 0.29 per cent magnesium and 0.61 per cent sulphur (Table 4), which might have improved the secondary nutrient content of the soil along with the applied FYM. Mazur *et al.* (1986) claimed that zeolite can increase the calcium and magnesium content of the soil due to its slow release properties. The zeolite can exchange calcium and magnesium to a greater extent (Guo *et al.*, 2008). Slow release of sulphate can be obtained when surfactant modified zeolite is used as the sulphate carrier and subsequently sulphate leaching in the soil can be reduced (Li and Zhang, 2010).

5.2.6 Changes in micronutrients

Application of organic nano NPK formulation showed significant influence on micronutrient status of the soil. The micronutrient content increased upto 45th day of incubation period except for iron which declined after 30th day of incubation (Fig.16, 17,18,19 and 20).

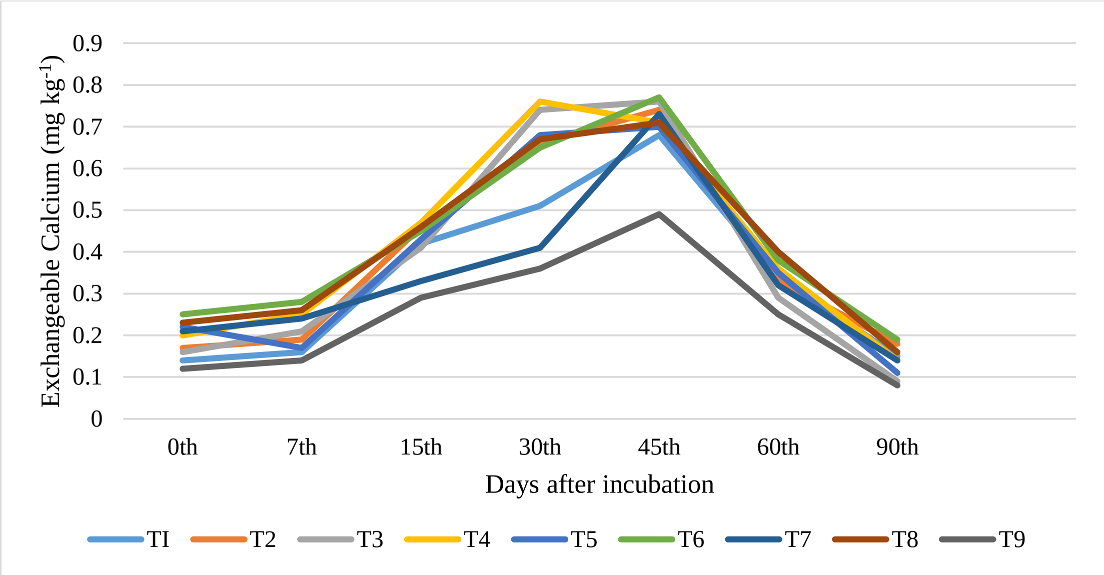

Fig. 13. Influence of organic nano NPK formulation on exchangeable Ca content (mg kg^{-1}) of soil during period of incubation

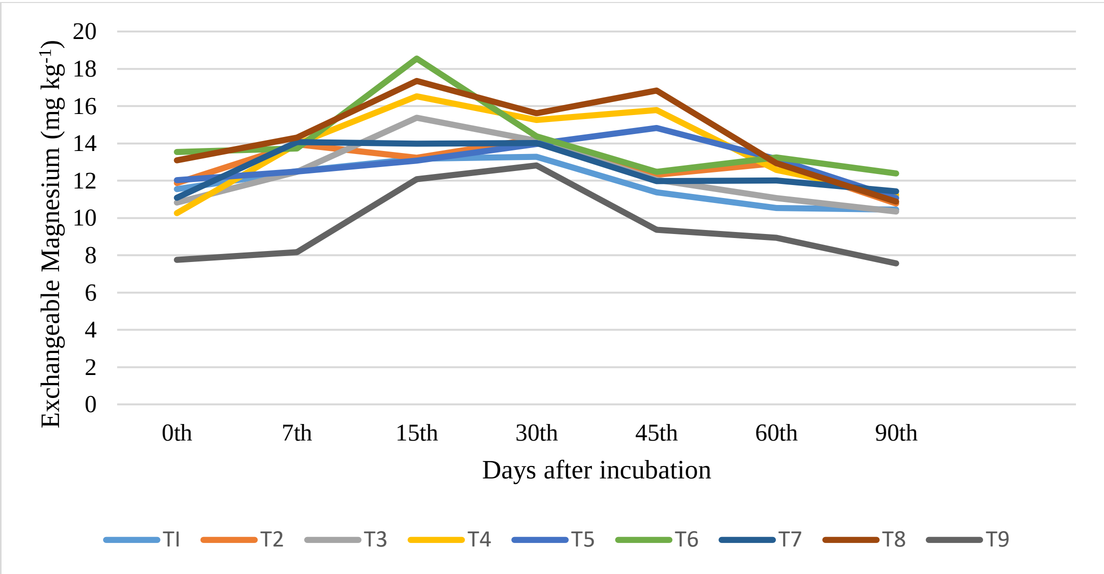

Fig. 14. Influence of organic nano NPK formulation on exchangeable Mg content (mg kg^{-1}) of soil during the period of incubation

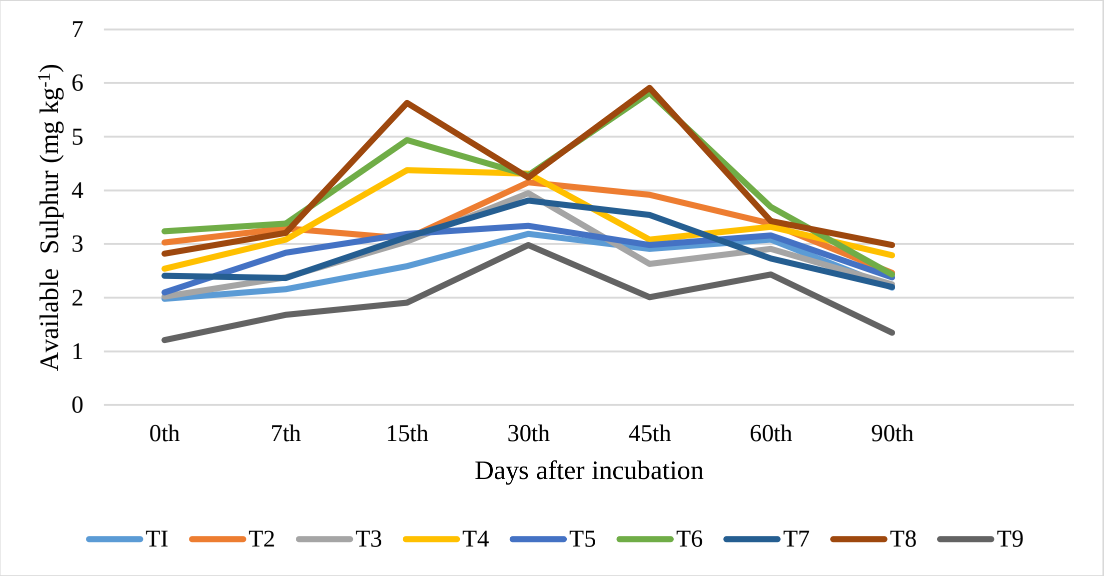

Fig. 15. Influence of organic nano NPK formulation on available sulphur content (mg kg^{-1}) of soil during period of the incubation

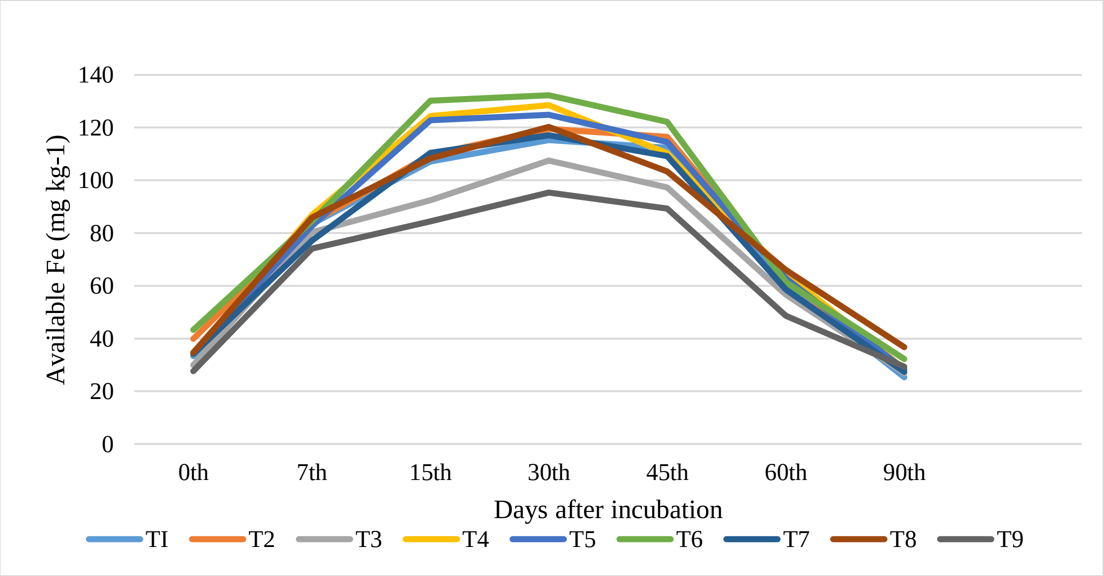

Fig. 16. Influence of organic nano NPK formulation on available Fe content (mg kg^{-1}) of soil during the period of incubation

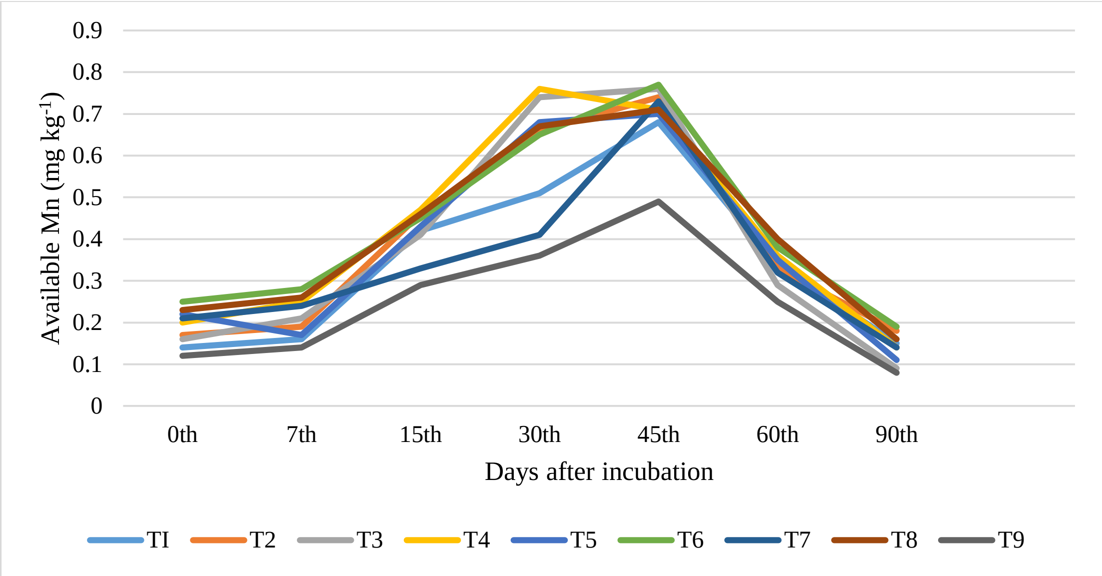

Fig. 17. Influence of organic nano NPK formulation on available Mn content (mg kg^{-1}) of soil during the period of incubation

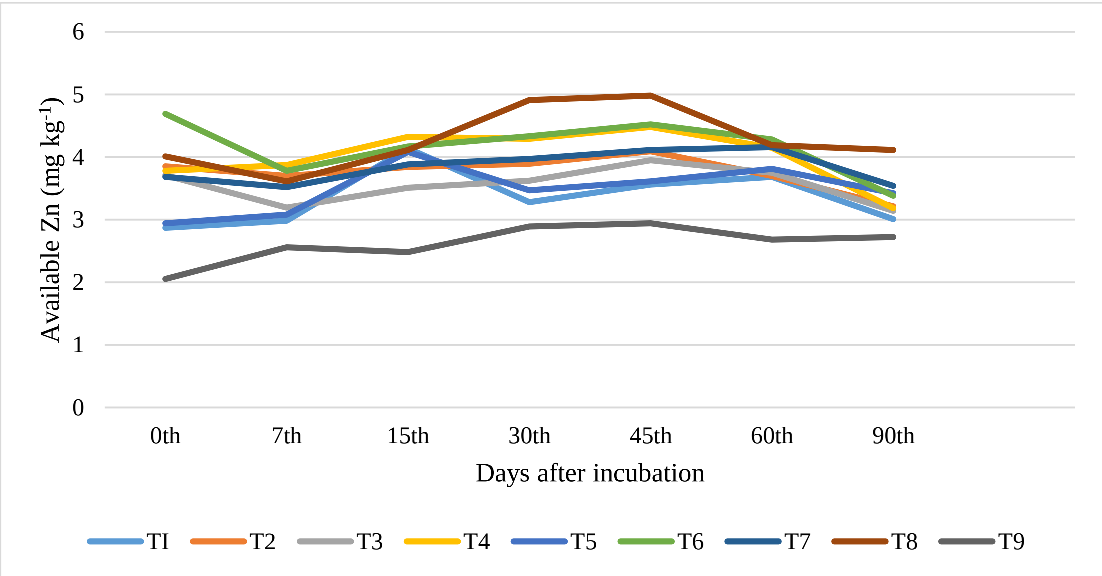

Fig. 18. Influence of organic nano NPK formulation on available Zn content (mg kg^{-1}) of soil during the period of incubation

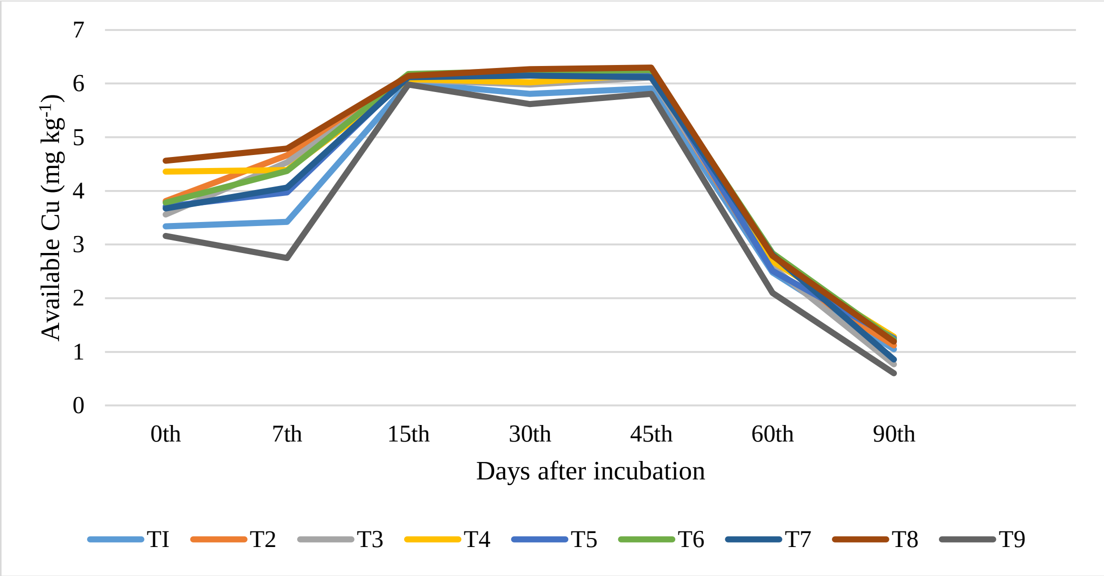

Fig.19. Influence of organic nano NPK formulation on available Cu content (mg kg^{-1}) of soil during the period of incubation

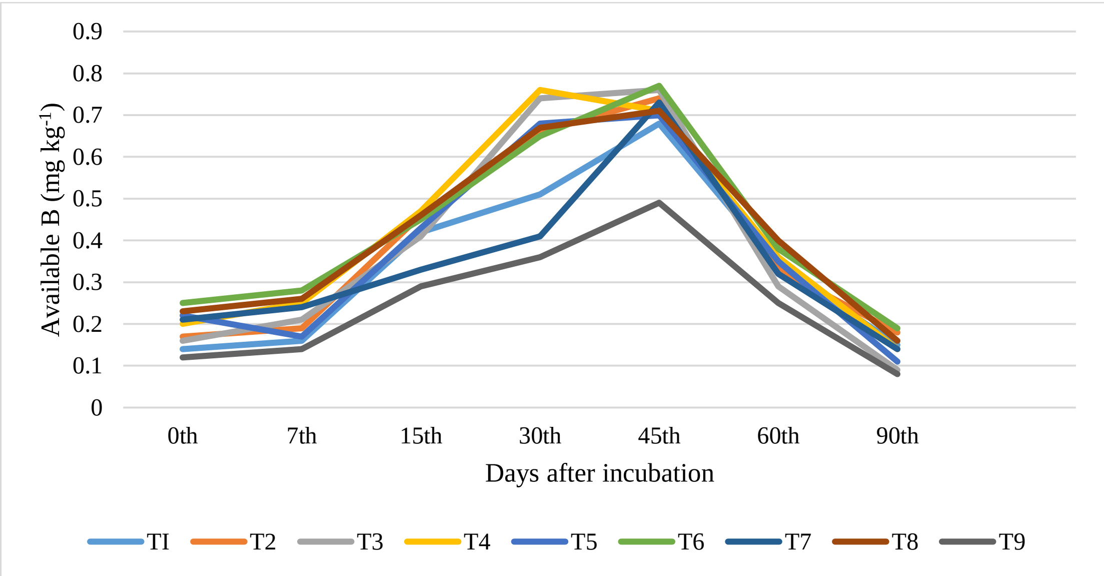

Fig. 20. Influence of organic nano NPK formulation on available B content (mg kg^{-1}) of soil during the period of incubation

In general, the highest iron and zinc availability was recorded in the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). The combined application of organic nano NPK, FYM and 50 per cent recommended dose of NPK resulted in higher Mn (T_8), Cu (T_8) and B(T_4) availability. Treatments containing organic nano NPK released more micronutrients into the soil over time. This may be due to the presence of humic and fulvic acid in the organic nano NPK which will chelate the micronutrients and increase its availability. Sheta *et al.* (2003) pointed out that the natural zeolites and bentonites have the ability to adsorb and release Fe and Zn and can be used for the slow release of micronutrients. The humic acid forms stable, soluble or insoluble complex with micronutrients. Similar results were also obtained by Tavakoli and Khoshkam (2013) who reported that humic acid in the nano fertilizer increases the micronutrient availability in the soil by its chelating effect.

