MATRIX BASED SLOW RELEASE FERTILIZER FOR INCREASING NUTRIENT USE EFFICIENCY IN THE ONATTUKARA SANDY PLAINS

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"MATRIX BASED SLOW RELEASE FERTILIZER FOR INCREASING NUTRIENT USE EFFICIENCY IN THE ONATTUKARA SANDY PLAINS"** 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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CERTIFICATE

Certified that this thesis entitled **"MATRIX BASED SLOW RELEASE FERTILIZER FOR INCREASING NUTRIENT USE EFFICIENCY IN THE ONATTUKARA SANDY PLAINS"** is a record of research work done independently by Ms. Adithya G. Raj. (2017-11-123) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	Per cent
$\mu g\ g^{-1}$	microgram per gram
B	Boron
B:C	Benefit : Cost
Ca	Calcium
CD	Critical Difference
cm	Centimetre
CRD	Completely Randomized Design
Cu	Copper
cv	Cultivar
$dS\ m^{-1}$	deci Siemens per metre
et al	Co- authors/ co- workers
Fig	Figure
FYM	Farm Yard Manure
g	Gram
g $plant^{-1}$	Gram per plant
ha	Hectare
K	Potassium
KAU	Kerala Agricultural University
kg ha^{-1}	kilogram per hectare
KSPB	Kerala State Planning Board
MAP	Months after planting
Mg	Magnesium
mg $100g^{-1}$	milligram per 100 gram
mg kg^{-1}	milligram per kilogram
Mn	Manganese
N	Nitrogen

OC	Organic Carbon
P	Phosphorous
pH	Negative logarithm of H^+ ion concentration
POP	Package of practices
S	Sulphur
TSS	Total soluble solids
viz.,	Namely
Zn	Zinc

INTRODUCTION

1. INTRODUCTION

Onattukara sandy plain, a unique landscape which is surrounded by Neendakara in the south, Edanad in the east, Arabian sea in the west and Thottapally spillway in the north, spreads over an area of 40495 ha and is classified as AEU 3 of the state (Rajasekharan *et al.,* 2013). The soils of the Onattukara sandy plain exhibit wide spatial variability in their properties. These soils are sandy loam with poor organic matter, CEC and nutrient holding capacity. They also have poor physical, chemical and biological properties. Excess levels of phosphorus and wide spread deficiencies of calcium, magnesium, boron and zinc are the major limitations to crop production in this region (Mini and Mathew, 2015).

In Onattukara sandy plains, major share of applied nutrients are lost through leaching because of poor nutrient and water holding capacity of this soil leading to nutrient deficiencies. To obtain higher yield, farmers mostly apply higher amount of fertilizers than the actual crop requirement and this may cause serious environmental hazards like eutrophication, soil acidity, ground water pollution, nitrate toxicity etc. Increasing nutrient use efficiency is the only solution for obtaining profitable yield with lesser amount of fertilizers. Balanced nutrition of crops with optimum quantity of fertilizers through correct method of application is the key in enhancing nutrient use efficiency of Onattukara sandy plains. It has been realized that excessive use of inorganic fertilizers are not suitable for any farming practice from both economic as well as ecological point of view (Singh *et al.*, 2010).This creates an alarming situation indicating an urgent need for improving efficiency of chemical fertilizers by slow release and customized fertilizers.

The use of slow release/ controlled release and other customized fertilizer formulations have been reported for many crops like rice (Dahiya *et al.*, 2004) and tomato (Montemurro, 2005). Most of the commercially available coating materials are non-degradable, costly and unfriendly to the environment. Recently a new group of slow release fertilizer formulation was developed by entrapping the chemical fertilizers in a base material called matrix. These matrices can be developed out of inorganic and organic sources. Most of these formulations are based on expensive chemicals, so it is not easily accessible by Indian farmers (Singh *et al.*, 2012). In this context the matrix based fertilizers developed out of locally available materials are relevant.

The matrix based fertilizer technology is a need based technology for increasing the nutrient use efficiency of N and K fertilizers especially for easily drained soils. These matrix based fertilizer formulations are capable of releasing nutrients at a rate comparable to plant uptake and help to reduce nutrient leaching (Entry and Sojka, 2007).

It has been reported that chemical fertilizers entrapped in organic matrix containing cow dung, clay soil, neem leaves powder and acacia gum prepared in the form of super granules enhanced growth, productivity and yield in rice and Indian mustard (Singh and Sharma, 2011). Organic matrix itself acts as a nutrient source in soil and they enhance the efficiency of chemical fertilizers due to higher nutrient holding and slow releasing nature. Agro waste materials can increase the water holding capacity of soil and are bio degradable. They can also be used as a medium for quality seedling production in portrays. Thus matrix based fertilizers offer an economically attractive and ecologically sound alternative to the chemical fertilizers. Hence these organic matrix based slow release fertilizer can be a low cost technology to optimize the fertilizer use efficiency and productivity of Onattukara sandy plains.

Research findings had shown that organic matrix based slow release technology could effectively sustain supply of nutrients for a prolonged time and minimize economic loss and adverse effects on the environment. Hence the present study has been undertaken to develop low cost sustainable organic matrix entrapped slow release fertilizers using various local biodegradable agro waste materials like rice husk ash, clay, cow dung, rice husk, coir pith compost, vermicompost and neem cake as matrix and to assess the effects of this slow release fertilizers in increasing nutrient use efficiency in the sandy loam soils of Onattukara using tomato as test crop. This study was conducted with the following objective.

"To develop low-cost sustainable matrix based slow release fertilizer using local biodegradable agro waste as matrix and to evaluate the effect of this slow release fertilizer in increasing nutrient use efficiency in the sandy loam soils of Onattukara."

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Agriculture is the backbone of Indian economy and 60% of the Indian population depends on agriculture. Fertilizers contribute the major source of nutrients for crop production. Due to urbanization the area under crop production is decreasing year by year and the nutrient load per unit area is increasing. Sims (1998) forecasted possible environmental problems associated with the excessive application of fertilizers. Surface runoff and leaching loss contribute to the accumulation of NPK fertilizers in the surface water bodies and also leads to the ground water pollution.

Nutrient recovery from fertilizers depends on crop species, nutrient management (Bock and Hergert, 1991) and nutrient sources (Dilz, 1988). Inspite of the significant developments in the crop production, the nutrient use efficiency remained low for N, P and K. This causes severe environmental and health issues *viz.*, eutrophication, soil acidification, ground water pollution and various diseases. Eutrophication is the accumulation of excess quantities of nitrates and phosphates and algal bloom is the accelerated growth of algae in the surface water bodies. The excessive load of fertilizers also raised the cost of cultivation.

Therefore, there is an urgent need to develop some technology which can reduce the cost and can increase the yield and nutrient use efficiency in a sustainable way. The application of slow release and customized fertilizers have been reported as increasing nutrient use efficiency in rice (Dahiya *et al.*, 2004), potato (Prugar and Hadacova, 1996), tomato (Montemurro, 2005), soy bean (Kaushal *et al.*, 2006), beans (El Tohamy *et al.*, 2009), grape, mango, banana, date palm (Hassan *et al.*, 2010) and wheat (Mubeen *et al.*, 2006). However most of these fertilizer formulations are based on costly inputs. Hence a study entitled "Matrix based slow release fertilizer for increasing nutrient use efficiency in the Onattukara sandy plains" was conducted to develop a low cost, sustainable, ecofriendly slow release fertilizer for Onattukara sandy loam soil. The literatures related to this study is detailed in this chapter.

2.1 ONATTUKARA SANDY PLAIN

Generally Onattukara sandy loam soils are acidic in reaction with poor CEC. In earlier days this area contributed the major share of agricultural production, hence it was renamed as Onattukara which indicates the past prosperity of this area (Premachandran, 1998).

Onattukara soil is coarse textured soil with greater permeability which enhance the percolation of water and nutrients. Hence crops in this region are mostly prone to nutrient stresses. It was reported that application of FYM and coir pith along with compaction, improved soil physical properties like soil strength, nutrient and water retention capacity, porosity etc. (Baskaran *et al.*, 2009).

Onattukara soils are generally immature profile with poor nutrient and water holding capacity. Organic matter and most of the plant nutrients are deficient in these soils. Excess levels of phosphorus and wide spread deficiencies of calcium, magnesium, boron and zinc are the major limitations to crop production in this region (Mini and Mathew, 2015). Majority of the soils are moderately acidic to strongly acidic and the main reason for this acidification was reported as heavy load of fertilizer per unit area (Rajasekharan *et al.,* 2013).

2.2 METHODS TO IMPROVE NUTRIENT USE EFFICIENCY

Evaluation of cropping system is necessary to enhance the nitrogen use efficiency, because cropping system affects many of the nitrogen related physiological processes in both plant and soil (Moll *et al.,* 1982).

Divya (1999) reported that the coated diammonium phosphate and urea had significant effect on growth and yield of rice. The incubation study with this coated fertilizers revealed that the release of available N, P and K was retained up to 30 days and hence the fertilizer use efficiency and plant uptake found to be increased.