PART III

5.3 FIELD EXPERIMENT

A field experiment was conducted to study the effect of organic nano NPK on growth, yield, quality and soil health by using sesame as a test crop in Onattukara (AEU 3). The possible explanation of the results obtained are discussed below.

5.3.1 Effect of organic nano NPK on biometric characters

Variation in the biometric characters like growth parameters, yield parameters and quality parameters and plant uptake are discussed below.

5.3.1.1 Growth parameters

5.3.1.1.1 Plant height

From the Table 20 (Fig. 21) it is evident that the organic nano NPK produced significant effect on plant height. The plant height was seen to increasing upto harvest and the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded the tallest sesame plant throughout the study. This increase in height might be due to the slow release and timely availability of nutrients to sesame. Due to the reduced size of nano fertilizers, they might have easily penetrated into the roots (Eichert and Goldbach, 2008), which might have improved the plant uptake thereby leading to an increase in growth and development. Ajirloo *et al.* (2015) also got similar results who reported that the application of potassium nano fertilizer 400 kg ha^{-1} significantly increased the height of tomato plants.

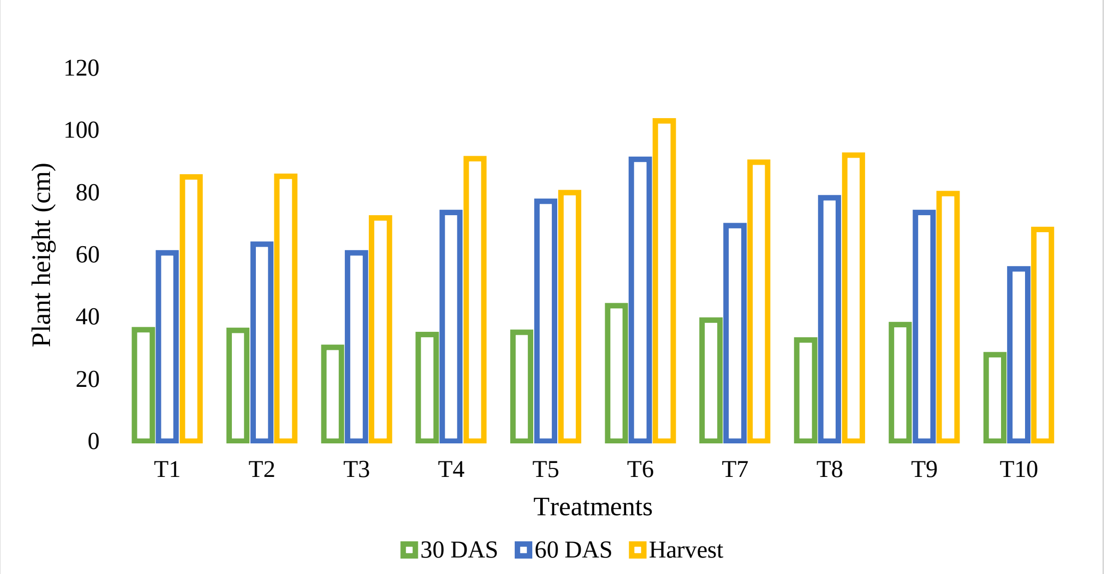

Fig. 21. Influence of organic nano NPK formulation on plant height (cm) of sesame

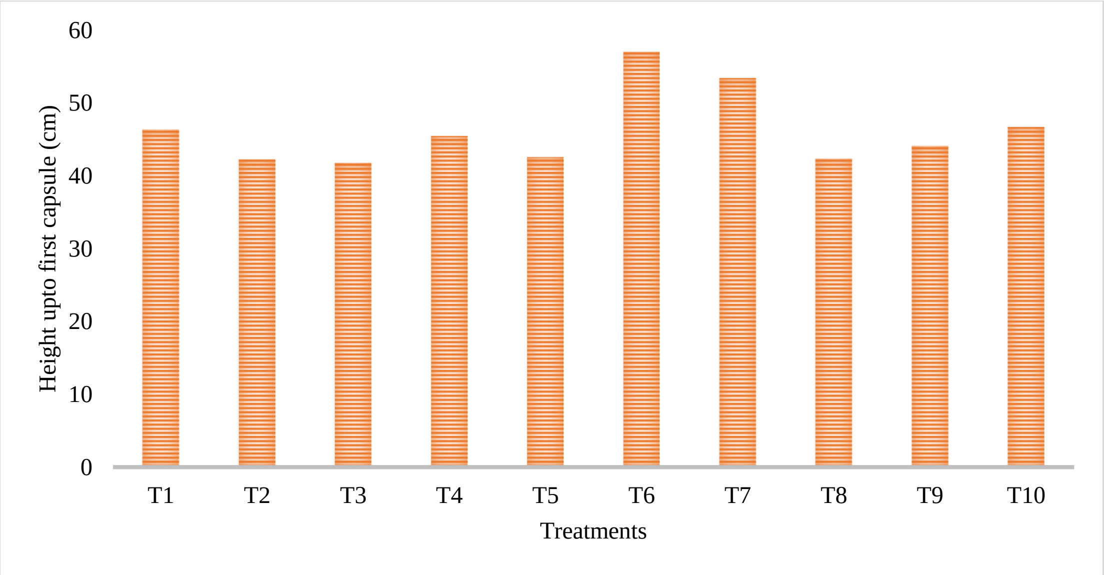

Fig. 22. Influence of organic nano NPK formulation on height upto first capsule (cm) of sesame.

Tarafdar *et al*. (2013) reported that application of nano Zn fertilizer significantly improved the shoot length of pearl millet compared to ordinary zinc and control treatment.

5.3.1.1.2 Height upto first capsule

The height upto first capsule was significantly influenced by the application of organic nano NPK (Fig. 22).

The treatment T_3 (organic nano NPK 25 kg ha^{-1} + 50 per cent recommended dose of NPK) produced capsules from the lower height which was comparable with T_2, T_8, T_5, T_9, T_4 and T_1. The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) produced capsules from the higher height and was on par with T_7. Height upto first capsule is a yield parameter. Lower values indicate that the capsules can be produced from lower portion of the plant which will further increase the yield. Hence, it is inferred that the application of organic nano NPK resulted in the production of capsules from the lower heights.

5.3.1.1.3 Primary branches per plant

The application of organic nano NPK significantly influenced the number of branches per plant of sesame (Fig. 23). It was observed that number of primary branches per plant increased upto the harvest and recorded higher values in treatment T_5 (organic nano NPK 50 kg ha^{-1}). Even though the treatment T_2 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1}) recorded the higher value at 30 DAS, it was found to be on a par with T_7, T_6 and T_5. The increase in primary branches may be due to the increase in meristematic activity and accumulation of carbohydrates by the application of organic nano NPK. Similar results were also obtained by Salem *et al.* (2016) in *Cucurbita pepo* where the application of green synthesized nano particles significantly improved the number of branches per plant. Drostkar *et al.* (2016) reported that foliar application of nano formulation of NPK and micronutrients increased the number of branches per plant of chickpea.

5.3.1.1.4 Leaf area per plant

Leaf area per plant was significantly increased throughout the crop period by the application of organic nano NPK (Fig. 24). The treatment T_5 (organic nano NPK 50 kg ha^{-1})

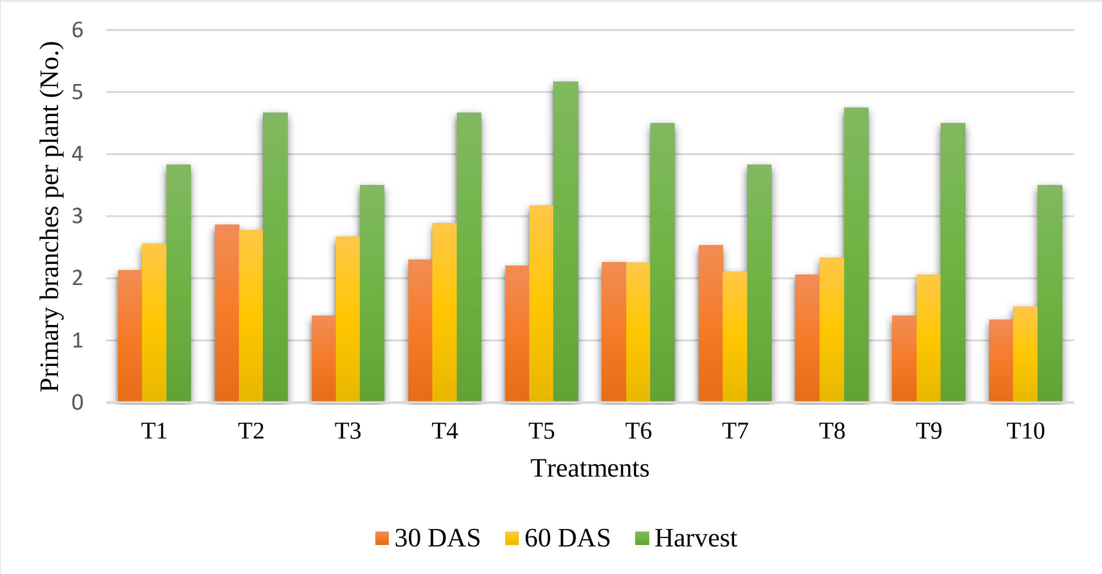

Fig. 23. Influence of organic nano NPK formulation on number of primary branches per plant of sesame

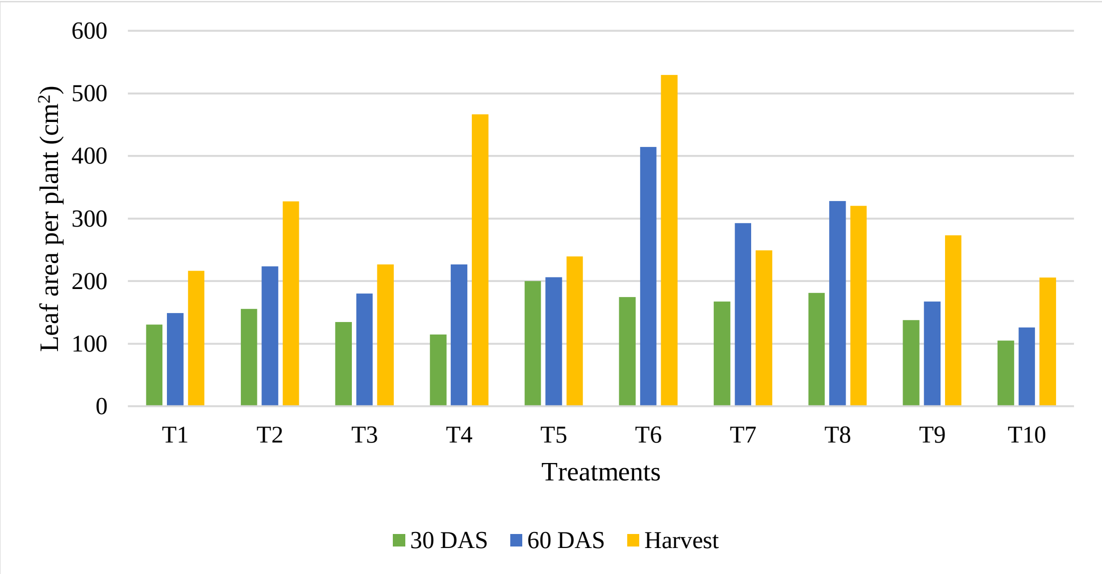

Fig. 24. Influence of organic nano NPK formulation on leaf area per plant (cm^2) of sesame

recorded the highest leaf area per plant at 30th DAS and the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) registered highest value at 60th DAS and at harvest. Increase in leaf area might be due to the increased uptake and translocation of nutrients, which might have enhanced the activity of meristematic cells. Increase in leaf area increases the light interception and thus the photosynthetic efficiency which in turn improve the yield of the crop. This result is in line with the findings of Ashfaq *et al.* (2016). Application of copper nano particle grown carbon nano fiber significantly improved the higher chlorophyll content in *Cicer arietinum.* Application of multi-walled carbon nano tubes was found to increase the photosynthetic efficiency by enhancing electron transport chain between chloroplast and multi-walled carbon nano tubes (Giraldo *et al.*, 2014).

5.3.1.1.5 Root characters

The perusal of the data (Table 23, Table 24, Fig. 25 and Fig. 26) indicates that root spread and root volume were found to be higher in treatments T_4 (organic nano NPK 25 kg ha^{-1}+ 50 per cent recommended dose of NPK+ FYM 5 t ha^{-1}) and T_6 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}). This might be due to the enhanced absorption of the nano fertilizer through the plant roots due to its smaller size. Application of FYM may increase the effect of nano fertilizer by improving the nutrient status of the soil. Darwish *et al*. (1995) opined that by modifying soil physical conditions and nutrient status of the soil, the crop growth and yield can be improved by the changes in root environment which eventually results in the enhanced biomass production. Jayarambabu *et al.* (2014) suggested that application of 20 mg Zinc nano particles can increase the root length of mung bean. Prasad *et al*. (2012) also reported the positive influence of nano ZnO on crops compared to bulk $ZnSO_4$ fertilizer.

5.3.1.1.6 Dry matter production

It can be observed from the Fig. 27 that the highest dry matter production was recorded in treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) at 30 DAS and was found on par with T_8. Treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) resulted in higher dry matter at 60 DAS and at harvest. The increased uptake of nutrients and its conversion into metabolites will increase the dry matter content of the plant.

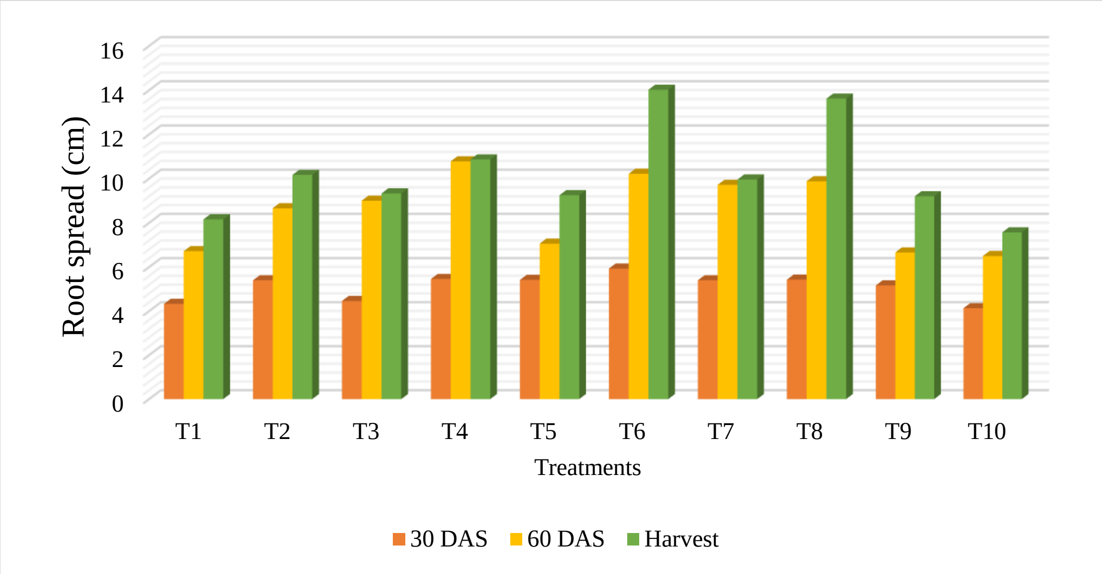

Fig. 25. Influence of organic nano NPK formulation on root spread (cm) of sesame

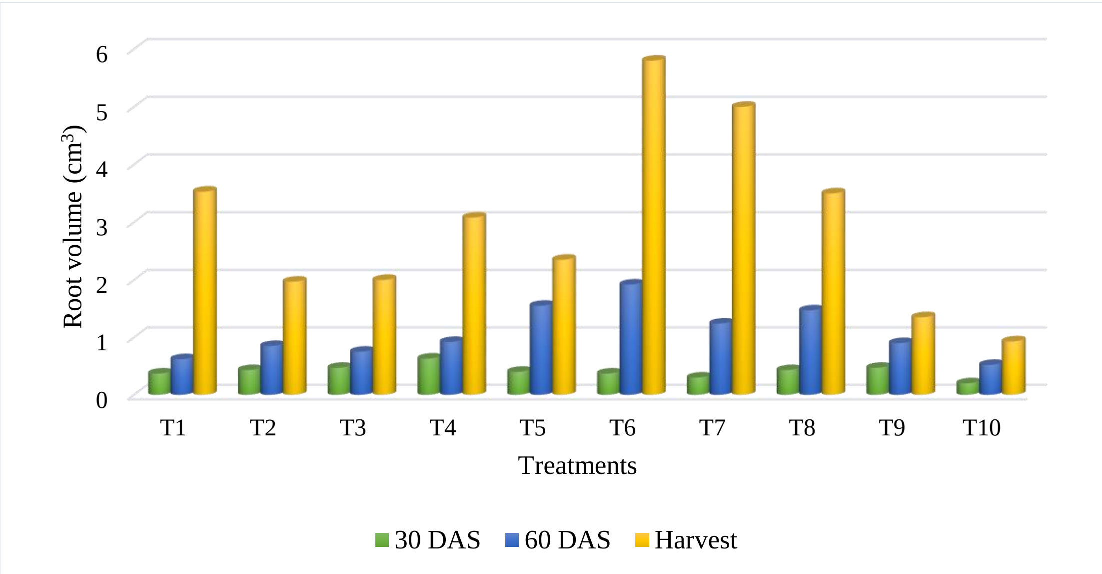

Fig. 26. Influence of organic nano NPK formulation on root volume (cm^3) of sesame

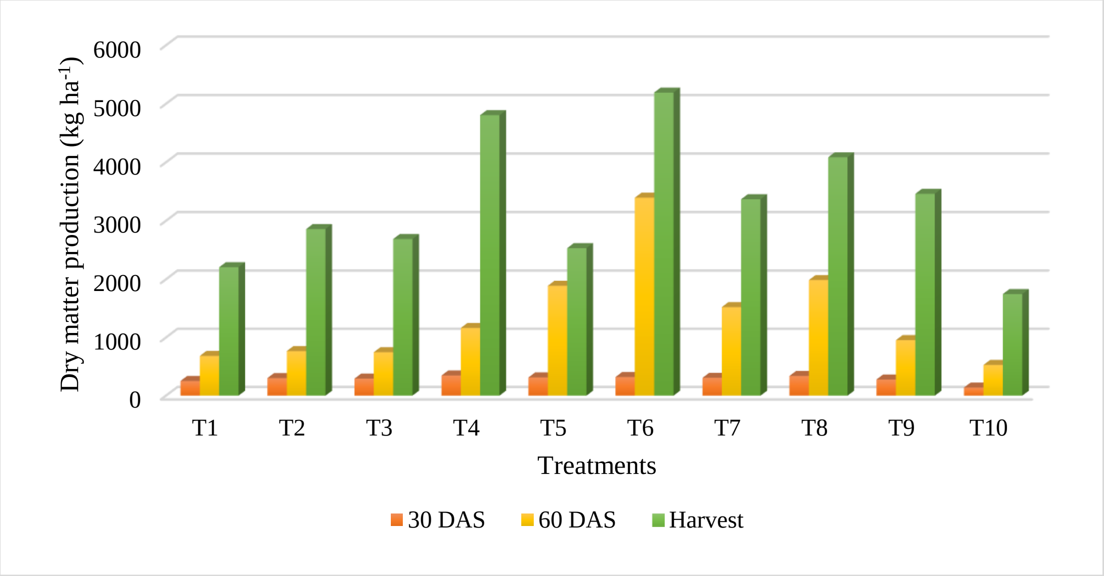

Fig. 27. Influence of organic nano NPK formulation on dry matter production (kg ha^{-1}) of sesame

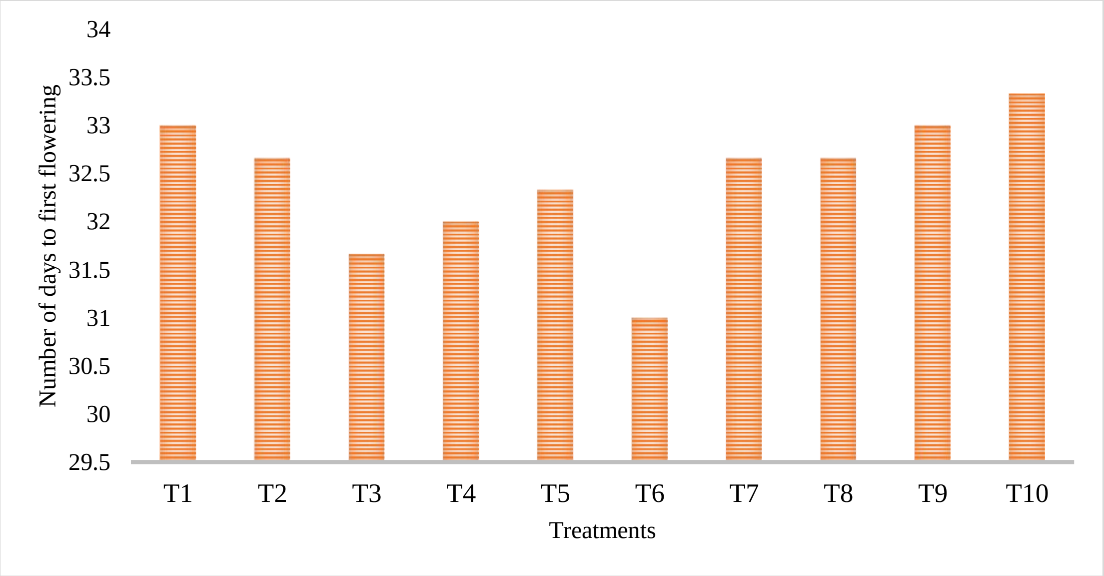

Fig. 28. Influence of organic nano NPK formulation on number of days to first flowering in sesame

Tarafdar *et al*. (2014) reported that the foliar application of nano zinc fertilizer in pearl millet significantly improved the plant dry matter content. Rezaei and Abbasi (2014) opined that the increase in dry matter content in cotton by the application of zinc nano fertilizer might be due to the improved physiological process like chlorophyll formation or antioxidant activity. The application of nano TiO_2 significantly increased dry matter content of maize by enhancing the nitrogen assimilation, photo-reduction activities of photosystem II and electron transport chain and scavenging of reactive oxygen species (Morteza *et al*., 2013). Raliya *et al*. (2015) got similar results in tomato plants.

5.3.1.2 Effect of organic nano NPK formulation on yield and yield parameters

5.3.1.2.1 Days to first flowering and Days to 50 per cent flowering

The application of organic nano NPK reduced the days to first flowering and 50 per cent flowering (Fig. 28 and 29). Eventhough, the organic nano NPK did not produce any significant difference on number of days to flower and days to 50 per cent flowering, lowest number of days were recorded by T_6 and T_4 respectively. Janmohammadi *et al.* (2016) revealed that the nano TiO_2 significantly influenced the days to anthesis.

5.3.1.2.2 Days to maturity

All treatments reduced the maturity period of sesame compared to the absolute control (Table 26, Fig. 30). But the organic nano NPK treatments was found to be on par with the soil test based recommendation. The increased rate of metabolism might have resulted in the accumulation of sugars and proteins in plants which will accelerate the maturity of the crop. Similar results were also obtained by Ibraheem *et al.* (2021) who reported that application of iron nano fertilizers reduced the period to 50 per cent curd maturity in broccoli.

5.3.1.2.3 Number of capsule per plant and Number of seed per capsule

Number of capsule per plant is a major factor that decides the yield of sesame and application of organic nano NPK showed significant influence on it (Fig.31 and 32).

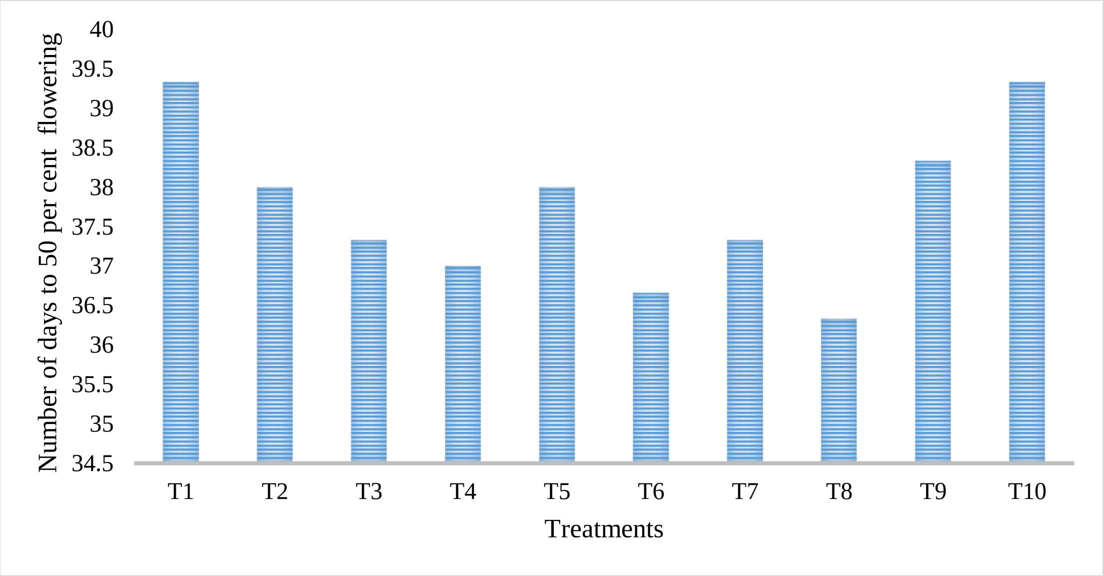

Fig. 29. Influence of organic nano NPK formulation on no. of days to 50 per cent flowering of sesame

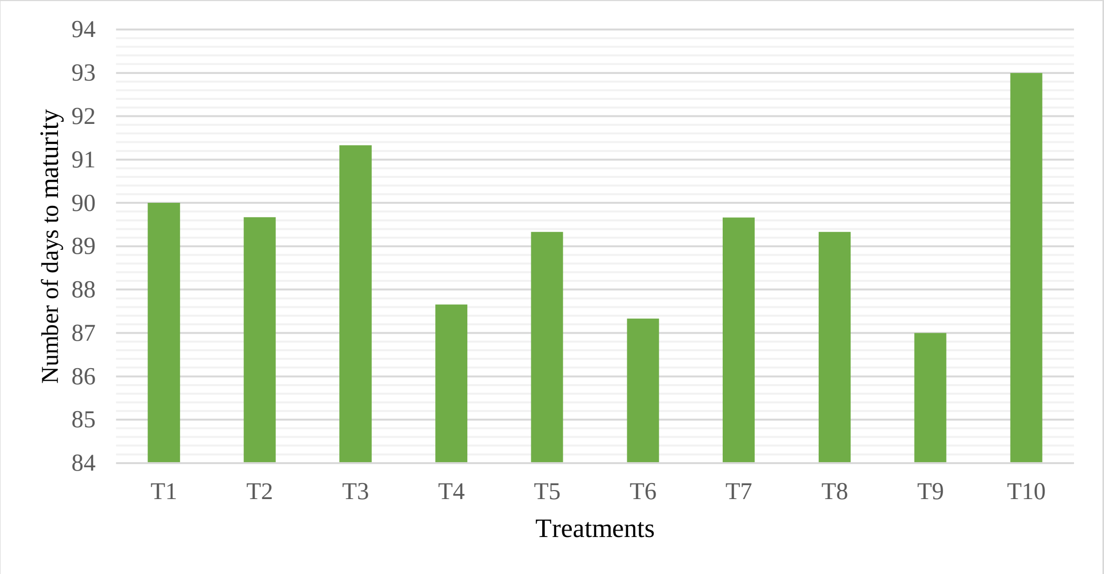

Fig. 30. Influence of organic nano NPK formulation on no. of days to maturity in sesame

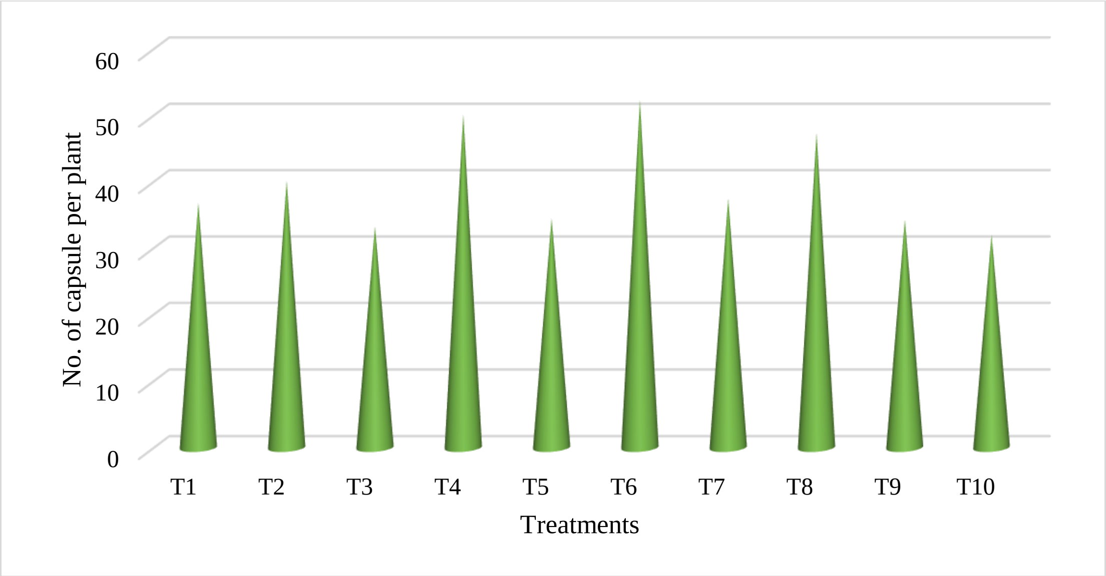

Fig. 31. Influence of organic nano NPK formulation on number of capsule per plant of sesame

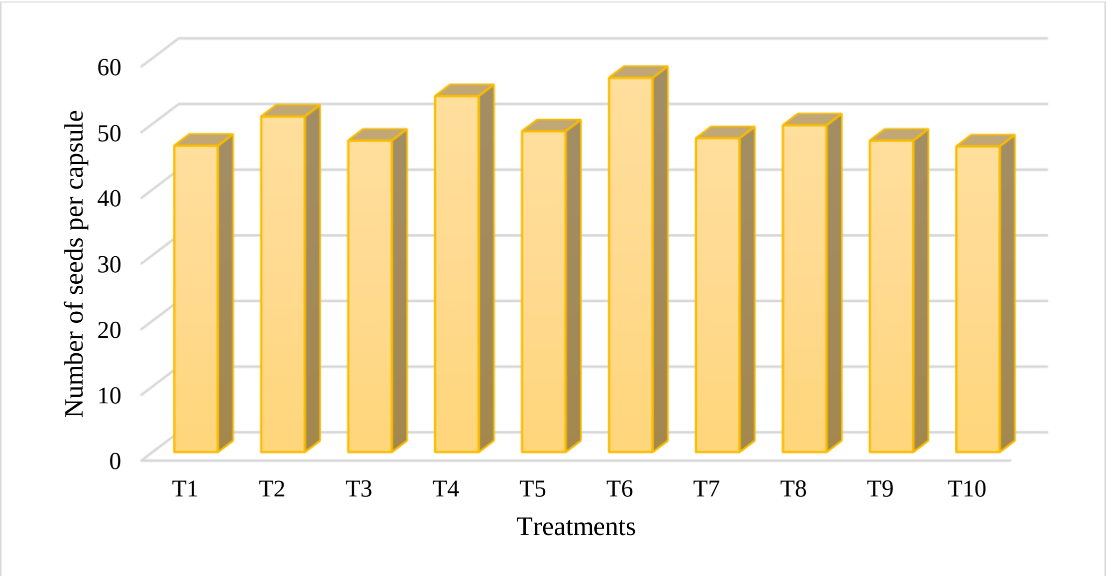

Fig. 32. Influence of organic nano NPK formulation on number of seeds per capsule of sesame

The maximum capsules per plant and number of seeds per capsule were recorded highest in treatment T_6 followed by T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK). The addition of organic nano NPK might have resulted in floral primordial initiation which increased the number of capsule per plant and number of seeds per capsule. Similar results were also obtained by Rezaei and Abbasi (2014) who reported that application of nano chelate of zinc in cotton increased the number of bolls per plant and boll weight.