A study on effect of controlled release fertilizers (CRFs) and nitrification inhibitors on nitrogen use efficiency was conducted and it was revealed that the CRF technology could enhance the nitrogen use efficiency by timely meeting the crop requirement (Shoji *et al.*, 2001).

The microbial inoculants can be effectively used for increasing the nutrient uptake and can support the overall growth of the plant. Adesemoye *et al.* (2008) reported that microbial inoculants like PGPR and AMF have a significant influence on nutrient uptake.

With respect to the changes in tillage system, economics and environmental awareness, efficient placement methods of fertilizers are getting importance for the enhancement of nutrient use efficiency (Randall and Hoeft, 1988).

Gupta *et al.* (2015) reported that the fertigation practices in hybrid tomato gave better response with lesser quantity of fertilizers and they also noted that excessive fertilizer application have negative impacts on yield. Hence fertigation is a practically viable technology to increase the uptake efficiency of nutrients.

Mini and Mathew (2016) conducted a study to assess the nutrient status of Onattukara region to develop a customized nutrient mixture for the balanced nutrition and optimum yield of okra. Since micronutrient deficiency is the major yield barrier in Onattukara condition, they revealed that foliar application of micronutrient mixture @ 5 kg ha^{-1} in two splits was superior to soil application of micronutrients.

Nano fertilizers (size below 100 nm) can be used as an efficient fertilizer technology because of their high penetration rate, more surface area and enhanced efficiency. These fertilizer application at nano level helps to prevent nutrient fixation in soil especially that of phosphorus, this will in turn increases the nutrient availability and nutrient use efficiency (Singh, 2017).

Lekshmi and Mini (2018) reported that the application of rice husk ash along with soil test based recommendation and supplementary foliar application of fertilizers improved yield and reduced nutritional deficiencies in rice.

Leaching loss of nitrogen and potassium fertilizers are the major constraints in rice cultivation in sandy soil. Phongchanmixay *et al.* (2019) reported that split application of nitrogenous fertilizers could supply the nutrients at its critical growth stages. Hence the nutrient use efficiency can be increased.

2.3. POTENTIAL ADVANTAGES OF CONTROLLING NUTRIENT SUPPLY

The seasonal crop uptake of micronutrients are generally in sigmoidal pattern (Christianson and Shultz, 1991). Shaviv and Mikkelsen (1993) suggested that sigmoidal supply of nutrients synchronized with crop demand can deliver nutrition for optimal plant growth and reduced nutrient losses by competing with the nutrient uptake by the plant.

The nutrient use efficiency of N and P fertilizers are very low because the only fraction that can be utilized by plants are the soluble fraction (Vassilev and Vassileva, 2003).

Singh *et al.* (2006) found that the excessive application of chemical fertilizers are unjustifiable for any agricultural practice from both economic as well as ecological perspective.

Datta *et al.* (2012) informed about the ammonia volatilization loss in Indo-Gangetic Planes, Uttar Pradesh, Punjab, Haryana and other parts of India with the application of 120.0 kg N ha^{-1} in rice and wheat.

Rawat and Singh (2010) reported that ground water is also affected by excess application of nitrogen fertilizers (nitrate pollution).

Slow and controlled release fertilizers can be produced by some technical interventions which plays a vital role in improving fertilizers use efficiency by plants, thereby alleviating environmental hazards (Zhao *et al.*, 2010).

Slow release fertilizers (SRF)s are planned to control the nutrient release pattern in harmony with the nutritional requirements of plants, thereby enhancing the fertilizer use efficiency, ensuring the reduction in the cost of fertilizers and increasing the productivity of crop (Azeem *et al.*, 2014).

2.4. IMPORTANCE OF SLOW RELEASE FERTILIZERS (SRFs)

Reactive layer coated urea (RCL) is a potential nitrogen SRFs in turf and could minimize the leaching loss of nitrogen (Peacock and DiPaola, 1992).

AAPFCO (Association of American Plant Food Control Officials) (AAPFCO, 1997) defined SRFs are "chemically or biologically decomposable materials with a high molecular weight, complex structure and small solubility, whereas controlled release fertilizers are materials in which the release of mineral components takes place through a polymer layer or a membrane".

A polyurethane-like coating over the fertilizers forming an abrasion-resistant Reacted Layer Coated Fertilizer (RLCF).The coating was developed by the chemical reaction of poly-isocyanates and polyols. The application of RLCF technology had an advantage of better nutrient release rate. Polyon, Plantacote and Multicote are some marketed products utilizing RLCF technology (Trenkel, 1997).

Guertal (2000) reported that leaching loss of nitrogen from sandy soils can be reduced by using slow release materials of nitrogen.

Pasda *et al.* (2001) stated that a new nitrification inhibitor (NI) named 3,4-dimethyl pyrazole phosphate (DMPP) increased the crop yield of winter wheat, wetland rice, grain maize, tuber yield of potatoes, sugar yield of sugar beets and reduced the concentration of nitrates in leafy vegetables and thus improved the quality of various agricultural crops.

Granular fertilizers can be coated using thermoplastic resins, developed by dissolving in chlorinated fast-drying hydrocarbon solvent. Surfactants and ethylene-vinyl acetate were added as agents controlling nutrient release pattern, because of their impermeability in water and ideal diffusion characteristics. The level of these agents determine the release pattern and the rates can be altered by mixing talc into the resin coating (Sartain and Kruse, 2001).

Osmocote is a slow release fertilizer with an alkyd-type of resin coating. The resin is made up of a copolymer of dicyclopentadiene with glycerol ester. The thickness or composition of coating controls the release rate of osmocote and the weight of coating ranges 10% - 20% of the total weight. A wide variety of NPK fertilizers were developed out of this technology (Sartain, 2004).

Shaviv (2001) reported that elemental sulfur (S) is an inexpensive material with low melting point that can be used as a coating material. Sulphur coated urea (SCU) was produced commercially by spraying molten sulphur over urea prills. The sulphur coated urea has imperfection in its coating due to which one third product released rapidly ("burst") and about one third is released in locked off manner, hence an uneven release rate is seen. To have more control over the N release from the SCU, an additional resin layer was used to get better control over release of nitrogen from the product, hence it is named as polymer sulfur-coated urea (PSCU). Although PSCU has properties better than SCU, SCU is preferred because of the tailing effect of PSCU on plants.

Carreres *et al.* (2003) showed that, when Polymer coated urea (PCU) (32% and 40% N) and Isobutylidenediurea (IBDU) applied before flooding, improved biological N_2 fixation as compared to conventional fertilizers.

Nitrification inhibitors were usually proposed for reducing nitrous oxide emissions during nitrification, denitrification and leaching (Di and Cameron, 2005). Customized fertilizers reduces the nutrient losses and boost up the availability of nutrients in the soil and polyolefin-coated urea reduces runoff and leaching losses of nitrogen from soil (Kondo *et al*., 2005).

Urease inhibitors, can effectively be used in controlling volatilization loss of nitrogen (Zaman *et al*., 2009).

A wide range of synthetic or natural polymers are used to encapsulate the controlled release fertilizers (eg. sulphur-coated urea), which releases the nutrients gradually to the soil solution (Trenkel, 2010).

Zhang *et al*. (2016) found that resin coated fertilizers like ammonium nitrate and urea can reduce the uptake of Cd in *B. chinensis*.

2.5. RELEASE PATTERN STUDY

The confirmation of nutrient release pattern is important for evaluating the efficiency of CRFs . However, no such official laboratory methods can validate such claims, because it is affected either directly or indirectly by various factors. They also observed that the coating materials can change their properties with temperature, thus the rate of release will be greater than the expected rate of simple diffusion and by varying the thickness of coating material, the permeability of coating material can be controlled. It was found that in loamy soils when moisture range exceeds permanent wilting point to field capacity, which did not affect considerably the nutrient release from CRFs applied to the soil (Oertli and Lunt, 1962).

Ahmed *et al*. (1963) reported that release rate of nutrients and temperature were directly proportional to each other. Kochba *et al*. (1990) conducted an incubation study with CRFs and reported that change in nutrient release is an exponential function of temperature.

Ingram (1981) proved that as the soil temperature increased from 21°C to 40°C within black containers in nursery, significantly increased release rate of nutrients from CRF.

Kochba *et al.* (1990) postulated that substrate vapor pressure is the limiting step in nutrient release. Since reduced substrate moisture level at field capacity does not affect substrate vapour pressure, the main hypothesis of nutrient release from CRFs was related to the penetration of water vapour through the coating or to the rate of diffusion to the soil solution

Trenkel (1997), described the three criteria of SRF s at 25 ^{0}C (i) nutrient release should be less than 15% in 24 hours, (ii) should be less than 75% in 28 days, and (iii) minimum 75% release by stated time of release.

Cabrera (1997) found that the nitrogen leaching pattern from the CRF closely followed the pattern of change of daily temperature in pot culture experiments under controlled condition. Trenkel (1997) stated that soil temperature and permeability of polymer coating towards soil moisture, are the major factors affecting nutrient release. It is not much affected by other factors like pH, CEC, salt content, texture, biological activity and redox. The placement and the soil moisture content also affect the release rate of nutrient from CRF. Cabrera (1997) reported that top dressing of CRFs decrease the release rate of nutrient than incorporation.