5.3.1.2.4 Thousand seed weight

Organic nano NPK had significantly influenced the thousand seed weight of sesame (Fig. 33). Thousand seed weight was significantly higher in treatment T_5 (organic nano NPK 50 kg ha^{-1}) which was on par with T_6, T_7 and T_4. This might be due to the increased activity of cytokinin hormone which increases the cell division (Bihmidine *et al.*, 2013). These findings confirm the results reported by Bekhard *et al.* (2017). The application of nitrogen along with nano fertilizer increased the thousand grain weight of sesame. Afshar *et al*. (2014) pointed that the nano fertilizer application enhanced the spikelet per spike, thousand kernel weight owing to the enhanced carbohydrate metabolism and enzyme activity. Al-Juthery *et al.* (2018b) revealed that application of tri nano mixed fertilizer containing N, P and K increased the thousand grain weight of wheat. Delfani *et al.* (2014) suggested that foliar application of 0.5 g L^{-1} nano iron increased the number of pods per plant and weight of thousand seeds of black eyed pea compared to conventional iron.

5.3.1.2.5 Seed yield

Seed yield was significantly influenced by the organic nano NPK application (Fig. 34 and 35). The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded highest seed yield per plot (1.42 kg) and seed yield per hectare (712.52 kg). The yield was increased by 42 per cent through the combined application of organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1} (T_6) compared to the control. This yield increase might be attributed to the increased uptake and translocation of nano fertilizers, increased metabolic activity and accumulation of photosynthates. Nano fertilizers promote the plants to absorb water as well as nutrients which will increase yield attributes resulting in enhanced growth and yield (Wu, 2007).

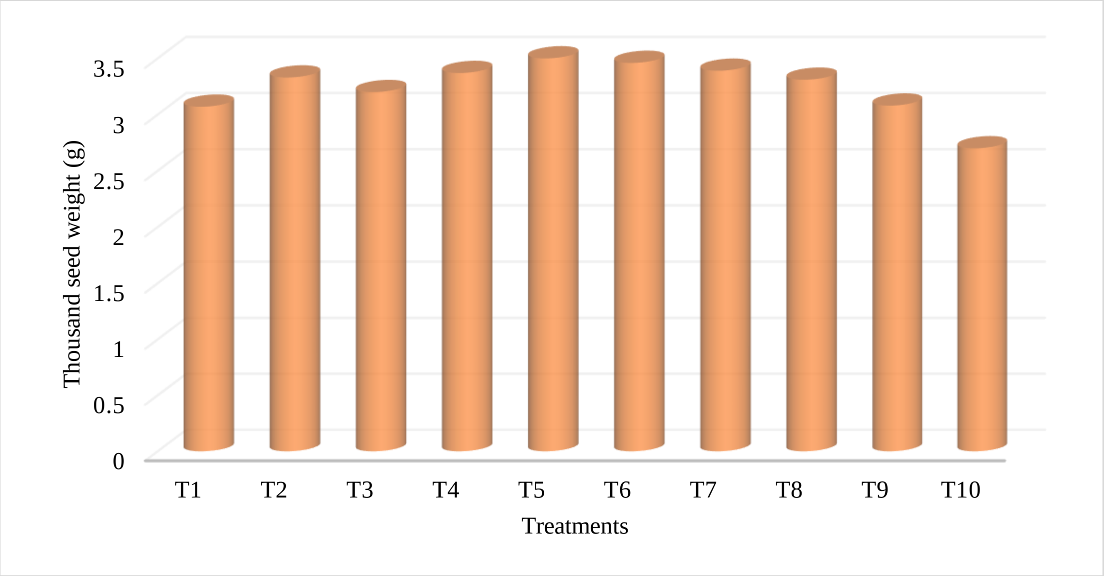

Fig. 33. Influence of organic nano NPK formulation thousand seed weight (g) of sesame

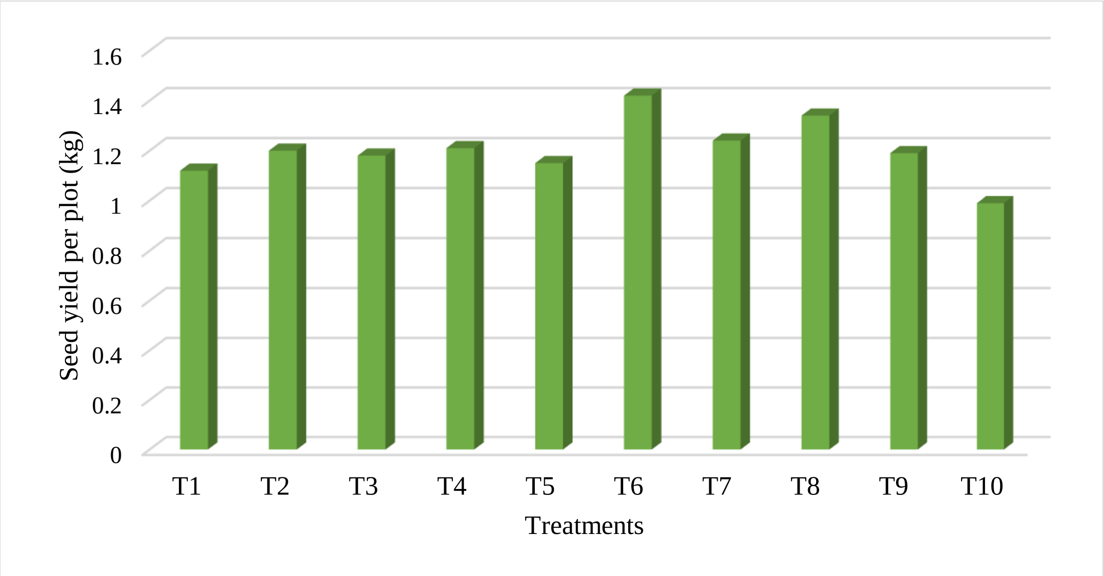

Fig. 34. Influence of organic nano NPK formulation seed yield per plot (kg) of sesame

Liu *et al*. (2017) also reported that application of nano fertilizers enhanced yield and the yield attributing characters due to the slow and sustained release of nutrients to the plants. This result is in line with the findings of Prasad *et al*. (2012). They reported that nano scale ZnO application increased the pod yield per plant of groundnut compared to the bulk $ZnSO_4$, since nano scale ZnO is absorbed to a larger extent than in bulk form. Zeng *et al*. (2005) explained the possible reason for the increase in yield characters by the application of nano TiO_2. The photosynthetic activity is increased by promoting cyclic and linear photophosphorylation by spraying nano TiO_2 and the source capacity of the leaves were increased by the increased photosynthesis which ultimately led to enhanced yield. Liu and Lal (2014) suggested that application of hydroxyapatite nano particle can increase the growth and yield of soybean compared to the water soluble phosphorus due to its reduced size.

5.3.1.2.6 Bhusa yield

The bhusa yield was significantly increased by the application of organic nano NPK (Fig. 36). The highest bhusa was yielded in treatment T_5 (organic nano NPK 50 kg ha^{-1}) followed by T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). Increased bhusa yield might be due to the increased photosynthesis and increased metabolic activities of the plant. Janmohammadi *et al*. (2016) observed that application of nano fertilizer increased the grain yield and straw yield of barley by improved fertilizer use efficiency.

5.3.1.3 Quality parameters

5.3.1.3.1 Oil content

The organic nano NPK significantly influenced the oil content of sesame (Fig. 37). The application of treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) resulted in highest oil content and was comparable with T_8. Biochemical composition of the plant can be improved by choosing accurate amount and appropriate type nano fertilizer (Drostkar *et al*., 2016; Roche *et al*., 2006). At flowering, there is an increase in need for nutrients (Varamin *et al.,* 2020). Availability of essential nutrients at critical stage of crop growth can improve the photosynthesis and plant metabolites which ultimately results in the accumulation of oil (Kaluzewicz *et al*., 2017; Monica and Cremonini, 2009).

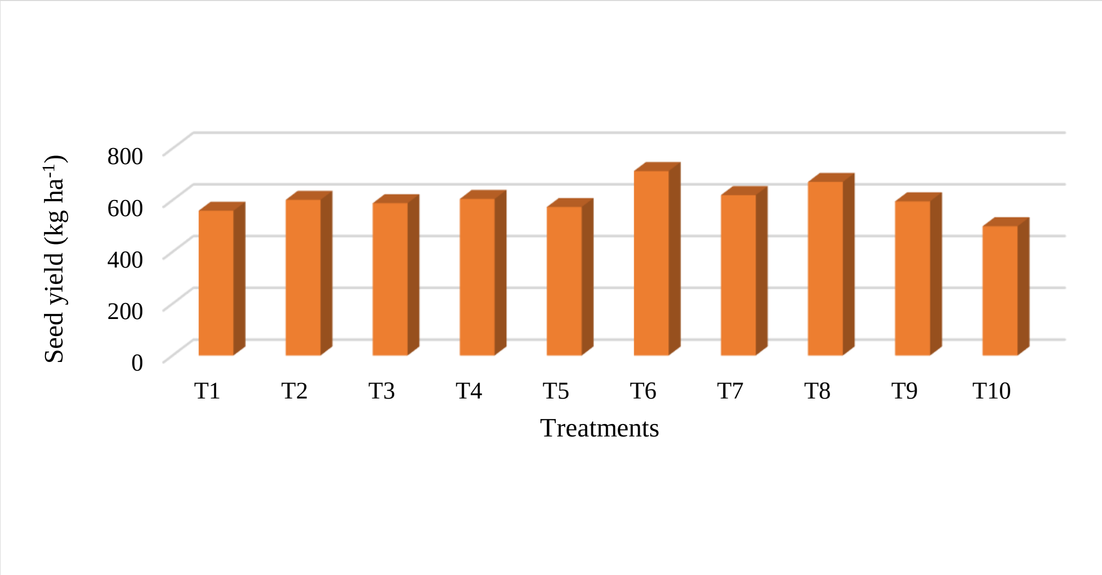

Fig. 35. Influence of organic nano NPK formulation seed yield (kg ha^{-1}) of sesame

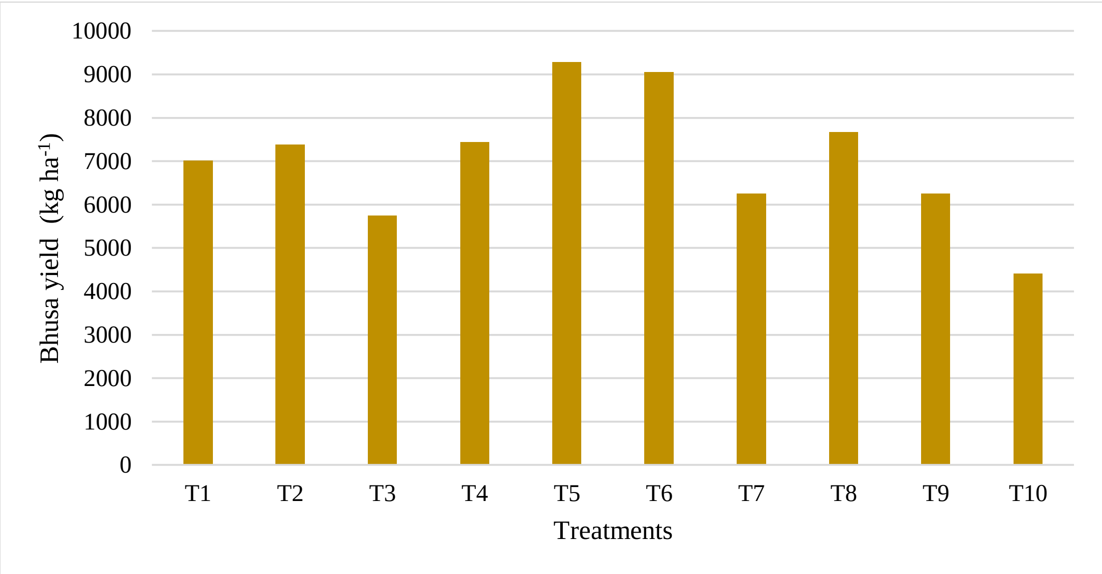

Fig. 36. Influence of organic nano NPK formulation bhusa yield (kg ha^{-1}) of sesame

The increased oil content might be attributed to the higher sulphur uptake of the plant. A strong positive correlation was found between sulphur uptake and seed yield (r =0.846*). When chemical and nano fertilizer are combined, essential oil content can be increased (Amooaghaie and Golmohammadi, 2017). Increase in yield will result in increases the oil yield of the crop. According to Zarei *et al.* (2020), application of phosphorus nano chelate with chitosan increased the quantitative and qualitative characteristics of sesame and resulted in increased growth and quality in drought stress conditions. Sham (2017) also got similar result in sunflower.

5.3.1.3.2 Grain protein content

The grain protein content was significantly influenced by the application of organic nano NPK (Fig. 38). The highest protein content was obtained in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and was on par with T_8 and T_7. This increase may be due to slow availability of nutrients throughout the crop period. This prolonged availability of nutrients, especially nitrogen can enhance the formation of various metabolites like protein in the plants. Delfani *et al*. (2014), indicated that application of nano iron in black eyed pea, increased the protein content by 2 per cent compared to the control. Nano calcium application in peanut also increased the protein content in aerial parts of the plant (Liu *et al*., 2005).

5.3.1.4 Plant uptake

5.3.1.4.1 Primary nutrient uptake

Primary nutrient uptake was increased by the application of organic nano NPK (Fig. 39). The higher primary uptake was found in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). This might be due to the higher dry matter production in organic nano formulation applied plots. Kottegoda *et al*. (2017) observed that application of urea nano hydroxyapatite particles in paddy showed higher nitrogen uptake and reduced the urea requirement by 50 per cent. The application of N-loaded zeolite in kalmi plants resulted in increased nitrogen uptake than the conventional urea uptake (Rajonee *et al.*, 2016). Al-Juthery *et al*. (2018b) reported that the foliar application of tri nano mixed fertilizer of N, P and K significantly increased the N, P, K content in wheat plant.

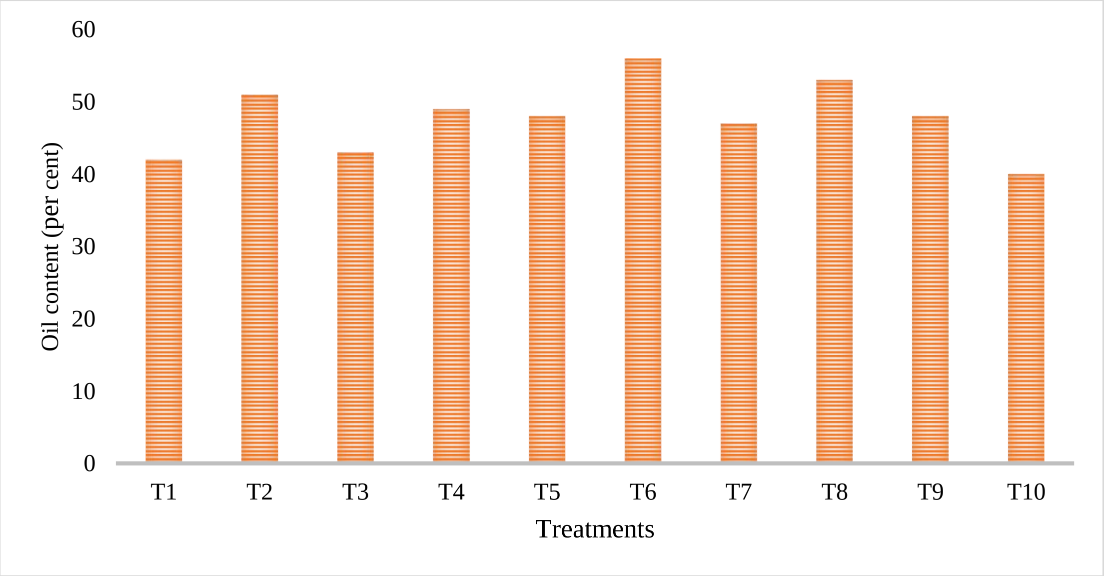

Fig. 37. Influence of organic nano NPK formulation oil content (per cent) of sesame

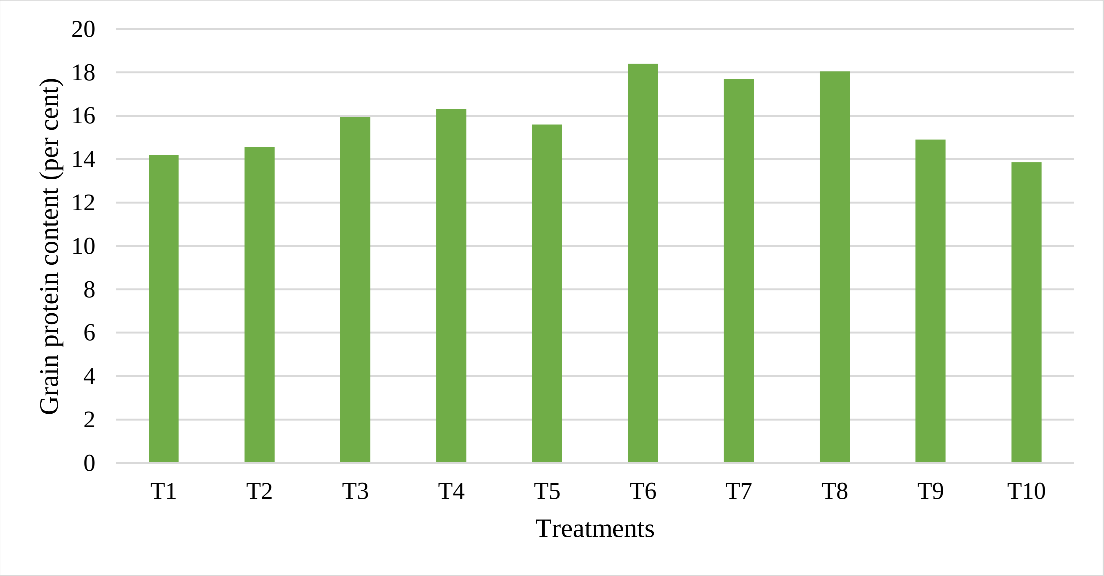

Fig. 38. Influence of organic nano NPK formulation in grain protein content (per cent) of sesame

Lettuce plants treated with nano hydroxyapatite showed increased P uptake due the higher penetration of nano fertilizers into the plant (Taskin *et al.*, 2018). Similar results were also obtained by Montalvo *et al.* (2015). The P uptake from the nano hydroxyapatite was higher compared to the bulk hydroxyapatite in wheat plants. The SiO_2 nano particle as foliar application avoided leaching loss of N and helped in more accumulation of nitrogen in leaf (Siddique and Al-whaibi, 2014). Jinghua (2004) reported that a patented nano composite N, P, K, micronutrients, mannose and amino acid increased the nutrient utilization by the grain crops.

5.3.1.4.2 Secondary nutrient uptake

Analysis of the data (Table 30, Fig. 40) implies that the application of organic nano NPK had significantly influenced in the secondary nutrient uptake. The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) resulted in higher Ca and S uptake followed by T_4 whereas, treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}+ 50 per cent recommended dose of NPK) resulted in higher Mg uptake which was comparable with T_6. This trend is similar in available secondary nutrients in soil (Table 35) which might had increased the secondary nutrient uptake. The reduced size of organic nano NPK will aids in improved uptake and translocation of the nutrients inside the plant. Thirunavakkarasu (2014) studied the effect of zeolite loaded sulphur in groundnut and he found that application of nano sulphur at 30 kg ha^{-1} had higher sulphur use efficiency by reducing conventional sulphur fertilization by 25 per cent. Li and Zhang (2010) studied surfactant modified zeolite as fertilizer additive to control the release of sulphur and suggested that it could be used as a good carrier for sulphate and can improve the sulphur availability in the soil.

5.3.1.4.3 Micronutrient uptake

From the data (Table 31, Fig. 41), it can be found that the organic nano NPK significantly influenced the micronutrient uptake in plants. The highest uptake of all micronutrients was showed by treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was comparable with T_4 (Fe, Mn, B), T_7 (Fe) and T_8 (Fe, Zn, Cu, B). The micronutrients present in the organic nano NPK are in chelated form and hence they are easily soluble and readily available to the plants. Increase in dry matter production also result in higher micronutrient uptake by plants.

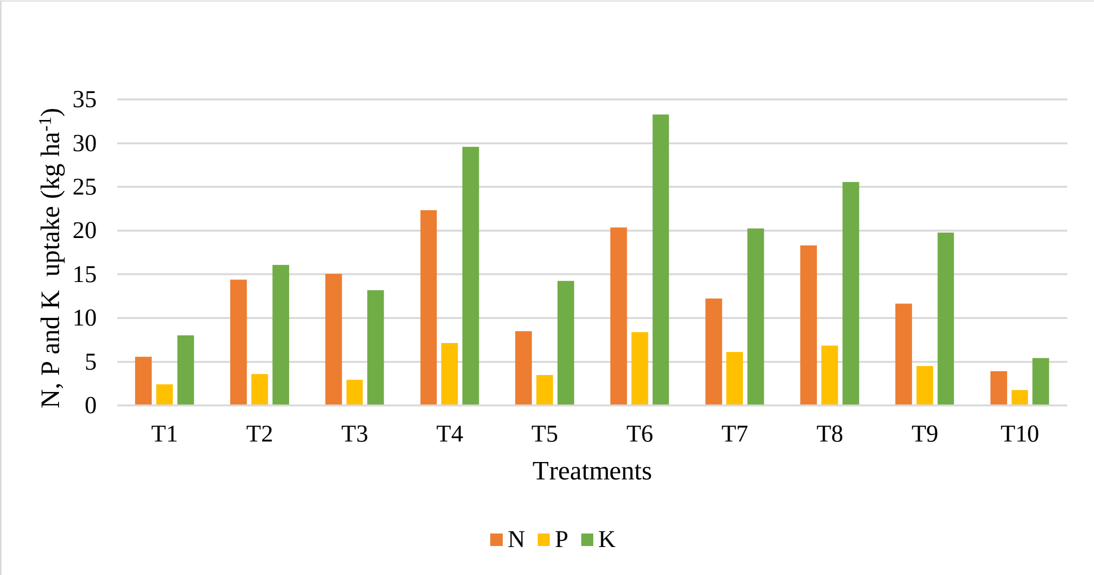

Fig. 39. Influence of organic nano NPK formulation in NPK uptake (kg ha^{-1}) of sesame

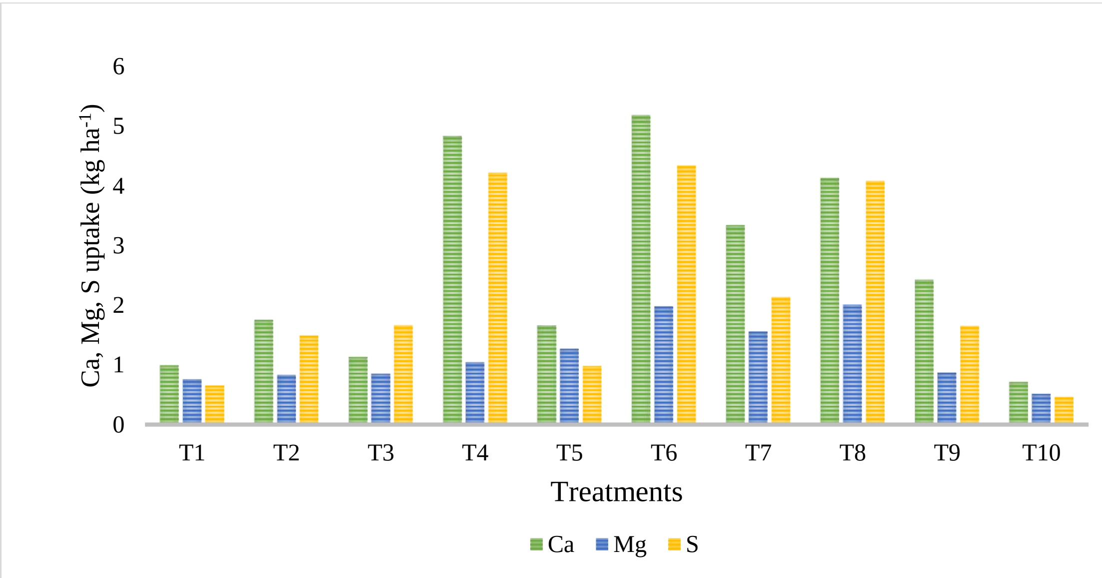

Fig. 40. Influence of organic nano NPK formulation in secondary nutrient uptake (kg ha^{-1}) of sesame

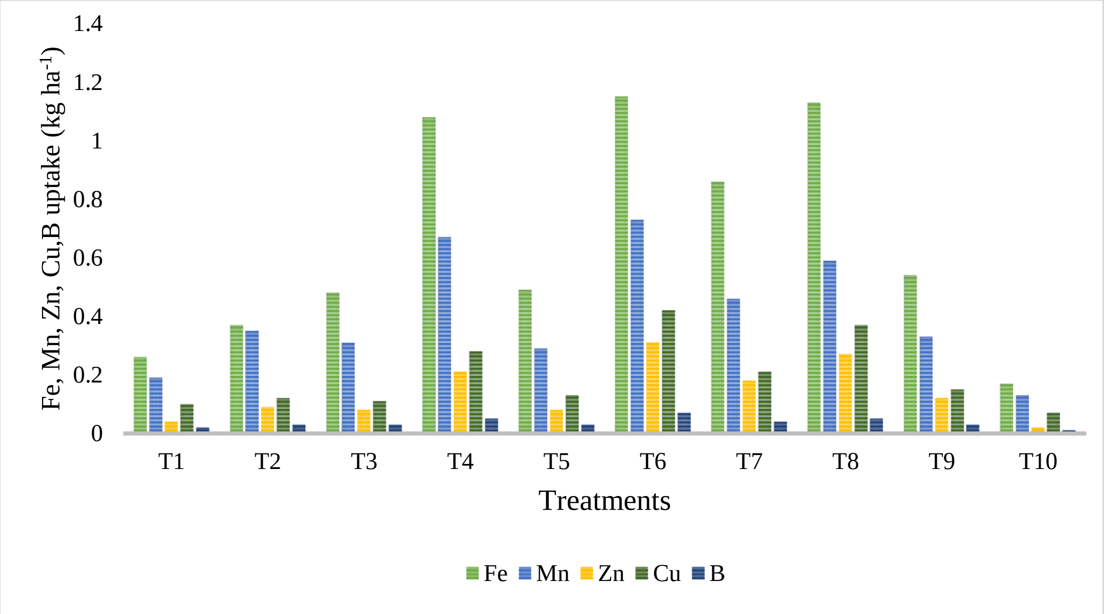

Fig. 41. Influence of organic nano NPK formulation in micronutrient uptake (kg ha^{-1}) of sesame

Yuvaraj and Subramanian (2017) observed that the zinc uptake by shoot was increased upto 17 per cent when the rice plant was fertilized with Zn fortified nano hollow shell compared to the bulk $ZnSO_4$. Mahajan *et al*. (2011) reported that the Zn content in the roots of mung bean and gram increased significantly with the increase of nano ZnO application. It indicates that the ZnO nano particles are absorbed and translocated in seedlings resulting in increase in Zn content at corresponding nano ZnO treatment. Lee *et al.* (2008) reported significant uptake of nano sized copper by mung bean and wheat. Ashfaq *et al.* (2016) pointed out that the more copper uptake was found in leaf than root and shoot of *Cicer arietinum* by the application of copper nano particle grown carbon nano fiber due to the higher translocation capacity of nano particles. The foliar application of ZnO nano particles increased the Mn, Fe, Cu in shoot, Mn and Cu in grains and Mn in roots (Bala *et al.,* 2019). Similar results were obtained for Zeidan *et al.* (2010) and Prasad *et al.* (2012). They reported an increase in Zinc content of test crops by the application of ZnO nano particles.

5.3.2 Effect of organic nano NPK on soil properties after the experiment

5.3.2.1 Soil physical property

5.3.2.1.1 Bulk density

Organic nano NPK did not have any significant influence on bulk density of the soil (Fig. 42). The organic fertilizers tend to decrease the bulk density of the soil by increasing the total porosity (Celic *et al*., 2010). The organic nano NPK was found to have an organic carbon content of 2.34 per cent (Table 4). Long term application of these organic nano fertilizer may help to improve the soil physical properties.

5.3.2.2 Soil chemical properties

5.3.2.2.1 pH and EC

The soil pH and EC increased by the application of organic nano NPK (Fig. 43 and Fig. 44). The highest pH was recorded in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). The organic nano NPK used has a pH of 7.81 (Table 4). Hence its application might have increased the pH of the soil. The result is in line with Rajonee *et al*. (2016) who suggested that application of surface modified zeolite with nitrogen

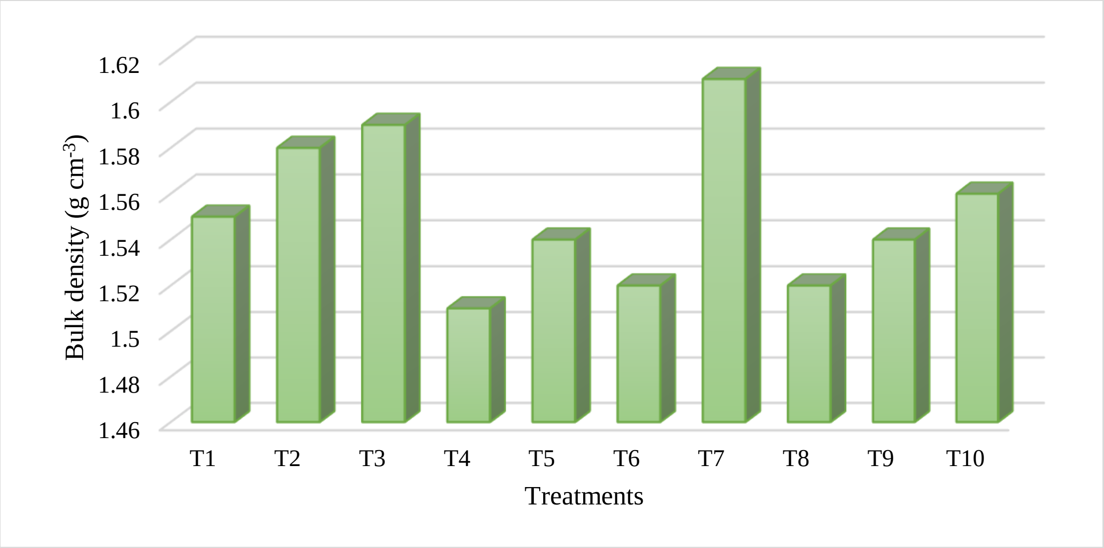

Fig. 42. Influence of organic nano NPK formulation in bulk density (Mg m^{-3}) of soil after the experiment

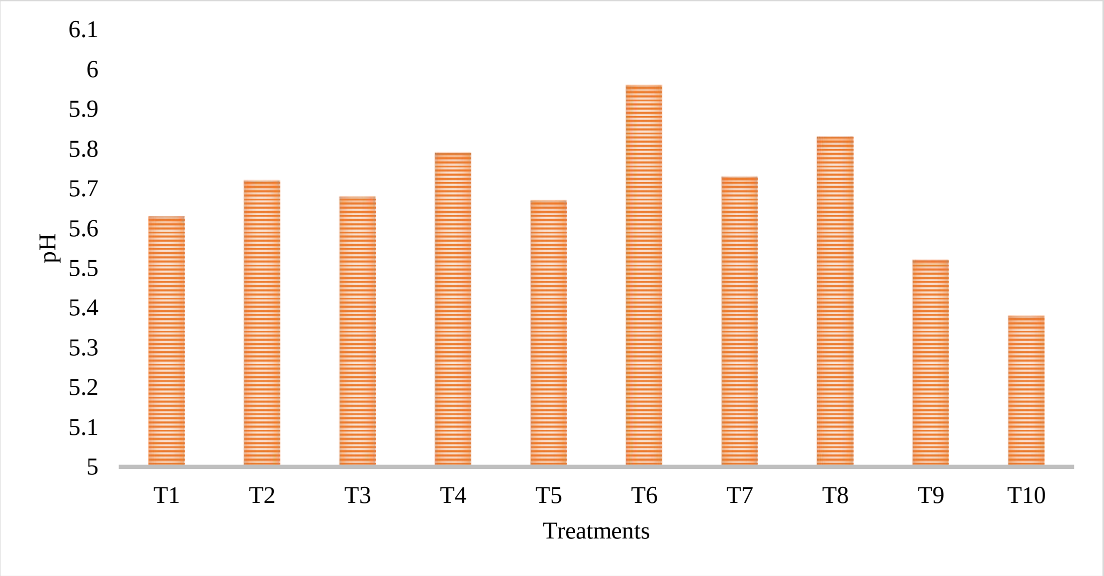

Fig. 43. Influence of organic nano NPK formulation in pH of soil after the experiment