Among existing controlled release fertilizer (CRF) technology, polymer coated fertilizers (PCFs) are the fast growing sector because of its improved flexibility in release of nutrients compared to other CRF products (Sartain, 2004).

In slow release fertilizers, the release characteristics are not well controlled but the conditions like temperature, soil moisture content and microbial activities affects the release pattern (Shaviv, 2001).

Thickness of coating material has an influence on the nutrient release rate. Heavily coated CRFs shows lower release rates and lightly coated CRFs have higher release rates. They also proved that nitrogenous fertilizers released nutrients more promptly than potassium and phosphate under similar environmental situations. The nutrient release from CRFs are affected by nature of the coating material and the source of N fertilizer being coated (Sartain and Kruse, 2001).

Husby *et al.* (2003) examined the release pattern of Polymer coated fertilizers (PCFs) in sand columns under varying temperature levels. The results proved that, as the temperature raised from 20°C to 40°C, the nutrient release was also increased and vis versa. They also reported that the daily container temperature had a rapid effect in nutrient level and release longevity of PCFs.

2.6. MATRIX BASED FERTILIZERS

Various materials had been tried for the development of matrix. Otey *et al.* (1984) produced a gelatinized matrix of starch flour and urea. Starch flour was selected as controlled device, since it is biodegradable. The result was poor because only 15-60% urea was recovered when 5 gram was immersed in 50 ml for one hour at 30^0C.

Matrix based fertilizers produced by combining powdered ammonium sulfate with a binder (asphalt-wax) and extruded into pellets and found to be superior to sole ammonium sulfate in rice cultivation. (Tisdale *et al.,* 1985).

Matrix based fertilizers (MBF) are one type of slow release fertilizers in which nutrients are entrapped in either inorganic or organic matrix. Entry and Sojka (2007) developed a matrix based fertilizer formulation (MBF) containing, inorganic nitrogen and phosphorus compounds and high ion exchange materials like starch, chitosan and lignin. The leaching experiment with the matrix formulation proved that the composition of matrix ($Al(SO_4)_3$ H_2O and/or Fe_2 $(SO_4)_3$ starch-chitosan-lignin matrix) was capable of holding the released nutrients temporarily. In matrix based slow-release fertilizers, the entrapped nutrients are uniformly dispersed in the matrix and hence diffusion of nutrients and outward flow of fertilizers are hampered by the tortuosity of the matrix system. Materials that can be used for entrapping nutrients are gels, oils, paraffins, polymers, resins or waxes.

Liu *et al*. (2007) developed a multifunctional matrix based slow release organic- inorganic compound fertilizer made up of natural attapulgite (APT) clay matrix with sodium alginate inner coating and sodium –g-poly/humic acid (super adsorbent polymer) as outer coating to enhance the fertilizer use efficiency and to control environmental pollution.

2.7. ORGANIC MATRIX BASED FERTILIZERS

The use of biodegradable materials for entrapping materials helps to overcome the problems of high cost of polymer based controlled release matrix based devices (Baker and Lonsdale, 1975).

Singh and Sharma (2011) developed organic matrix based slow release fertilizers (SRFs) from the agrowaste materials cow dung, clay soil, neem leaves and rice bran in 2:2:1:1 proportion and were used to entrap the chemical fertilizers. They revealed that it was a cost effective method as the agro waste materials were utilized effectively. Singh *et al*. (2012) reported that granular OMEU (Organic matrix entrapped urea) was prepared from biodegradable agrowaste materials like cow dung, rice bran, neem leaf powder, and clay soil in 1:1:1:1 ratio, respectively. In which half of recommended dose of free urea was incorporated along with the matrix to evaluate the efficiency of OMEU on growth and yield of rice (*Oryza sativa* L. cv. Basmati). The yield parameters revealed that OMEU enhanced the efficacy of chemical urea.

Singh *et al*. (2014) reported that the organic matrix entrapped form of biofertilizers can release nutrients in a slow released manner as compared to free solulbe fertilizers. They proved that efficacy of microbial biofertilizer consortium (*Azotobacter chroococcum* and *Bacillus subtilis*) could be improved by entrapping in suitable organic matrix based carriers and also stated as a possible alternative for wheat production with organic based technologies(*Triticum aestivum* L. cv. PBW-343).

Bauddh and Singh (2015) reported that fertilizers can affect concentration of Cd in brassica species when they are applied in organic matrix entrapped form. The entrapped form of diammonium phosphate and urea reduced the concentration of Cd in *B. juncea*.

Singh *et al.* (2015) revealed that organic matrix entrapped chemical fertilizers (urea and DAP) can increase the efficacy of chemical fertilizers for rice cultivation. They also proved that even half dose of the fertilizers could produce better yield in OMECF (organic matrix entrapped chemical fertilizers i.e. Urea and DAP). OMECF was prepared from cow dung, powder of neem leaves, and clay soil in 1:1:1 ratios and urea and DAP were incorporated in various doses.

Effect of conventional fertilizer (urea), charcoal based conventional biofertilizer and organic matrix entrapped form of biofertilizer consortium (*Azotobacter chroococcum*, *Azospirillum brasilense* and *Pseudomonas putida* with clay soil, neem leaves, and cow dung in 1:1:1 ratio) on plant growth parameters and secondary metabolite production of *Rauwolfia serpentina* was evaluated through a field experiment. The results proved that organic matrix entrapped biofertilizers in higher dose can replace chemical fertilizer for the higher growth and production of *R. serpentina* (Singh *et al.*, 2017).

2.7.1. Effect on yield and productivity

Many reports are available regarding the slow release property of organic manures. Goyal *et al.* (1992) found that the nitrogen uptake, recovery and yield of *Pennisetum glaucum* were increased even after 4 years with mixed application of FYM, sesbania and urea as compared to sole urea application. Higher yield was also recorded from the 25 % Leucaena-25 % urea combinations as compared to100% leucaena treatments. It might be due to the superior effects of combined application of organic sources with chemical fertilizers (Mittal *et al*., 1992).

Singh and Sharma (2011) suggested that a significant increase in the yield attributes of *Brassica juncea* was observed in the plants treated with organic matrix based SRF granules. Singh *et al.* (2012) also stated that organic matrix entrapped urea increased the grain yield of rice by 3.6 fold and productivity by 32%.

The application of organic matrix entrapped urea and DAP either in half dose or in one fourth dose of recommended fertilizers, increased the growth parameters significantly (Singh *et al.,* 2013).

Singh *et al.* (2017) stated that *R. serpentina* recorded higher biomass yield in terms of shoot and root with the application of organic matrix entrapped bio fertilizers as compared to loose application of fertilizers. They also stated that the double and triple dose of biofertilizers in entrapped form gave the same concentration of alkaloid content as that of single dose. This might be due to the proper nutrient enrichment in accordance with the crop requirement from the single dose itself due to reduced leaching and increased plant uptake.

Wu *et al.* (2018) reported that the low cost sustainable slow release matrix based urea fertilizer was an ecofriendly method of wheat (*Tritium aestivum* L.) production as it reduce the risk of nitrogen loss and increase the yield more than 11%.

2.7.2. Effect on soil properties

Singh *et al.* (2012) reported that OMEU (Organic matrix entrapped urea) increased % OC, total NPK in plant and available N, P and K in soil. It might be due to the agro waste materials that helped in increasing the organic matter content in soil.

Singh *et al.* (2013) revealed that the application of organic matrix entrapped chemical fertilizers could affect the soil physical properties significantly by increasing soil pH, water holding capacity, OC% and organic matter. These matrix also significantly increased the nitrate content in the rhizosphere at 0-15 cm depth. In addition to that available N, available P and soluble K were significantly increased on crop harvest when it is treated with entrapped fertilizers over unentrapped fertilizers

Singh *et al.* (2014) also reported the same that organic matrix entrapped bio fertilizers had significant influence in soil physical and chemical properties. They also suggested that the nutrient rich components used in these organic matrices might be the reason for this.

2.7.3. Effect on uptake of nutrients

The assimilation of nitrate in the leaves of *Brassica juncea* at different growth stages was significantly affected by the granular organic matrix based SRF application (Singh and Sharma, 2011).

The higher levels of nitrates, nitrites and phosphates were reported in organic matrix entrapped bio fertilizers applied soils in triple dose as compared to free bio fertilizer and recommended dose of fertilizer (Singh *et al.,* 2017).

Wu *et al.* (2018) reported that the organic matrix based fertilizer could increase the agronomic and apparent recovery efficiencies as compared to unentrapped conventional urea. This might be due to the reduced nitrogen loss (leaching and ammonia emission) and increased availability of nitrogen.

2.7.4. Effect on cost of production

Al-Zahrani (1999) reported that the preparation of matrix based slow release urea was easier and was having a lower cost of production.

The economic analysis of Indian mustard production with the application of organic matrix based slow release fertilizer proved that this agro waste material based formulation is cost effective method (Singh and Sharma, 2011).