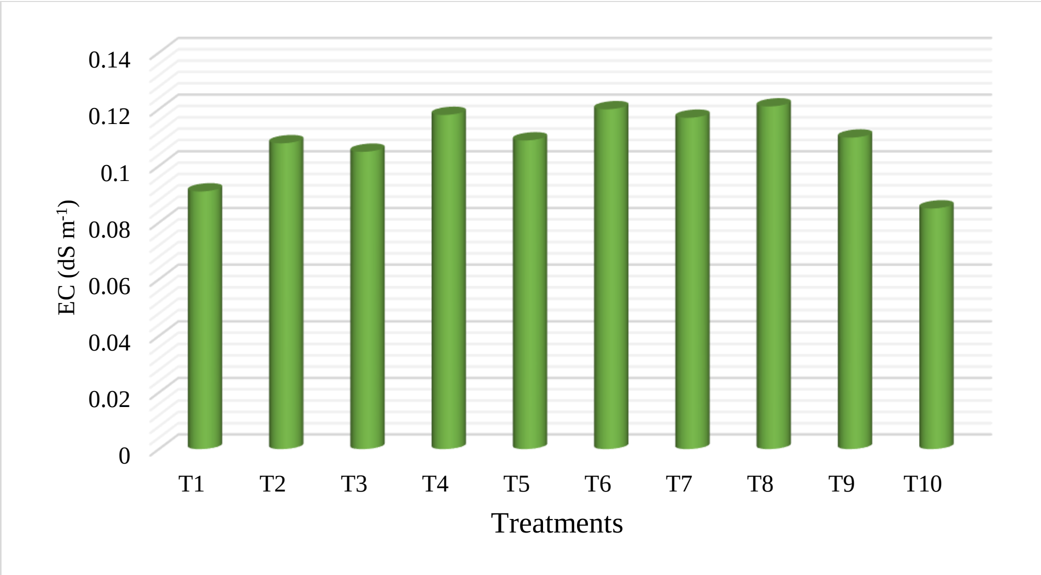

Fig. 44. Influence of organic nano NPK formulation on EC (dS m^{-1}) of soil after the experiment

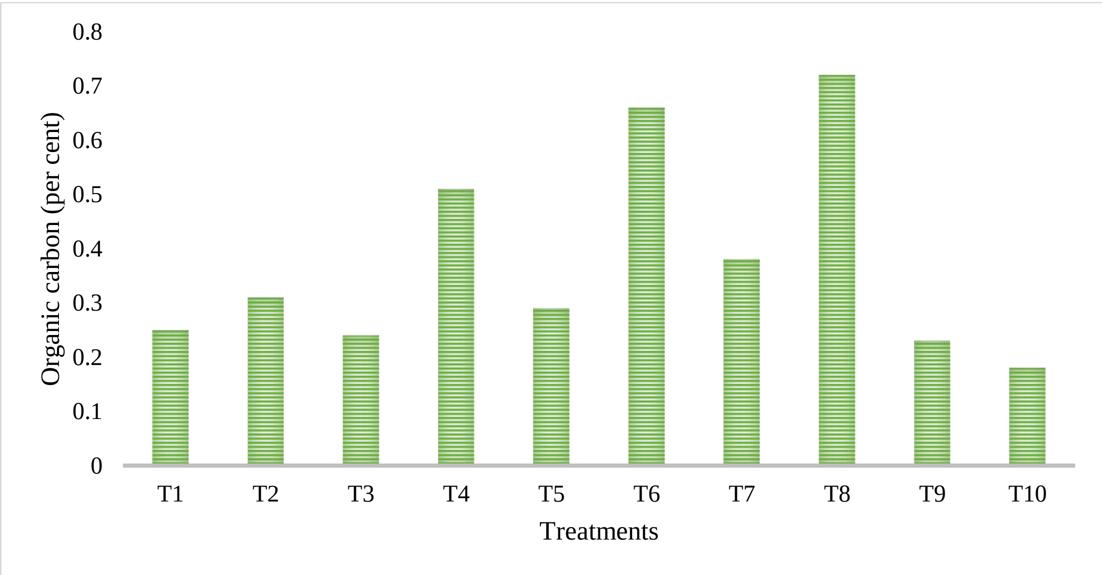

Fig. 45. Influence of organic nano NPK formulation in organic carbon content (%) of the soil after experiment

slightly improved the pH of the soil due to the alkalinity of zeolite. Addition of FYM may also increase the pH of the soil due to the increase in bases by the active degradation of organic matter and suppression of Fe and Al oxides and hydroxides activities. The organic nano NPK significantly influenced the EC of the soil after experiment (Fig. 44). The highest EC was noticed in treatment T_6 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}) which was on par with T_4. Increase in electrical conductivity may attributed to the dissolution of salts and their rapid release from the organic nano NPK into the soil. Rus *et al.* (2004) reported that the application of nano fertilizer can increase the EC of the soil due to its high dissolution rates.

5.3.2.2.2 Organic carbon

A detailed perusal of the soil after the experiment revealed that the treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) registered highest organic carbon content followed by T_6 (Fig. 45). The organic carbon content of organic nano NPK is found to be 2.34 per cent (Table 4). Hence, the application of organic nano NPK and organic amendment (FYM) might have resulted in the increased organic carbon content of the soil. In the characterization study, organic nano NPK indicated the presence of humic acid (19.18 %), fulvic acid (31.54 %) and humin (5.80 %), which might have a positive effect on the organic matter content of the soil. The result is in line with Elisha *et al*. (2014). They pointed out that the application of organic acids based products (Amino acid, gluconic acid and lactic acid) increased the per cent of soil organic carbon.

5.3.2.2.3 Primary nutrients

The primary nutrient content of the soil increased after the harvest (Fig. 46). This might be due to the leftover fertilizer and nano fertilizers in the soil which will hold higher amount of nutrient in the soil. The organic nano NPK resulted in a significant increase in available primary nutrient content of the soil and found to be higher in the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). From the laboratory incubation study, it was observed that the nutrients present in this formulation were available for a longer period. This will maintain the fertility of the soil.

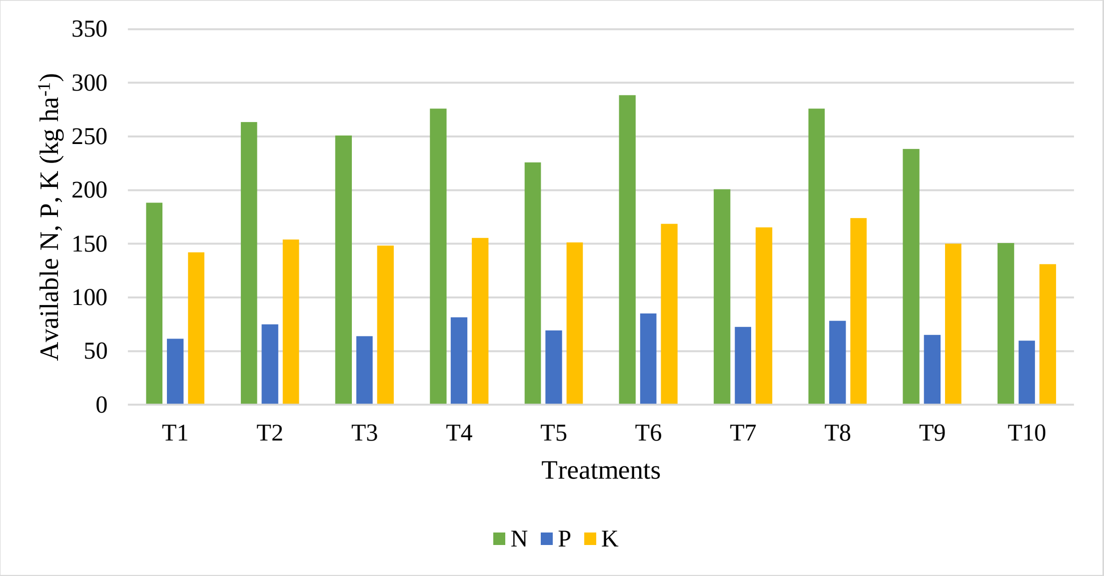

Fig. 46. Influence of organic nano NPK formulation in primary nutrient content (kg ha^{-1}) of the soil after experiment

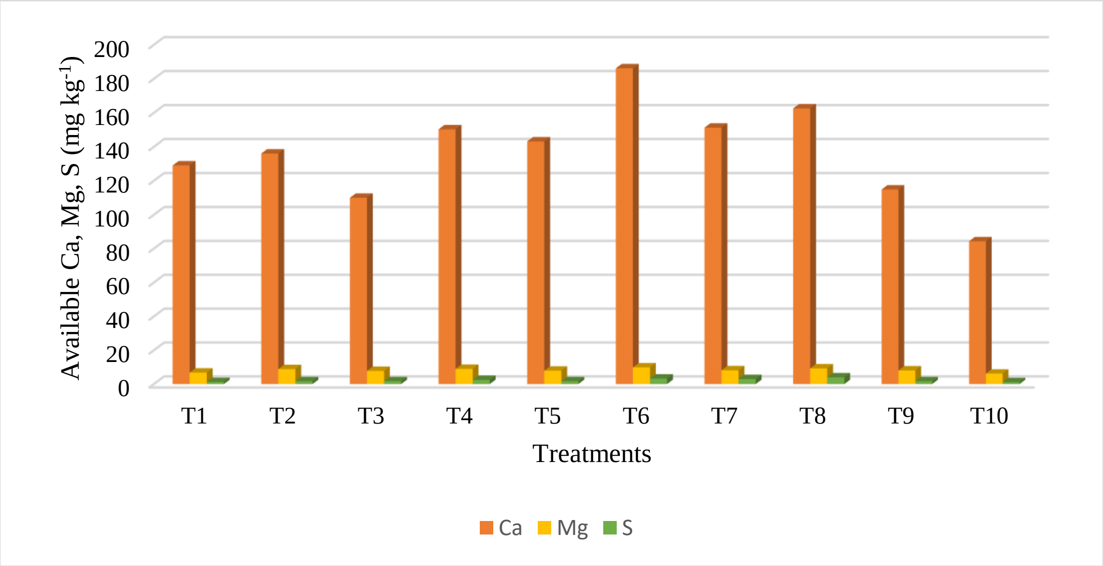

Fig. 47. Influence of organic nano NPK formulation in secondary nutrient content (mg kg^{-1}) of the soil after experiment

Wang *et al*. (2012) in a soil column leaching experiment found that the recovery of nano hydroxyapatite was higher in the leachate with increasing concentration of the humic acid. This will improve the P availability of soil. So it is inferred that the humic acid present in the organic nano NPK might also had improved the nutrient availability to the soil. Treatments with compost or nano NPK fertilizer in saline soil is reported to increase the nutrient content in the soil by increasing the soil microbial activity. Mazur *et al.* (1986) opined that the use of zeolite along with potassium chemical fertilizer recorded the largest amount of potassium in the soil. This may be due to the absorption of potassium on zeolite and reduction in its loss.

5.3.2.2.4 Secondary nutrients

From Table 35, it is evident that the organic nano NPK improved the secondary nutrient content of soil (Fig.47). The Ca and Mg availability was found higher in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and S availability was found higher in treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK). The nano fertilizers can either deliver nutrients to plants or aid in the transport or absorption of nutrients, resulting in improved crop development. The Supapron *et al.* (2002) revealed that the zeolite released Ca and Mg slowly into the soil and increased their availability.

5.3.2.2.5 Micronutrients

Soil micronutrients were found to be increased by the application of organic nano NPK formulation (Fig. 48). The Fe, Zn and B availability was recorded highest by the application of 50 kg ha^{-1} organic nano NPK along with FYM (T_6). The highest iron availability was found on a par with T_8. The Zn availability from treatment T_6 was found on a par with T_7, T_4 and T_8. The highest boron availability was comparable with soil treated with T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK). The nutrient enhanced effect may be due to the slow release characteristics of organic nano NPK and it makes the nutrients more available to the plants. Similar results were obtained for Sheta *et al*. (2003). The zeolite minerals are reported to release Zn and Fe very slowly to the soil due to higher sorption capacity of zeolite.

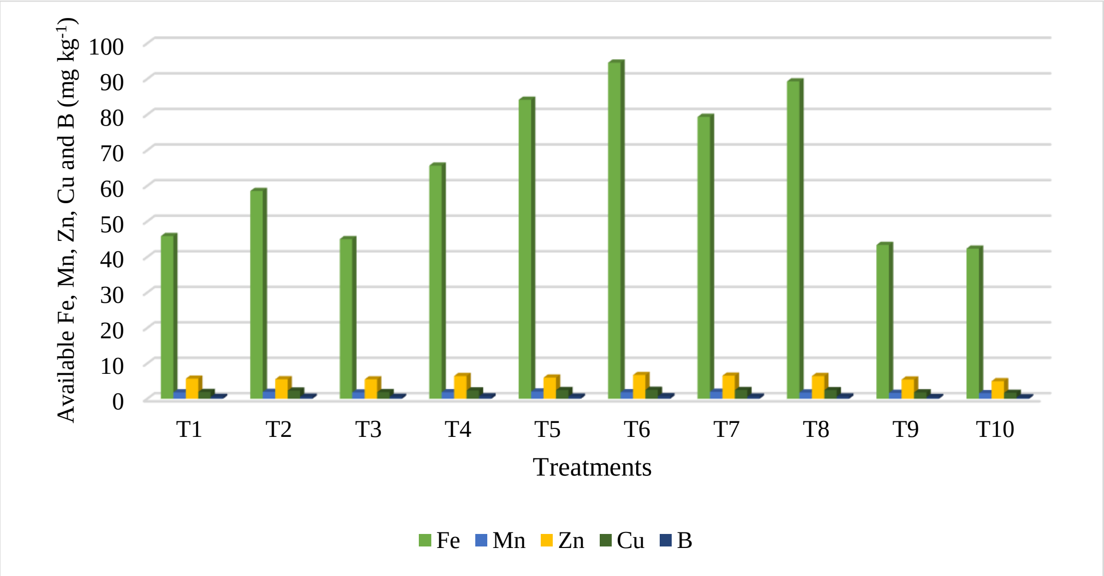

Fig. 48. Influence of organic nano NPK formulation in micronutrient content (mg kg^{-1}) of the soil after experiment

5.3.2.3 Soil biochemical properties

The nutrient status of the soil and microbial activity can be indirectly measured by the soil biochemical properties like dehydrogenase activity and microbial biomass carbon. These parameters act as an indicator of soil health (Adhikari and Ramana, 2019). From this study, organic nano NPK had significantly influenced the microbial biomass carbon and dehydrogenase activity (Fig. 49 and Fig. 50). Both the parameters recorded highest response in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and the highest dehydrogenase activity was found to be on a par with T_4, T_2, T_5, T_8 and T_1. Organic nano NPK is a proteino- lacto-gluconate formulation. Hence, the enhancement in microbial activity might be due to the supply of carbon rich organic acid especially glucose, which is an ideal food for the microbes. Yadav *et al*. (2014) reported that application of zinc oxide nano particles enhanced the soil microbial population, dehydrogenase activity and enzyme activity. Similar results were obtained for Raliya and Tarafdar (2013) and Tarafdar *et al.* (2014).

5.3.3 Economics of cultivation

The organic nano NPK increased the B: C ratio of sesame (Table 38). The highest B: C ratio (1.99) was recorded by the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which might be due to the highest yield of T_6 compared to other treatments. Eventhough the yield of soil test based recommendation was not much pronounced compared to other organic nano NPK treatments, it resulted in a better B: C ratio of 1.90 due to the low cost of chemical inputs and it was comparable with T_7. The advantage of nano fertilizer is that the quantity of fertilizer needed and frequency of application is much lower. This will reduce the input cost and labour cost which will raise the net returns. Nano fertilizer development are still at infancy. More economically benign technologies of nano fertilizer synthesis should be developed to reduce the cost of nano fertilizers.

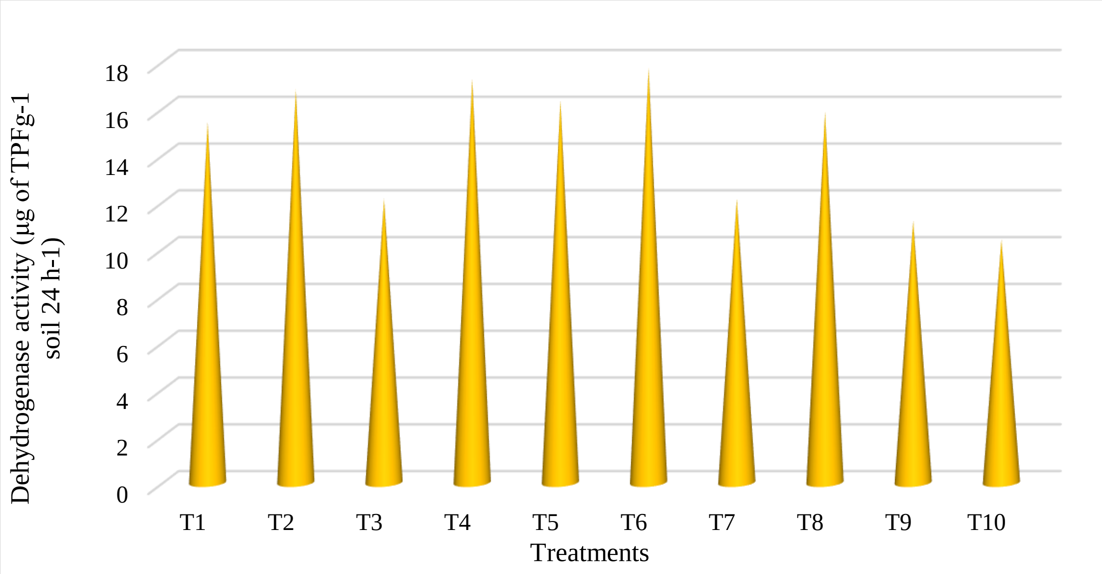

Fig. 49. Influence of organic nano NPK formulation on dehydrogenase activity (µg of TPFg^{-1} soil 24 h^{-1}) of the soil after experiment

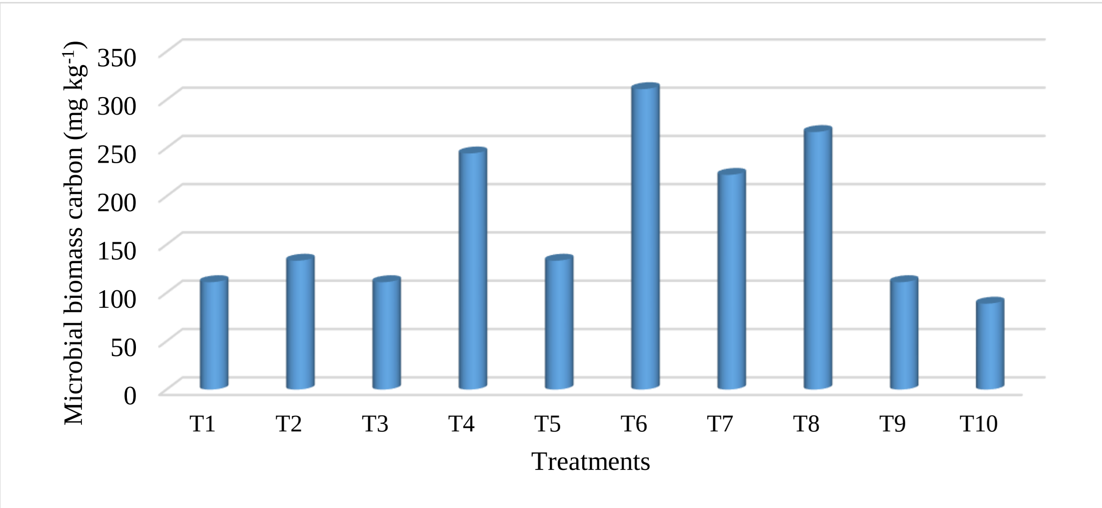

Fig. 50. Influence of organic nano NPK formulation on microbial biomass carbon (mg kg^{-1}) of the soil after experiment

Summary

6. SUMMARY

The study entitled "Effect of soil application of organic nano NPK formulation on growth and yield of sesame (*Sesamum indicum*) in Onattukara (AEU 3)" was conducted at ORARS, Kayamkulam and College of Agriculture, Vellayani during December 2020 to April 2021. The investigation was aimed to characterize the organic nano NPK formulation, to assess the nutrient release pattern under laboratory conditions and to study the effect of soil application of organic nano NPK formulation on crop growth, yield, quality and soil health using sesame as a test crop in Onattukara (AEU 3). 'TAG NANO NPK' is the commercial formulation of organic nano NPK used in this study.

The experiment consisted of three parts. The characterization of organic nano NPK formulation was the first part of this investigation. The second part was the laboratory incubation study to assess the nutrient release pattern. The design of the experiment was CRD with 9 treatments and 3 replications. The treatments applied are soil application of organic nano NPK formulation 25 kg ha^{-1} (T_1), organic nano NPK formulation 25 kg ha^{-1} + FYM 5 t ha^{-1} (T_2), organic nano NPK formulation 25 kg ha^{-1} + 50 per cent of recommended dose of NPK (T_3), organic nano NPK formulation 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent of recommended dose of NPK (T_4), organic nano NPK formulation 50 kg ha^{-1} (T_5), organic nano NPK formulation 50 kg ha^{-1} + FYM 5 t ha^{-1} (T_6), organic nano NPK formulation 50 kg ha^{-1} + 50 per cent of recommended dose of NPK (T_7), organic nano NPK formulation 50 kg ha^{-1} + FYM 5 t ha^{-1} +50 per cent of recommended dose of NPK (T_8) and absolute control (T_9).

The last part of the experiment was the field study to find out the effect of soil application of organic nano NPK formulation on crop growth, yield, quality and soil health using sesame (variety-Thilak) as a test crop in Onattukara (AEU 3). Randomized block design were laid out with 10 treatments (T_1- Soil application of organic nano NPK formulation 25 kg ha^{-1}, T_2 – Soil application of organic nano NPK formulation 25 kg ha^{-1} + FYM 5 t ha^{-1}, T_3 - Soil application of organic nano NPK formulation 25 kg ha^{-1} + 50 per cent of recommended dose of NPK, T_4 - Soil application of organic nano NPK formulation 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent of recommended dose of NPK, T_5 - Soil application of organic nano NPK formulation 50 kg ha^{-1}, T_6 - Soil application of organic nano NPK formulation 50 kg ha^{-1} + FYM 5 t ha^{-1}, T_7 - Soil application of organic nano NPK formulation 50 kg ha^{-1} + 50 per cent of recommended dose of NPK, T_8 - Soil application of organic nano NPK formulation 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent of recommended dose of NPK, T_9 - Soil test based recommendation of NPK + FYM 5 t ha^{-1} and T_{10} - Absolute control) replicated thrice. The salient features of this experiment are summarized below.

PART I

Characterization of organic nano NPK formulation

The particle size of organic nano NPK formulation was found to be 70.44 nm and it had a surface area of 140.31m^2 g^{-1}. The zeta potential of the formulation recorded a highly negative (-64.10 mV) value, which confers its stability against flocculation. The organic nano NPK recorded a basic pH (7.81) with an electrical conductivity of 0.13 dS m^{-1}. Organic carbon content was 2.34 per cent. The organic matter present had 5.80 per cent humin, 19.18 per cent humic acid and 31.54 per cent fulvic acid. The primary nutrient composition of organic nano NPK were 1.96 per cent nitrogen, 1.81 per cent phosphorus and 2.96 per cent potassium. Secondary nutrient contents were 0.32 per cent calcium, 0.29 per cent magnesium and 0.61 per cent sulphur. The micronutrient contents recorded were Fe (398 mg kg^{-1}), Mn (528 mg kg^{-1}), Zn (352 mg kg^{-1}), Cu (98.86 mg kg^{-1}) and B (33.40 mg kg^{-1}). The formulation recorded 248 mg kg^{-1} amino acid.

PART II

Laboratory incubation study

The organic nano NPK released nutrients slowly into the soil. The pH and organic carbon content of the soil increased throughout the incubation study, whereas the electrical conductivity of the soil declined after 30 days of incubation. In general, the primary nutrients increased upto 45^{th} day of incubation. The highest release of P and K were recorded by the application of 50 kg ha^{-1} organic nano NPK, 5 t ha^{-1} FYM and 50 per cent recommended dose of NPK (T_8), whereas N availability was recorded highest in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}).

Secondary nutrient release increased upto 30th day of incubation except for Ca which was available upto 45th day of incubation. The highest release of calcium and sulphur were recorded in treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) whereas, the magnesium availability was registered highest by the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). The nutrient contents were higher in the combined application of organic nano NPK, FYM and chemical fertilizer rather than sole application of organic nano NPK or its combination with chemical fertilizer.

Regarding the micronutrients, the Mn, Zn, Cu and B availability was increased upto 45th day of incubation, whereas iron availability declined after 30th day of incubation. Fe and Zn availability was recorded highest in treatments applied with organic nano NPK 50 kg ha^{-1} and FYM t ha^{-1} (T_6). The combined application of organic nano NPK, FYM and 50 per cent recommended dose of NPK resulted in higher Mn (T_8), Cu (T_8) and B (T_4) availability.

PART III

Field Experiment

The growth parameters like plant height, height upto first capsule, primary branches per plant, leaf area per plant were significantly influenced by the application of organic nano NPK formulation. Tallest sesame plants were produced in the plots which received organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}(T_6). The treatment T_3 (organic nano NPK 25 kg ha^{-1} + 50 per cent recommended dose of NPK) produced sesame capsules from the lowest height (41.77 cm) and treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded the highest value (57 cm). The sole application of organic nano NPK 50 kg ha^{-1} (T_5) had resulted in more number of primary branches per plant throughout the experiment. The leaf area increased as the plant matured. The treatment T_5 (organic nano NPK 50 kg ha^{-1}) resulted in higher leaf area at 30 DAS and treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) registered significantly higher leaf area per plant at 60 DAS and at harvest.

The root spread was also found higher in plot which received 50 kg organic nano NPK and 5 t ha^{-1} FYM (T_6) throughout the observation period. The treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) recorded significantly higher root volume at 30 DAS whereas, treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) was found to be significantly superior at 60 DAS and at harvest. Similar trend of root volume was observed in dry matter production also, which implies that improvements in root characters enhanced the dry matter production by the increased uptake of nutrients.

The organic nano NPK had significant influence on yield and yield characters of sesame. The sesame plants flowered earlier and 50 per cent plants flowered in short time by the application of treatments with organic nano NPK, eventhough the results were found insignificant. The organic nano NPK did not produce any significant difference from soil test based application of NPK in case of crop maturity. Number of capsules per plant and number of seeds per capsule was recorded highest in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) followed by T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK). Thousand seed weight of sesame was maximum in treatment with organic nano NPK 50 kg ha^{-1} (T_5) and was comparable with T_6, T_7 and T_4. Application of organic nano NPK 50 kg ha^{-1} along with FYM 5 t ha^{-1} increased the yield of sesame by 42 per cent compared to control. This treatment (T_6) was significantly superior than all other treatments. The treatment T_5 (organic nano NPK 50 kg ha^{-1}) recorded highest bhusa yield followed by T_6.

The quality parameters of the sesame were also found to be enhanced by the application of organic nano NPK. Oil content was registered higher in treatment T_6 followed by T_8. The higher grain protein content was recorded by the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was on par with T_8 and T_7.

The organic nano NPK increased the uptake of major nutrients and micronutrients. The treatment T_4 (organic nano NPK 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) resulted in significantly higher N uptake and was found to be on par with T_6 whereas, P and K uptake was registered higher in treatment T_6 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1}) and P uptake was comparable with

T_4. Regarding secondary nutrient uptake, Ca and S uptake was showed maximum in the treatment T_6 and was found to be on par with T_4 whereas, the magnesium uptake was found higher in treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) which was comparable with T_6. The highest uptake of all micronutrients were recorded in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which were comparable with T_4 (Fe, Mn, B), T_7 (Fe) and T_8 (Fe, Zn, Cu, B).

Soil analysis after the experiment showed that organic nano NPK failed to register any significant results on bulk density of the soil. The pH and EC of the soils which received the organic nano NPK treatments were increased. The plots which received treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed significantly higher pH due to the basic nature of the organic nano NPK. The EC was higher in treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) and was found to be on par with T_6 and T_4. The organic carbon content also registered higher in treatment T_8 followed by T_6.

The primary nutrient availability of the soil was positively affected by the application of organic nano NPK. The nitrogen availability was found to be significantly higher in T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was on par with T_8 and T_4. The highest P content in soil was recorded from treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and was significantly superior to all other treatments. The highest K content was recorded from the plot which received treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} and 50 per cent recommended dose of NPK) and was found to be on par with T_6.

Significantly higher Ca and Mg availability was registered in plot which received the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and was on par with T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK). Sulphur availability was found to be significantly higher in treatment T_8 (organic nano NPK 50 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK). The highest iron availability was found in plot that received treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) which was found to be on par with T_8. The treatment

T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) recorded the higher Zn availability which was comparable with T_7, T_4 and T_8. The highest boron was available from the plots which received the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and was found to be on par with $T_{4.}$

Soil biochemical properties were also found to be enhanced by the application of organic nano NPK. The treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) showed highest dehydrogenase activity and was comparable with T_4, T_2, T_5, T_8 and $T_{1.}$ Microbial biomass carbon was found high in the treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}) and it was significantly superior to all other treatments. From the economic analysis, it was found that application of organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1} was economically excellent treatment with a B: C ratio of 1.99.

From the characterization study, it was obvious that the organic nano NPK had a particle size in nano scale range and possessed higher surface area. It is a complete nutritional organic fertilizer which contains major nutrients, micronutrients, amino acids and humic substances. The incubation study concluded that the nutrient release in organic nano NPK was slower and longer. Nutrient availability was increased upto 45th day of incubation. From the field study, it is evident that the combined soil application of organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1} as basal dose improved the physical, chemical and biochemical properties of the soil and enhanced growth, yield and quality of sesame in Onattukara. Hence it was concluded that the soil application of organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1} as basal can be an economically and environmentally sustainable substitute for chemical fertilizers in sesame grown in constrained loamy sand soils of Onattukara.

FUTURE LINE OF WORK

- To standardize the recommendation rate of various nano fertilizers including organic nano NPK (TAG NANO NPK) for various crops and locations in Kerala.
- To study the long term effect of organic nano NPK (TAG NANO NPK) on soil physical properties and nutrient dynamics in soil.

- The effect of combined use of organic nano NPK (TAG NANO NPK) and bio-fertilizers should be studied.
- Effect of organic nano NPK (TAG NANO NPK) on stress alleviation should be studied.

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EFFECT OF SOIL APPLICATION OF ORGANIC NANO NPK FORMULATION ON GROWTH AND YIELD OF SESAME (*Sesamum indicum*) IN ONATTUKARA (AEU 3)

by

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ABSTRACT

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ABSTRACT

The study entitled "Effect of soil application of organic nano NPK formulation on growth and yield of sesame (*Sesamum indicum*) in Onattukara (AEU 3)" was conducted at ORARS, Kayamkulam and College of Agriculture, Vellayani, during December 2020 to April 2021. This investigation aimed to characterize the organic nano NPK formulation, to assess the nutrient release pattern under laboratory conditions and to study the effect of soil application of organic nano NPK formulation on crop growth, yield, quality and soil health using sesame as a test crop in Onattukara (AEU 3). 'TAG NANO NPK' is the commercial formulation of organic nano NPK used in this study.

The experiment consisted of three parts. Characterization of organic nano NPK formulation was the first part of this investigation. The particle size of organic nano NPK formulation confirmed the nanoscale dimension (70.44 nm) with higher surface area (140.31 m^2 g^{-1}) and stable zeta potential (-64.10 mV). The organic nano NPK recorded a basic pH (7.81) with an electrical conductivity of 0.13 dS m^{-1}. The presence of major nutrients (1.96 % N, 1.81% P, 2.96 % K, 0.32% Ca, 0.29% Mg and 0.61 % S), micronutrients (398 mg kg^{-1} Fe, 528 mg kg^{-1} Mn, 352 mg kg^{-1} Zn, 98.86 mg kg^{-1} Cu and 33.40 mg kg^{-1} B), organic carbon (2.34 %), organic matter fractions (5.80 % humin, 19.18% humic acid and 31.54 % fulvic acid) and amino acids (248 mg kg^{-1}) were determined.