Singh *et al.* (2012) evaluated OMEU with half of the recommended dose of urea, resulted in almost equal net returns as compared to the full recommended dose of free urea. Thus the reduced fertilizer cost was also confirmed.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A study on "Matrix based slow release fertilizer for increasing nutrient use efficiency in the Onattukara sandy plains" was carried out during 2017-19 in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. Objective of the study was developing a low-cost sustainable matrix based slow release fertilizer using local biodegradable agro waste as matrix and to evaluate the effect of this slow release fertilizer in increasing nutrient use efficiency in the sandy loam soils of Onattukara. The study included three parts *viz.,* 1. Development of matrix based slow release fertilizer 2. Incubation study and 3. Evaluation of the effect of matrix based slow release fertilizer in increasing nutrient use efficiency. Pot culture experiment was carried out at Onattukara Regional Agricultural Research Station, Kayamkulam for evaluating the efficiency of organic matrix based slow release fertilizer under Onattukara condition. The materials and methods are described in this chapter.

3.1 DEVELOPMENT OF MATRIX BASED SLOW RELEASE FERTILIZER

A matrix based slow release fertilizer was developed by combining local biodegradable agro waste materials with conventional NPK fertilizers. For developing the matrix, various agro waste materials like rice husk ash, clay, cow dung, rice husk, coir pith compost, vermicompost and neem cake were used.

3.1.1 Characterization of agro waste materials

The collected agro waste materials were characterized and nutrient composition were determined using the standard analytical procedures given in Table 1 and the characteristics are given in Table 2.

Table 1. Standard analytical procedures used for the characterization of agro waste materials

Sl. No	Parameter	Method	Reference
1	N	Microkjeldhal distillation after digestion in H_2SO_4	Jackson (1973)
2	P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdo yellow colour method	Jackson (1973)
3	K	Nitric-perchloric (9:4) acid digestion and flamephotometry	Jackson (1973)
4	Ca, Mg	Versanate titration method	Hesse (1971)
5	S	Nitric – perchloric acid (9:4) and Turbidimetry-$BaCl_2$ method (0.15% $CaCl_2$ extraction)	Chesnin and Yien (1950)
6	Fe, Cu, Zn and Mn	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry	Lindsay and Norvel (1978)
7	B	Azomethine- H specrophotometry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Bingham (1982)

Table 2. Characteristics of agro waste materials used for matrix development

	Rice husk ash	Vermi compost	Coirpith compost	Neem cake	Rice husk	Cow dung
pH	8.02	6.70	6.20	6.60	7.10	6.62
EC (dSm^{-1})	0.29	0.39	0.26	0.36	0.25	0.20
N (%)	0.12	1.95	0.24	3.70	0.31	1.03
P (%)	0.19	0.70	0.06	0.83	0.19	0.78
K (%)	0.30	0.98	1.20	0.70	0.22	0.47
Ca (%)	0.62	0.54	0.25	0.16	0.17	0.27
Mg (%)	0.38	0.26	0.48	0.92	0.52	0.28
S (%)	0.13	0.26	0.18	0.250	0.08	18.0
Fe (ppm)	26.40	17.30	39.35	17.20	34.00	14.52
Mn (ppm)	15.50	11.0	25.00	16.40	17.00	10.20
Zn (ppm)	37.90	76.00	15.80	48.70	38.20	41.0
Cu (ppm)	39.50	24.00	6.20	36.30	40.70	21.0
B (ppm)	18.90	11.28	1.13	1.08	19.20	0.70

3.1.2 Development of matrix based slow release fertilizer

Different combinations of various biodegradable agro waste materials like rice husk ash, clay, cow dung, rice husk, coir pith compost, vermicompost and neemcake (Plate 1) were combined to develop the suitable matrix.

Biodegradable agro waste materials were collected separately, oven dried at 60-70^{0}C for 2 days and powdered in a grinder. These powdered materials combined in various combinations like 1:1:0.5:0.5:0.5:0.5:0.5, 1:1:1:1:1:1:1 and 1:1:1:1:0.5:0.5:0.5. Both disc and granular matrices were developed. Granular matrices were developed by using a mechanical stirrer. The disc shaped matrices were developed by using a mould (Plate 2). pH, electrical conductivity, dissolution rate and cost of production of each combination were worked out. Matrices were tested for their dissolution rate in 250 ml water at 25^{0}C for 4 hrs (Heikal and Khalil, 2015). Visual observation on degradation of the matrix was observed (Plates 3, 4 and 5). The best combination was selected based on the pH, electrical conductivity, dissolution rate and cost of production. These matrices showed an observable difference in their characteristics (Table 3). Among these three matrices, 1:1:0.5:0.5:0.5:0.5:0.5 combination was selected based on their desirable characteristics such as high pH (6.02), low electrical conductivity (0.37 dS m^{-1}), low dissolution rate and low cost of production (Rs. 5.64/- per kg).

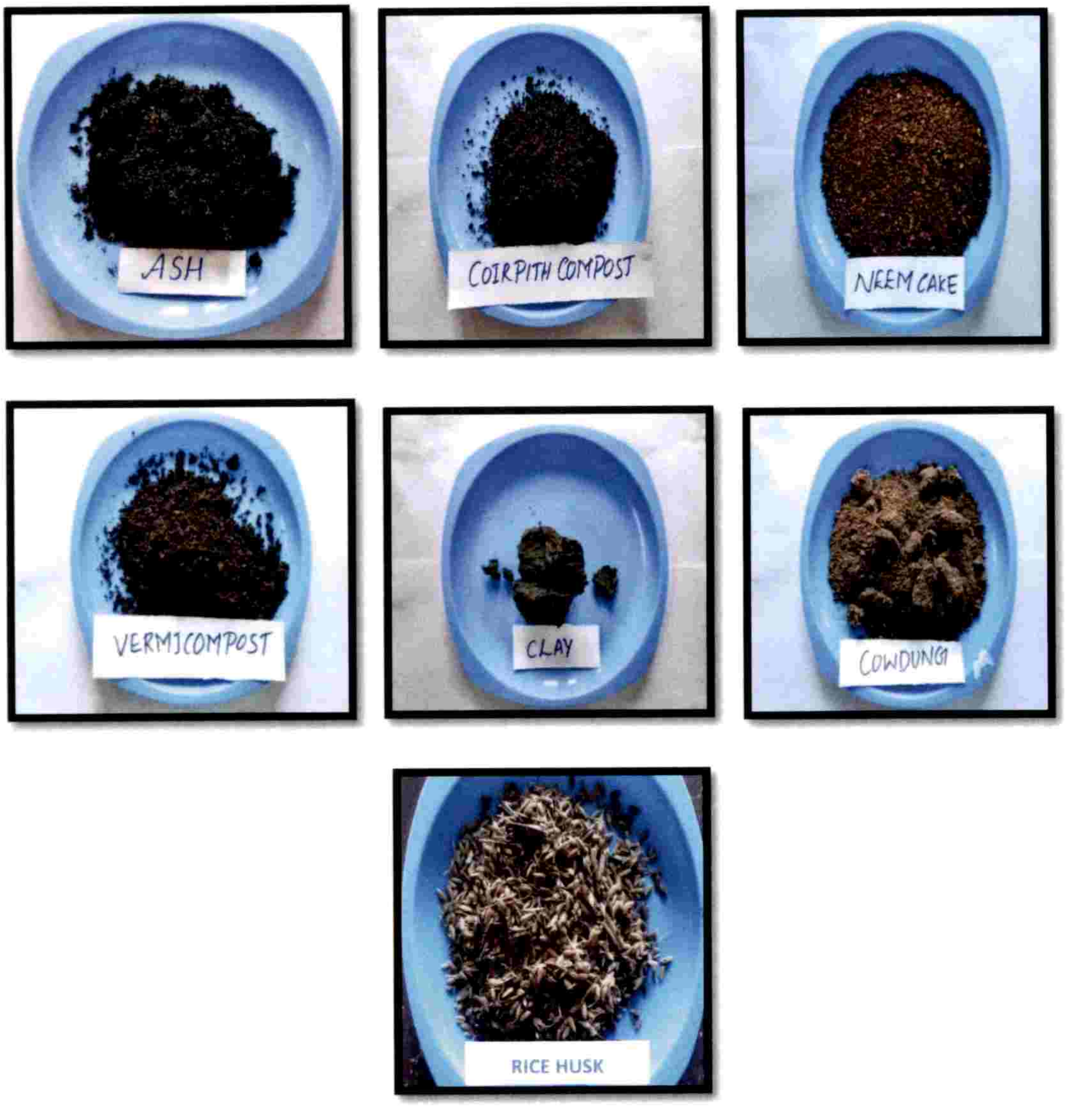

Plate 1. Ingredients used for matrix development

Plate 2. Mould used for the development of disc shaped matrix

Plate 3.Visual observation of matrix- 1:1:1:1:1:1:1 ratio after 4 hrs

Plate 4. Visual observation of matrix- 1:1:1:1:0.5:0.5:0.5 ratio after 4 hrs

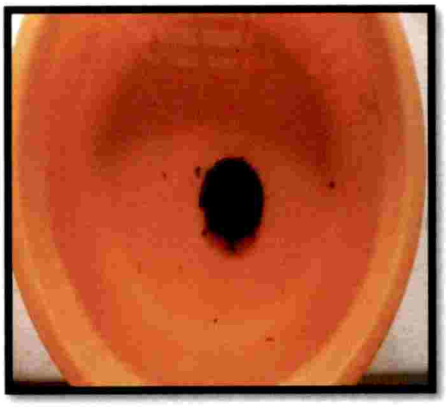

Plate 5. Visual obsevation of matrix- 1:1:0.5:0.5:0.5:0.5:0.5 ratio after 4 hrs

Table 3. Characteristics of different matrix combinations

Combinations	Characteristics			
	pH	EC ($dS\ m^{-1}$)	Dissolution rate	Cost (Rs. /kg)
1:1:1:1:1:1:1	5.5	0.50	High	11
1:1:1:1:0.5:0.5:0.5	5.6	0.42	Medium	7.14
1:1:0.5:0.5:0.5:0.5:0.5	6.2	0.37	Low	5.64

3.2 INCUBATION STUDY

An incubation study was conducted for 2 months period using the loamy sand soil of Onattukara Regional Agricultural Research Station, Kayamkulam. From the first part, the best matrix combination (1: 1:0.5:0.5:0.5:0.5:0.5) was selected to entrap the NPK fertilizers. The sources of NPK fertilizers used were urea, rajphos and MOP. They were entrapped in various proportions of matrix: fertilizers (by weight) *viz.*, 1: 1, 2: 1, 0.5: 1 and matrix alone. Granular and disc forms (Plates 6, 7, 8 and 9) of these 4 proportions were used for incubation to study the nutrient release pattern of various matrices. The treatment combinations finalized for incubation are as follows.

Design: CRD

Treatments: 8

Replications: 3

Plate 6. Disc and Granular forms of Matrix: fertilizer (1:1)

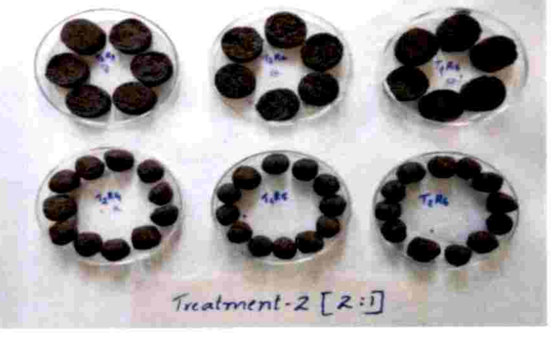

Plate 7. Disc and Granular forms of Matrix: fertilizer (2:1)

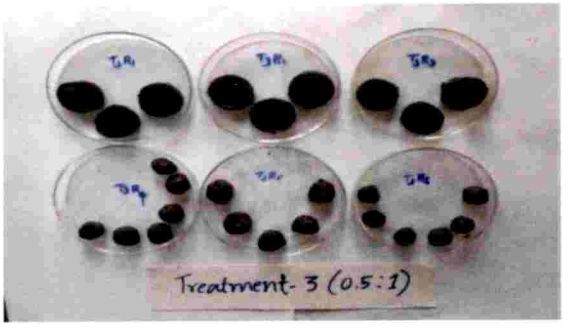

Plate 8. Disc and Granular forms of Matrix: fertilizer (0.5:1)

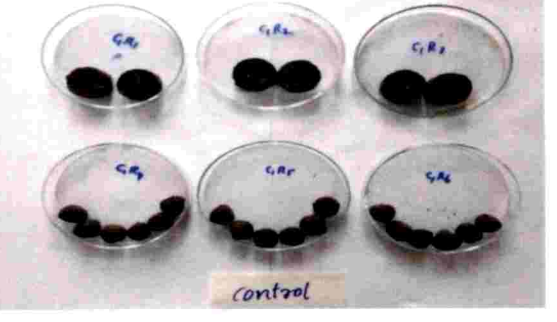

Plate 9. Disc and Granular forms of Matrix alone

T_1	1:1 (Matrix : Fertilizer)- Disc
T_2	1:1 (Matrix : Fertilizer)- Granule
T_3	2:1(Matrix :Fertilizer)-Disc
T_4	2:1(Matrix :Fertilizer)-Granule
T_5	0.5:1(Matrix : Fertilizer)- Disc
T_6	0.5:1(Matrix :Fertilizer)-Granule
T_7	Matrix alone- Disc
T_8	Matrix alone-Granule

Two kg soil was taken in each bucket and incubated at field capacity by replenishing the evaporation loss by calculating the weight difference (Plate 10). Initial nutrient status of the soil was analysed before incubation using standard analytical procedures given in Table 4. The initial nutrient status is given in table 5.The pH of the initial soil was 5.26 (strongly acidic) and electrical conductivity was 0.193 dS m^{-1}. Organic carbon status of soil was low (0.32 %). Available N (139 kg ha^{-1}) and K (17.47 kg ha^{-1}) were recorded low status whereas, the P status was high about 78.45 kg ha^{-1}. With respect to secondary and micronutrient status, except Fe and Mn all other nutrients were deficient. Soil samples were collected from these buckets after imposing the treatments at 15 days intervals up to two months and analysed for various parameters. Based on the results from the incubation study the best matrix combination was selected for conducting the pot culture experiment to evaluate the nutrient use efficiency of matrix based slow release fertilizer.

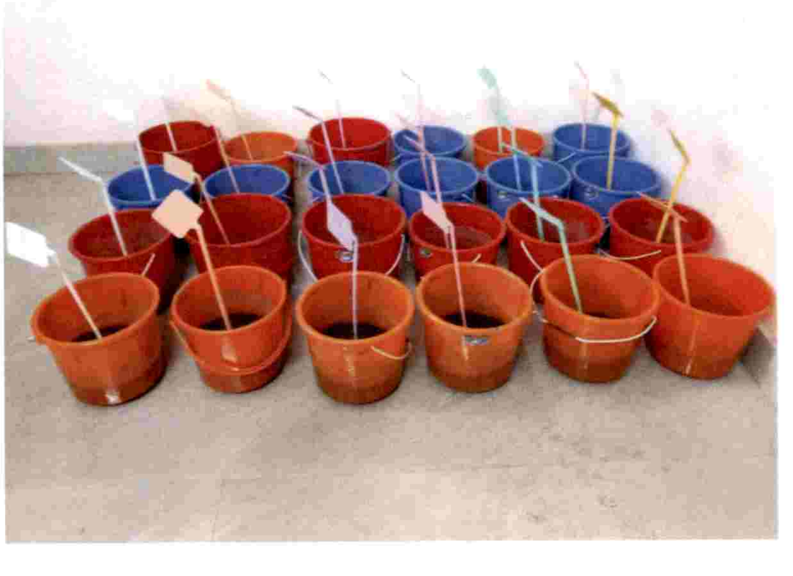

Plate 10. Incubation study

Table 4. Standard analytical procedures used for soil analysis

Parameter	Method	Reference
Mechanical composition	International pipette method	Piper (1967)
Particle density	Pycnometer method	Black *et al.*(1965)
Bulk density	Undisturbed core sample	Black *et al.*(1965)
CEC	Ammonium saturation using neutral normal ammonium acetate and distillation	Jackson(1973)
pH (1:2.5)	pH meter	Jackson (1958)
EC (1:2.5)	Conductivity meter	Jackson (1958)
Organic Carbon	Walkley and Black rapid titration method.	Walkley and Black (1934)
Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
Available P	Bray and Kurtz extraction method and spectrophotometry.	Jackson (1973)
Available K	Neutral 1N ammonium acetate extraction and flame photometry	Jackson (1958)
Available Ca, Mg	Neutral 1N ammonium acetate extraction and titration with EDTA	Hesse (1971)
Available S	0.01 N $CaCl_2$ extraction and turbidimetry	Chesnin and Yien (1950)
Available Fe, Mn, Zn, Cu	0.1 N HCl extraction and atomic absorption spectrophotometry	Sims and Johnson (1991)
Available B	Hot water extraction and colorimetry (Azomethine – H method)	Hesse (1971)

Table 5.Initial status of the soil used for incubation study

Parameter	Mean value	Status
pH	5.26	Strongly acidic
EC(dS m^{-1})	0.193	Safe
OC (%)	0.32	Low
Available N (kg ha^{-1})	139	Low
Available P (kg ha^{-1})	78.5	High
Available K (kgha^{-1})	17.5	Low
Available Ca (mg kg^{-1})	209.5	Deficient
Available Mg (mg kg^{-1})	73.25	Deficient
Available S (mg kg^{-1})	2.98	Deficient
Available Fe (mg kg^{-1})	20.4	Sufficient
Available Mn (mg kg^{-1})	2.77	Sufficient
Available Zn (mg kg^{-1})	0.58	Deficient
Available Cu (mg kg^{-1})	0.409	Deficient
Available B (mg kg^{-1})	0.174	Deficient

3.3. EVALUATION OF THE EFFECT OF MATRIX BASED SLOW RELEASE FERTILIZER IN INCREASING NUTRIENT USE EFFICIENCY

A pot culture experiment was conducted with Tomato (var. Vellayani Vijay) as the test crop to evaluate the effect of matrix based slow release fertilizer in increasing nutrient use efficiency in the Onattukara sandy plains during 2018-19.