The second part was the laboratory incubation study to assess the nutrient release pattern. The design of the experiment was CRD with 9 treatments and 3 replications. The treatments applied were soil application of organic nano NPK formulation 25 kg ha^{-1} (T_1), organic nano NPK formulation 25 kg ha^{-1} + FYM 5 t ha^{-1} (T_2), organic nano NPK formulation 25 kg ha^{-1} + 50 per cent of recommended dose of NPK (T_3), organic nano NPK formulation 25 kg ha^{-1} + FYM 5 t ha^{-1} + 50 per cent of recommended dose of NPK (T_4), organic nano NPK formulation 50 kg ha^{-1} (T_5), organic nano NPK formulation 50 kg ha^{-1} + FYM 5 t ha^{-1} (T_6), organic nano NPK formulation 50 kg ha^{-1} + 50 per cent of recommended dose of NPK (T_7), organic nano NPK formulation 50 kg ha^{-1} + FYM 5 t ha^{-1} +50 per cent of recommended dose of NPK (T_8)

and absolute control (T_9). The pH and organic carbon content of the soil increased throughout the incubation study, whereas the electrical conductivity of the soil declined after 30 days of incubation. In general, major and micronutrient availability was increased upto 45th day of incubation except for Mg, S and Fe whose availability was reduced after 30th day of incubation. The treatment T_8 (organic nano NPK 50 kg ha^{-1}+ FYM 5 t ha^{-1} + 50 per cent recommended dose of NPK) showed highest availability of major nutrients except N and Mg, which were more available in treatment T_6 (Organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). Among micronutrients, Fe and Zn availability was recorded highest in treatment T_6 (organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}). The combined application of organic nano NPK, FYM and 50 per cent recommended dose of NPK resulted in higher Mn (T_8), Cu (T_8) and B (T_4) availability.

The third part of the experiment was the field study. It was designed as randomized blocks with 10 treatments replicated thrice. The treatments consisted of 2 levels of organic nano NPK (25 kg ha^{-1} and 50 kg ha^{-1}) with FYM (T_2 and T_6) and without FYM (T_1 and T_5) and combination of organic nano NPK (25 kg ha^{-1} and 50 kg ha^{-1}) and 50 per cent recommended dose of NPK with FYM (T_4 and T_8) or without FYM (T_3 and T_7) along with soil test based recommendation of NPK and FYM (T_9) and absolute control (T_{10}).

The growth and yield parameters of sesame *viz.,* plant height, height upto first capsule, primary branches per plant, leaf area per plant, root spread, root volume, number of capsules per plant, number of seeds per capsule, thousand seed weight, seed yield and bhusa yield were significantly influenced by the application of organic nano NPK. Application of organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1} (T_6) resulted in 42 per cent yield increase compared to absolute control. Oil content and grain protein content were also enhanced by the organic nano NPK application. Uptake of major nutrients and micronutrients were higher in treatment T_6(organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1}), whereas combined application of organic nano NPK, FYM and 50 per cent recommended dose of NPK resulted in higher N (T_4), Ca (T_8) and S (T_8) uptake. The soil was analysed after the crop harvest to determine the physical, chemical and biochemical properties of the soil and recorded a significant influence of organic nano

NPK in these parameters. The organic nano NPK showed a higher B:C ratio (1.99) against the control plot (1.67).

From the characterization study, it was obvious that the organic nano NPK (TAG NANO NPK) had a particle size in nano scale range (70.44 nm) and possessed higher surface area (140.31 m^2g^{-1}). It is a complete nutritional organic fertilizer which contains major nutrients, micronutrients, amino acids and humic substances. The incubation study concluded that the nutrient release in organic nano NPK was slower and longer. Nutrient availability was increased upto 45th day of incubation. From the field study, it was evident that the combined soil application of organic nano NPK 50 kg ha^{-1} and FYM 5 t ha^{-1} as basal dose improved the physical, chemical and biochemical properties of the soil and enhanced growth, yield and quality of sesame in Onattukara. From this experiment, it was concluded that the soil application of organic nano NPK in the form 'TAG NANO NPK' 50 kg ha^{-1} and FYM 5 t ha^{-1} can be an economically and environmentally sustainable substitute for chemical fertilizers in sesame grown in the constrained loamy sand soils of Onattukara.

സംഗ്രഹം

"ഓണാട്ടുകര മേഖലയിൽ എള്ളിന്റെ വളർച്ചയിലും വിളവിലും ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷന്റെ മണ്ണ് പ്രയോഗത്തിന്റെ പ്രഭാവം" എന്ന തലക്കെട്ടിലുള്ള പഠനം 2020 ഡിസംബർ മുതൽ 2021 ഏപ്രിൽ വരെയുള്ള കാലയളവിൽ ഓണാട്ടുകര മേഖല കാർഷിക ഗവേഷണ കേന്ദ്രത്തിലും, വെള്ളായണി കാർഷിക കോളേജിലുമായി നടത്തുകയുണ്ടായി. ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷന്റെ സവിശേഷത, ലബോറട്ടറി സാഹചര്യങ്ങളിൽ പോഷകങ്ങളുടെ റിലീസ് രീതി വിലയിരുത്തുക, ഓണാട്ടുകരയിൽ എള്ള് പരീക്ഷണ വിളയായി ഉപയോഗിച്ച് വിളയുടെ വളർച്ച, വിളവ്, ഗുണനിലവാരം, മണ്ണിന്റെ ആരോഗ്യം എന്നിവയിൽ ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷന്റെ മണ്ണ് പ്രയോഗത്തിന്റെ സ്വാധീനം എന്നിവ പഠിക്കാൻ ഈ അന്വേഷണം ലക്ഷ്യമിടുന്നു. ഈ പഠനത്തിൽ ഉപയോഗിച്ച ഓർഗാനിക് നാനോ എൻപികെ യുടെ വാണിജ്യ രൂപമാണ് 'ടാഗ് നാനോ എൻപികെ'.

പരീക്ഷണം മൂന്ന് ഭാഗങ്ങളായിരുന്നു. ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷന്റെ സ്വഭാവം ഈ അന്വേഷണത്തിന്റെ ആദ്യ ഭാഗമായിരുന്നു. ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷൻ ഉയർന്ന ഉപരിതല വിസ്തീർണ്ണവും സ്ഥിരതയുള്ള സീറ്റ പൊട്ടൻഷ്യലും ഉള്ള നാനോ സ്കെയിൽ അളവ് രേഖപ്പെടുത്തി. പ്രധാന പോഷകങ്ങളുടെയും സൂക്ഷ്മ പോഷകങ്ങളുടെയും സാന്നിധ്യവും രേഖപ്പെടുത്തി.

പോഷകങ്ങളുടെ റിലീസ് രീതി വിലയിരുത്തുന്നതിനുള്ള ലബോറട്ടറി ഇൻകുബേഷൻ പഠനമായിരുന്നു രണ്ടാം ഭാഗം. ഇൻകുബേഷൻ പഠനത്തിലുടനീളം മണ്ണിന്റെ പി. എച്ച്, ഓർഗാനിക് കാർബൺ എന്നിവ വർദ്ധിച്ചു. എന്നാൽ 30 ദിവസത്തെ ഇൻകുബേഷൻ കഴിഞ്ഞ് മണ്ണിന്റെ വൈദ്യുതചാലകത കുറഞ്ഞു. പൊതുവേ, ഇൻകുബേഷന്റെ 45 ദിവസം വരെ പോഷകങ്ങളുടെയും ലഭ്യത വർദ്ധിച്ചു. 'ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷൻ ഹെക്ടറിന് 50 കി. ഗ്രാം, കാലിവളം ഹെക്ടറിന് 5 ടൺ, എൻപികെയുടെ ശുപാർശ ഡോസിന്റെ 50 ശതമാനം' എന്ന വളപ്രയോഗം പ്രധാന പോഷകങ്ങളുടെ ഉയർന്ന ലഭ്യത കാണിച്ചു. അതേസമയം നൈട്രജൻ, മഗ്നീഷ്യം എന്നിവ കൂടുതൽ ലഭ്യമായത് 'ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷൻ ഹെക്ടറിന് 50 കി. ഗ്രാം, കാലിവളം ഹെക്ടറിന് 5 ടൺ' എന്ന വളപ്രയോഗത്തിൽ ആയിരുന്നു. സൂക്ഷ്മപോഷകങ്ങളിൽ ഇരുമ്പ്, സിങ്ക് എന്നിവയുടെ ലഭ്യത 'ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷൻ ഹെക്ടറിന് 50 കി. ഗ്രാം, കാലിവളം ഹെക്ടറിന് 5 ടൺ' എന്ന വളപ്രയോഗത്തിലാണ് ഏറ്റവും കൂടുതൽ രേഖപ്പെടുത്തിയത്. ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷൻ, കാലിവളം, എൻപികെയുടെ ശുപാർശ ഡോസിന്റെ 50 ശതമാനം എന്നിവയുടെ സംയോജിത പ്രയോഗം മാംഗനീസ്, ചെമ്പ്, ബോറോൺ എന്നിവയുടെ ഉയർന്ന ലഭ്യതയ്ക്ക് കാരണമായി.

പരീക്ഷണത്തിന്റെ മൂന്നാം ഭാഗം പാടത്തുള്ള പരീക്ഷണം ആയിരുന്നു. ചെടിയുടെ ഉയരം, ആദ്യത്തെ കത്തിക്ക വരെയുള്ള ഉയരം, ഓരോ ചെടിയുടെയും പ്രാഥമിക ശാഖകൾ, ഓരോ ചെടിയുടെയും ഇലയുടെ

വിസ്തീർണ്ണം, വേരിന്റെ വ്യാപനം, വേരിന്റെ വ്യാപ്തം, ഓരോ ചെടിയുടെയും കത്തിക്കകളുടെ എണ്ണം, കത്തിക്കയിലെ വിത്തുകളുടെ എണ്ണം, ആയിരം വിത്തിന്റെ ഭാരം, വിത്ത് വിളവ്, ഭൂസ വിളവ് എന്നിവയെ ഓർഗാനിക് നാനോ എൻപികെയുടെ പ്രയോഗം ഗണ്യമായി സ്വാധീനിച്ചു. ഓർഗാനിക് നാനോ എൻപികെ ഹെക്ടറിന് 50 കി. ഗ്രാം, കാലിവളം ഹെക്ടറിന് 5 ടൺ എന്നിവയുടെ പ്രയോഗം സമ്പൂർണ്ണ നിയന്ത്രണവുമായി താരതമ്യം ചെയ്യുമ്പോൾ 42 ശതമാനം വിത്തിന്റെ വിളവ് വർദ്ധിപ്പിച്ചു. ഓർഗാനിക് നാനോ എൻപികെയുടെ പ്രയോഗം എണ്ണയുടെ അംശവും ധാന്യ പ്രോട്ടീന്റെ അളവും മെച്ചപ്പെടുത്തി. ഓർഗാനിക് നാനോ എൻപികെ ഹെക്ടറിന് 50 കി. ഗ്രാം, കാലിവളം ഹെക്ടറിന് 5 ടൺ എന്നിവയുടെ പ്രയോഗത്തിൽ ചെടികളിൽ പ്രധാന പോഷകങ്ങളുടെയും സൂക്ഷ്മ പോഷകങ്ങളുടെയും അളവ് കൂടുതലായി കാണപ്പെട്ടു, അതേസമയം കാൽസ്യം, സൾഫർ എന്നിവയുടെ ലഭ്യത 'ഓർഗാനിക് നാനോ എൻപികെ ഫോർമുലേഷൻ ഹെക്ടറിന് 50 കി. ഗ്രാം, കാലിവളം ഹെക്ടറിന് 5 ടൺ, എൻപികെയുടെ ശുപാർശ ഡോസിന്റെ 50 ശതമാനം' എന്ന വളപ്രയോഗത്തിലാണ് കൂടുതൽ. വിളവെടുപ്പിനുശേഷം മണ്ണിന്റെ ഭൗതികവും രാസപരവും ജൈവ- രാസപരവുമായ ഗുണങ്ങൾ നിർണ്ണയിക്കാൻ മണ്ണ് വിശകലനം ചെയ്യുകയും ഈ പാരാമീറ്ററുകളിൽ ഓർഗാനിക് നാനോ എൻപികെ ഗണ്യമായ സ്വാധീനം രേഖപ്പെടുത്തുകയും ചെയ്തു.

പ്രസ്തുത പഠനത്തിൽ നിന്ന്, ഓർഗാനിക് നാനോ എൻപികെയ്ക്ക് (ടാഗ് നാനോ എൻപികെ) നാനോ സ്കെയിൽ വലിപ്പമാണെന്നും ഉയർന്ന ഉപരിതല വിസ്തീർണ്ണം ഉള്ളതായും വ്യക്തമായിരുന്നു. പ്രധാന പോഷകങ്ങൾ, സൂക്ഷ്മ പോഷകങ്ങൾ, അമിനോ ആസിഡുകൾ, ഹ്യൂമിക് പദാർത്ഥങ്ങൾ എന്നിവ അടങ്ങിയ സമ്പൂർണ പോഷക ജൈവ വളമാണിത്. ഓർഗാനിക് നാനോ എൻപികെയിലെ പോഷകങ്ങളുടെ റിലീസ് മന്ദഗതിയിലുള്ളതും ദൈർഘ്യമേറിയതുമാണെന്ന് ഇൻകുബേഷൻ പഠനത്തിൽ നിന്ന് വ്യക്തമായി. ഇൻകുബേഷൻ കഴിഞ്ഞ് 45 ദിവസം വരെ പോഷക ലഭ്യത വർദ്ധിച്ചു. പാടത്തുള്ള പരീക്ഷണത്തിൽ നിന്ന്, 'ഓർഗാനിക് നാനോ എൻപികെ ഹെക്ടറിന് 50 കി. ഗ്രാം, കാലിവളം ഹെക്ടറിന് 5 ടൺ' എന്നിവയുടെ സംയുക്ത മണ്ണ് പ്രയോഗം മണ്ണിന്റെ ഭൗതികവും രാസപരവും ജൈവ-രാസപരവുമായ ഗുണങ്ങൾ മെച്ചപ്പെടുത്തുകയും എള്ളിന്റെ വളർച്ചയും വിളവും ഗുണനിലവാരവും മെച്ചപ്പെടുത്തുകയും ചെയ്തു. ഈ പരീക്ഷണത്തിൽ നിന്ന്, ഓർഗാനിക് നാനോ എൻപികെ 'ടാഗ്, നാനോ എൻപികെ' എന്ന രൂപത്തിൽ ഹെക്ടറിന് 50 കി. ഗ്രാം, കാലിവളം ഹെക്ടറിന് 5 ടൺ എന്നിവ മണ്ണിൽ പ്രയോഗിക്കുന്നത് ഓണാട്ടുകരയിൽ എള്ളിനു ഉപയോഗിക്കുന്ന രാസവളങ്ങൾക്ക് സാമ്പത്തികമായും പാരിസ്ഥിതികമായും സുസ്ഥിരമായ പകരമാകുമെന്നാണ് നിഗമനം.

Appendices

APPENDIX – I

Weather parameters during the cropping period (13/12/2020 -20/03/2021)

Standard week	Temperature (°C)		RH (%)	Rainfall (mm)
	Maximum	Minimum		
51	33.70	22.28	78.14	41.3
52	32.40	21.28	77.92	0.0
53	32.00	22.40	75.20	0.0
1	32.00	23.00	89.00	23.0
2	30.85	21.43	90.14	55.1
3	29.71	23.57	92.71	34.5
4	32.43	23.00	88.86	9.1
5	33.86	21.71	81.00	0.0
6	34.28	20.57	71.00	0.0
7	33.86	20.14	64.14	0.0
8	34.00	20.00	69.93	10.0
9	34.14	19.71	70.64	0.0
10	32.57	19.71	72.93	0.0
11	34.14	17.57	74.85	10.0
12	35.71	20.57	74.71	0.0

APPENDIX – II

Correlation analysis of yield with plant nutrient uptake by sesame (n=12)

	Yield	N	p	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
Yield	1											
N	0.674*	1										
P	0.899*	0.804*	1									
K	0.890*	0.849*	0.972*	1								
Ca	0.854*	0.799*	0.985*	0.979*	1							
Mg	0.885*	0.470^{NS}	0.828*	0.761*	0.788*	1						
S	0.846*	0.895*	0.947*	0.948*	0.951*	0.754*	1					
Fe	0.897*	0.787*	0.979*	0.962*	0.979*	0.864*	0.960*	1				
Mn	0.886*	0.877*	0.975*	0.983*	0.980*	0.784*	0.976*	0.978*	1			
Zn	0.898*	0.744*	0.962*	0.951*	0.978*	0.864*	0.953*	0.987*	0.965*	1		
Cu	0.924*	0.773*	0.985*	0.965*	0.976*	0.877*	0.957*	0.991*	0.973*	0.985*	1	
B	0.946	0.809*	0.965*	0.973*	0.957*	0.843*	0.936*	0.975*	0.980*	0.963*	0.970*	1

* - Significant at 5% level, NS- Not significant