3.3.1. Experimental site and season

The experiment was laid out at Onattukara Regional Agricultural Research Station, Kayamkulam, located at 9^0 09' 34.56" N latitude and 76^0 33' 15.36" E longitude and an altitude of 3.05 m above mean sea level.

3.3.2. Weather Condition

A warm humid tropical climate was prevailing over the area. The weather parameters like maximum temperature, minimum temperature, relative humidity and monthly rainfall during the experiment (November, 2018 to January, 2019) were recorded and it is given in Appendix 1

3.3.3. Soil

Soil used in this pot culture experiment was *loamy, skeletal kaolinitic, isohyperthermic, ustic, quartzi psamments.* The soil samples collected were air dried ,sieved and analysed for various parameters (pH, EC, OC, available N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B). The standard analytical procedures used are given in Table 4 and the data regarding the physical and chemical properties of soil are presented in Table 6.

Table 6. Physico-chemical properties of the soil used for pot culture experiment

Sl. No.	Parameters	Value
1	pH	5.28
2	EC, dSm^{-1}	0.68
3	Sand %	82.5
4	Silt %	8.5
5	Clay %	9.0
6	Texture	Loamy sand
7	Bulk density	1.58 Mg m^{-3}
8	Particle density	2.43 Mg m^{-3}
9	Organic carbon , %	0.56
10	Available N, kg ha^{-1}	163.17 (low)
11	Available P, kg ha^{-1}	78.45 (low)
12	Available K, kg ha^{-1}	97.47 (low)
13	Available Ca, mg kg^{-1}	210 (deficient)
14	Available Mg, mg kg^{-1}	36(deficient)
15	Available S, mg kg^{-1}	3.28(deficient)
16	Available Fe, mg kg^{-1}	12.37(sufficient)
17	Available Mn, mg kg^{-1}	7.42 (sufficient)
18	Available Zn, mg kg^{-1}	0.45 (deficient)
19	Available Cu, mg kg^{-1}	0.254(deficient)
20	Available B, mg kg^{-1}	0.08 (deficient)

3.3.4 Experimental materials

3.3.4.1 Crop and Variety

The experiment was conducted with Tomato (var.Vellayani Vijay) as test crop. Vellayani Vijai is a bacterial wilt resistant variety of tomato. Seedlings were purchased from College of Agriculture, Vellayani.

3.3.4.2 Manures and Fertilizers

Farm yard manure (FYM) was given @ 1kg/pot based on the POP Recommendations of Kerala Agricultural University. The NPK nutrient source were urea, rajphos and MOP (Muriate of potash) respectively. Per plant requirement of each fertilizer was worked out and they were entrapped in 2:1 granular matrix, in which best nutrient release pattern was observed during the period of incubation. Total per plant requirement of these three fertilizers together were 15g and hence 30g matrix was used for entrapping the fertilizer to get 2:1 matrix: fertilizer ratio.

3.3.4.3 Raising of seedling

The tomato seeds were sown in potrays and were kept in polyhouses. One month old seedlings were used for transplanting. Seedlings were transplanted to the pot on 5th November 2018. Irrigation was given at regular intervals.

3.3.4.4. Design and layout of the experiment

Design : CRD

Treatments : 10

Replications : 3

3.3.4.5. Treatments

Ten treatments were applied and were replicated thrice. The treatments were applied as basal and split doses as per the treatment combinations. The finalized combinations are as follows.

T_1	Recommended dose of fertilizers and organic manure as per POP
T_2	Recommended dose of fertilizers as basal application
T_3	Recommended dose of fertilizers in two splits
T_4	Matrix entrapped *recommended dose (100%)of fertilizers as basal application

T_5	Matrix entrapped recommended dose (100%) of fertilizers in two splits
T_6	Matrix entrapped 75 % of recommended dose of fertilizers as basal application
T_7	Matrix entrapped 75 % of recommended dose of fertilizers in two splits
T_8	Matrix entrapped half of recommended fertilizers (50%) as basal application
T_9	Matrix entrapped half of recommended dose (50%) of fertilizers in two splits
T_{10}	Matrix alone

Note:* POP NPK (KAU, 2014)

Weather parameters during the pot culture experiment and lay out are given in Fig.1 and 2. The view of the pot culture experiment is given in Plate 11(a) and 11(b).

3.3.5. Biometric observations

3.3.5.1 Plant height

Plant height was recorded at 1 MAP. A field scale was used to measure the height from the base of the plant to the terminal bud. The mean value was calculated and recorded in cm.

3.3.5.2 Number of branches per plant

Number of branches per plant was recorded at 1 MAP and the mean value was recorded as number of branches per plant.

3.3.5.3 Days to first flowering

The number of days to reach the first flowering after transplanting was recorded and mean value was computed.

3.3.5.4 Days to fruit set

The number of days to reach the first fruiting was recorded for each plant and mean value was computed.

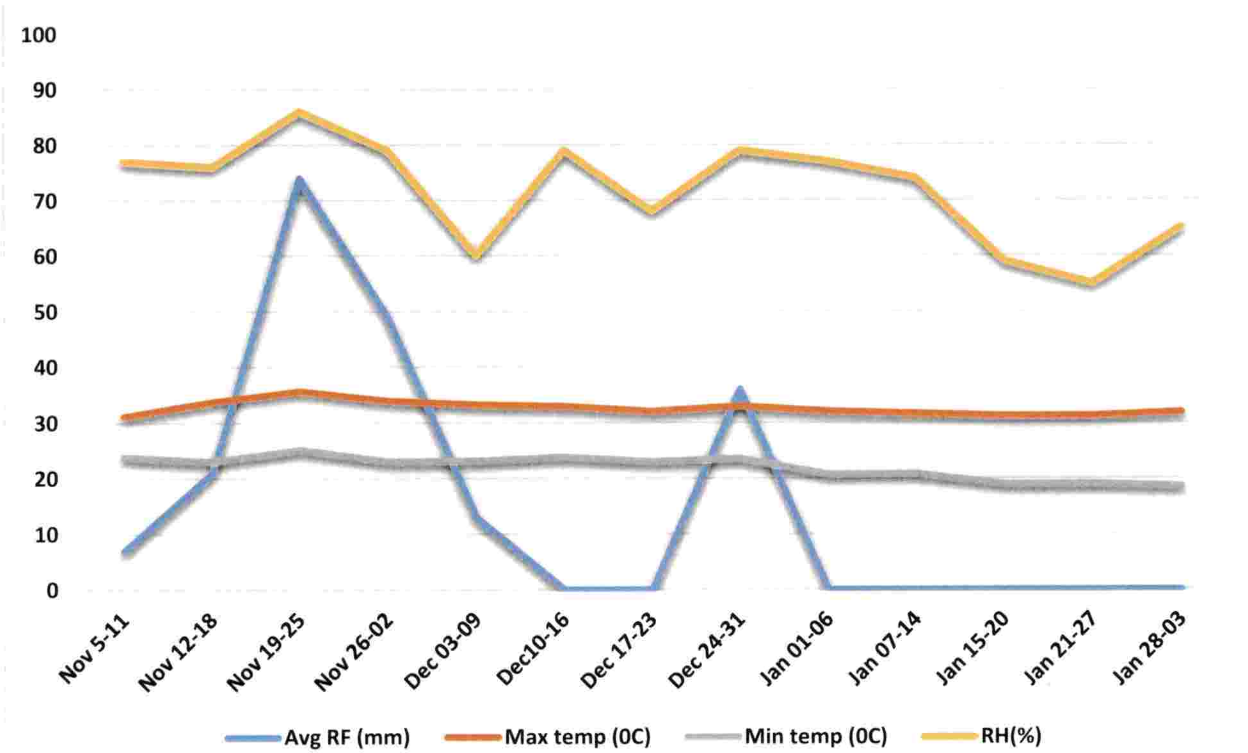

Fig.1 Weather parameter during the pot culture experiment

R1T3	R2T7	R1T4	R3T8	R2T3	R1T8
R3T10	R2T5	R3T9	R1T10	R3T4	R3T2
R2T4	R3T7	R1T1	R3T6	R3T1	R2T10
R3T5	R2T8	R2T2	R1T5	R2T6	R2T1
R1T2	R1T9	R2T3	R2T9	R1T7	R1T6

Fig. 2 Layout of the pot culture experiment

Plate 11(a). Pot culture experiment: Before transplanting of seedlings

Plate 11(b). Pot culture experiment: After transplanting of seedlings

3.3.5.5 Fruit set per cent

Fruit set percentage for each plant at full fruiting stage was calculated using the following formula.

$$\text{Fruit set percentage (\%)} = \frac{\text{Number of fruits/ Inflorescence}}{\text{Number of flowers/ inflorescence}} \times 100$$

3.3.6 Yield and yield attributes

3.3.6.1 Fruits per plant

Total number of fruits harvested from each plant was counted.

3.3.6.2 Fruit weight (g)

Weight of fruit from each plant was recorded and its mean value was computed and expressed in g.

3.3.6.3 Yield per plant (kg plant^{-1})

Weight of total fruits harvested from individual plant was recorded at the time of harvest and expressed in kg.

3.3.7 Quality parameters

3.3.7.1 TSS (%)

Fruits were crushed in a muslin cloth and Abbe hand refractometer was used to estimate the total soluble solids in fruits (Sadashivam and Manikyam, 1992).

3.3.7.2 Lycopene (μg/g)

Colorimetric method was used for estimating lycopene content in full ripe fruit and expressed in μg/g of full ripe fruit (Sadashivam and Manikyam, 1992).

3.3.7.3 Ascorbic Acid (mg/100g)

Ascorbic acid content in full ripe fruit was estimated by 2,6 dicholrophenol indophenol redox titration method and it was expressed in mg/100 g of full ripe fresh fruit (Sadashivam and Manikyam, 1992).

3.3.8 Post harvest soil analysis

The soil samples from each pot were collected, after harvest of the crop, air dried and sieved (2 mm sieve). The sieved samples were analysed for pH, EC, OC (0.5 mm sieved soil), available N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B using standard analytical procedures given in the Table 4.

3.3.9 Plant analysis

3.3.9.1 Index leaf analysis

Third fully opened leaf from the top most bud was collected for index leaf analysis (Rosen and Eliason, 2005). The leaves were oven dried at 70^0 C, powdered and used for the estimation of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B content in index leaf. Standard procedures adopted are given in Table 7.

3.3.9.2 Plant and fruit analysis

The plant sample was collected at final harvest. The samples were oven dried at 70^0C, powdered and used for estimation of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B content. Fruits samples were collected at final harvest. The samples were oven dried at 70^0C, powdered and used for estimation of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B content. Standard analytical procedures used for both plant and fruit analysis are given in Table 7.

3.3.10 Pest and disease incidence

All plants were monitored at regular intervals for the pest and disease incidence throughout the experiment. There was not much incidence of pest and disease except minor incidence of leaf miner. Neem oil garlic emulsion was sprayed for the control of leaf miner.

Table 7. Standard analytical procedures followed for plant and fruit analysis

Sl. No	Parameter	Method	Reference
1	N	Microkjeldhal distillation after digestion in H_2SO_4	Jackson (1973)
2	P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdate yellow colour method	Jackson (1973)
3	K	Nitric-perchloric (9:4) acid digestion and flame photometry	Jackson (1973)
4	Ca, Mg	Versanate titration method	Hesse (1971)
5	S	Nitric – perchloric acid (9:4) and Turbidimetry- $BaCl_2$ method (0.15% $CaCl_2$ extraction)	Chesnin and Yien (1950)
6	Fe, Cu, Zn and Mn	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry	Lindsay and Norvel (1978)
7	B	Azomethine- H specrophotometry (Double Beam UV-VIS spectrophotometer 2201, Systronics)	Bingham (1982)

3.3.11 Nutrient use efficiency

The nutrient use efficiency was calculated with respect to agronomic efficiency by using the following equation.

Agronomic efficiency (%)

$$= \frac{\text{Yield in fertilized pot (g/ pot)-Yield in unfertilized pot } (T_{10}) \text{ (g/ pot)}}{\text{Quantity of nutrient applied (g / pot)}} \times 100$$

3.3.11.1 Apparent nutrient recovery

$$= \frac{\text{Uptake in fertilized pot (kg ha}^{-1}\text{)-uptake in unfertilized pot (T}_{10}\text{) (kg ha}^{-1}\text{)}}{\text{Quantity of nutrient applied (kg ha}^{-1}\text{)}} \times 100$$

3.3.12 Economic analysis

The economics of organic matrix based slow release fertilizer based cultivation was worked out by considering the cost and prevailing market price.

3.3.12.1 B: C ratio

B: C ratio was calculated by using the following formula:

Benefit: Cost ratio = Gross income / Total expenditure

3.3.12.2 Net Income

Net income was calculated by the following formula:

Net income = Gross income – Total expenditure

3.3.13 Statistical analysis

The data generated from the experiment were subjected to various statistical analysis. The data collected from the experiment was analyzed using analysis of variance technique (ANOVA) in CRD and F test was applied for testing the significance (Cochran and Cox, 1965). CD values were calculated for detecting the significant difference between treatments.

RESULTS

4. RESULTS

The study entitled "Matrix based slow release fertilizer for increasing nutrient use efficiency in the Onattukara sandy plains" was carried out during 2017-19 in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. Incubation study and pot culture experiment were carried out at Onattukara Regional Agricultural Research Station, Kayamkulam, using the matrix based slow release fertilizer developed for the study as mentioned in materials and methods. The results obtained are given in this section.

4.1 INCUBATION STUDY

The incubation study was conducted using Onattukara sandy loam soil to examine the nutrient release pattern of different matrices. Granular and disc forms of these matrices entrapped with NPK fertilizers and matrix alone were used for incubation study. Results obtained from incubation study are given below.

4.1.1 pH

During the period of incubation, an increasing trend was observed in pH up to 60th day in all the treatments (Table 8). The pH values ranged from 5.31 to 5.6 without showing any significant difference between the treatments. But it showed an average increase in pH between the intervals and its value ranged from 0.017 to 0.06.

4.1.2 Electrical conductivity

Electrical conductivity showed an increasing trend (Table 9) from 0th day to 60th day of incubation. An average increase in electrical conductivity was observed between the intervals and its value ranged from 0.043 dS m^{-1} to 0.083 dS m^{-1}.

4.1.3 Available Nitrogen

Available nitrogen was estimated at 15 days interval up to two months to study the nitrogen release pattern from the matrix entrapped fertilizers. Available nitrogen in soil recorded significant difference among treatments at different intervals of sampling. Nitrogen release was increasing from 15th day to 30th day of sampling and from 30th day to 60th day, release of N recorded a decreasing pattern (Table 10). In all the treatments the highest nitrogen release was recorded at 30th day and then it showed a decreasing trend. The 2:1 granular matrix recorded the highest peak values at 30th day, 45th and 60th day of sampling and the values were 0.678g kg^{-1}, 0.484 g kg^{-1} and 0.442 g kg^{-1}, respectively. Treatment T_7 (Matrix alone -Disc) showed the lowest value at all intervals of sampling.

Table 8. Effect of different matrices on soil pH on incubation

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	5.31	5.42	5.43	5.38	5.42	5.31	5.33	5.46	NS
30th day	5.37	5.47	5.46	5.43	5.45	5.37	5.35	5.47	NS
45th day	5.40	5.49	5.51	5.47	5.48	5.40	5.37	5.53	NS
60th day	5.47	5.53	5.60	5.56	5.57	5.43	5.38	5.59	NS
Average increase per interval	0.05	0.04	0.06	0.06	0.05	0.04	0.02	0.04	

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

Table 9. Effect of different matrices on soil electrical conductivity on incubation, dS m^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	0.58	0.53	0.48	0.44	0.49	0.56	0.41	0.49	NS
30th day	0.63	0.56	0.52	0.51	0.53	0.64	0.55	0.55	NS
45th day	0.69	0.64	0.64	0.53	0.55	0.68	0.56	0.62	NS
60th day	0.71	0.70	0.68	0.63	0.62	0.69	0.59	0.67	NS
Average increase per interval	0.04	0.06	0.07	0.08	0.04	0.04	0.05	0.06	

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

Table 10. Effect of different matrices on soil available N on incubation, g kg^{-1}

Treatment	15th day	30th day	45th day	60th day
T_1	0.530	0.620	0.418	0.318
T_2	0.604	0.648	0.448	0.378
T_3	0.494	0.608	0.424	0.392
T_4	0.560	0.678	0.484	0.442
T_5	0.504	0.428	0.408	0.372
T_6	0.608	0.462	0.446	0.382
T_7	0.204	0.268	0.276	0.202
T_8	0.224	0.294	0.224	0.242
CD (0.05)	0.015	0.029	0.012	0.020

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

4.1.4. Available Phosphorus

Perusal of the data revealed that the treatments had a significant influence on available P status in soil. Available P recorded an increasing pattern from 0th day to 45th day and then a decreasing pattern (Table 11). The highest peak was observed on

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45th day after incubation for all treatments and among which the highest value (0.160 g kg^{-1}) was shown by 2:1 granule. Even though there was a decreasing trend after 45th day in all the treatments, the 2:1 granule showed the highest value on 60th day also.

4.1.5. Available potassium

Available K showed a significant difference between the treatments. Soil available potassium status increased in all the treatments throughout the incubation period (Table 12). The highest peak at 15th day (0.068 g kg^{-1}), 30th day (0.088 g kg^{-1}),

Table 11. Effect of different matrices on soil available P on incubation, g kg^{-1}

Treatments	15th day	30th day	45th day	60th day
T_1	0.096	0.114	0.144	0.110
T_2	0.116	0.134	0.158	0.110
T_3	0.116	0.140	0.154	0.122
T_4	0.106	0.128	0.160	0.130
T_5	0.108	0.110	0.142	0.086
T_6	0.098	0.104	0.140	0.124
T_7	0.070	0.082	0.090	0.056
T_8	0.078	0.086	0.090	0.052
CD (0.05)	0.03	0.018	0.016	0.016

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

Table 12. Effect of different matrices on soil available K on incubation, g kg^{-1}

Treatments	15th day	30th day	45th day	60th day
T_1	0.056	0.096	0.11	0.130
T_2	0.052	0.09	0.108	0.122
T_3	0.066	0.076	0.102	0.110
T_4	0.068	0.088	0.100	0.136
T_5	0.062	0.060	0.080	0.100
T_6	0.060	0.060	0.082	0.104
T_7	0.022	0.034	0.042	0.072
T_8	0.020	0.034	0.042	0.062
CD (0.05)	0.009	0.003	0.006	0.008

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

45th day (0.11 g kg^{-1}) and 60th day (0.136 g kg^{-1}) were recorded by 2:1 granule. A significant increase in the available K was seen in control also, which increased from 0.2 g kg^{-1} to 0.72 g kg^{-1}.

4.1.6. Available Calcium

Soil available Ca was almost stable in the initial period of incubation and later a slight increase was observed (Table 13). However there was no much drastic difference in values at different sampling intervals and the value ranged from 200 mg kg^{-1} to 216.67 mg kg^{-1}. An average increase in exchangeable Ca was observed between different intervals for each treatment.

4.1.7. Available Manganese

The results revealed that the treatments had no significant influence on available Mg status throughout the incubation period, even though a slight increase in Mg content was observed from the initial status (Table 14). The value ranged from

68.92 mg kg^{-1} to 73.6 mg kg^{-1}. An average increase in Mg content per interval was observed and it ranged from 1 mg kg^{-1} to 1.2 mg kg^{-1}.The highest increase per interval was observed in both 2:1 disc and 2:1 granular matrix.

4.1.8 Available Sulphur

Available sulphur content during the incubation period increased as compared to the initial value (Table 15). The average increase in sulphur content per interval ranged from 0.07 mg kg^{-1} to 0.16 mg kg^{-1}. The overall observation during the two month period showed that the sulphur content was increased due to the application of matrix based fertilizer.

Table 13. Effect of different matrices on soil available Ca on incubation, mg kg^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15^{th} day	200.0	210.0	203.3	206.7	210.0	216.7	200.0	203.3	NS
30^{th} day	200.0	210.0	203.3	206.7	210.0	216.7	200.0	203.3	NS
45^{th} day	206.7	213.3	210.0	220.0	216.7	216.7	206.7	210.0	NS
60^{th} day	210.0	220.0	213.3	220.0	220.0	220.0	210.0	216.7	NS
Average increase per interval	3.32	3.44	3.44	4.43	3.32	1.10	3.33	3.21	

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

Table 14. Effect of different matrices on soil available Mg on incubation, mg kg^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	69.22	70.4	68.92	68.98	67.37	69.53	70.32	70.71	NS
30th day	70.58	70.47	70.08	70.05	69.39	70.5	71.09	70.78	NS
45th day	70.58	71.47	70.34	71.22	70.23	70.58	72.43	71.43	NS
60th day	72.58	71.92	72.63	72.21	70.51	72.43	73.33	73.6	NS
Average increase per interval	1.1	1.00	1.20	1.20	1.0	1.00	1.00	1.00	

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

Table 15. Effect of different matrices in soil available S on incubation, mg kg^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	2.88	3.08	3.08	3.33	2.86	3.02	3.03	3.08	NS
30th day	2.96	3.14	3.33	3.59	3.00	3.15	3.22	3.18	NS
45th day	2.96	3.25	3.45	3.67	3.10	3.19	3.24	3.38	NS
60th day	3.25	3.4	3.55	3.80	3.17	3.24	3.50	3.41	NS
Average increase per interval	0.12	0.11	0.16	0.16	0.10	0.07	0.16	0.11	

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

4.1.9 Micronutrients

It is inferred from the table that there was not much difference in available Fe, Mn, Zn, Cu and B content during the incubation period (Tables 16, 17, 18, 19 and 20). But an average increase was seen between the intervals in all the micronutrients except Fe. There was a fluctuation in the status of available Fe at different intervals. In case of available B and Zn the highest average increase per interval (0.015 mg kg^{-1} and 0.020 mg kg^{-1}, respectively) was recorded for 2:1 granular matrix. Available Mn content was almost stable throughout the period of incubation with a slight average increase per interval. Average increase in Cu per interval ranged from 0.004 to 0.028 mg kg^{-1}.

Data of the incubation study showed that granular form of matrix is more efficient in nutrient release in comparison with disc forms. Among the various matrices 2:1 granular form recorded prolonged and sustained release of N, P and K nutrients even after 60 days of incubation and hence 2:1 granular form was selected for pot culture experiment.

Table 16. Effect of different matrices on soil available Fe on incubation , mg kg^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	20.82	20.92	22.68	22.59	22.09	21.66	22.63	23.95	NS
30th day	19.73	19.24	20.13	20.31	20.53	19.22	21.46	21.85	NS
45th day	20.83	20.25	22.12	22.55	21.93	21.25	23.34	22.63	NS
60th day	20.14	19.62	21.66	22.06	20.85	20.93	21.46	21.34	NS
Average decrease per interval	0.23	0.53	0.20	0.17	0.41	0.40	0.39	0.87	

T_1- 1:1 Disc, T_2- 1:1 granule, T_3- 2:1 Disc, T_4- 2:1 granular, T_5- 0.5:1 Disc, T_6- 0.5:1 granular, T_7- Matrix alone Disc (control), T_8- Matrix alone granule (control)

Table 17. Effect of different matrices on soil available Mn on incubation, mg kg^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	2.5	2.7	2.7	2.7	2.6	2.7	2.7	2.7	NS
30th day	2.7	2.7	2.8	2.7	2.9	2.8	2.8	2.7	NS
45th day	2.8	2.9	3.0	2.7	3.0	2.8	2.9	2.9	NS
60th day	2.9	3.0	3.0	3.1	3.0	2.8	2.9	2.9	NS
Average increase per interval	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

Table 18. Effect of different matrices on soil available Zn on incubation, mg kg^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	0.503	0.519	0.527	0.552	0.521	0.525	0.523	0.505	NS
30th day	0.523	0.534	0.529	0.579	0.538	0.544	0.542	0.522	NS
45th day	0.541	0.556	0.538	0.587	0.550	0.557	0.568	0.547	NS
60th day	0.552	0.566	0.554	0.612	0.567	0.566	0.575	0.556	NS
Average increase per interval	0.017	0.016	0.009	0.020	0.015	0.016	0.017	0.017	

T_1- 1:1 Disc, T_2- 1:1 granule, T_3- 2:1 Disc, T_4- 2:1 granular, T_5- 0.5:1 Disc, T_6- 0.5:1 granular, T_7- Matrix alone Disc (control), T_8- Matrix alone granule (control)

Table 19. Effect of different matrices on soil available Cu on incubation, mg kg^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	0.423	0.411	0.404	0.432	0.465	0.414	0.411	0.403	NS
30th day	0.434	0.432	0.423	0.439	0.466	0.418	0.440	0.426	NS
45th day	0.448	0.451	0.433	0.451	0.474	0.454	0.450	0.457	NS
60th day	0.439	0.475	0.444	0.466	0.477	0.472	0.464	0.487	NS
Average increase per interval	0.005	0.021	0.013	0.012	0.004	0.019	0.018	0.028	

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

Table 20. Effect of different matrices on soil available B on incubation, mg kg^{-1}

Days of incubation	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CD (0.05)
15th day	0.134	0.129	0.122	0.116	0.125	0.127	0.143	0.148	NS
30th day	0.146	0.153	0.132	0.134	0.143	0.135	0.166	0.155	NS
45th day	0.164	0.156	0.159	0.153	0.155	0.144	0.168	0.166	NS
60th day	0.166	0.167	0.163	0.162	0.157	0.167	0.173	0.189	NS
Average increase per interval	0.011	0.012	0.014	0.015	0.011	0.013	0.010	0.013	

T_1- 1:1 disc, T_2- 1:1 granule, T_3- 2:1 disc, T_4- 2:1 granular, T_5- 0.5:1 disc, T_6- 0.5:1 granular, T_7- Matrix alone disc, T_8- Matrix alone granule

4.2 EVALUATION OF THE EFFECT OF MATRIX BASED SLOW RELEASE FERTILIZER IN INCREASING NUTRIENT USE EFFICIENCY

4.2.1 Biometric observation

4.2.1.1 Plant height

Influence of matrix based fertilizer on plant height of tomato was given in table 21. There was a significant influence of matrix based fertilizer on plant height. The highest plant height (35.6 cm) was recorded for 50% fertilizer entrapped matrix in two split (T_9) and it was on par with T_1(POP), T_3 (POP -2 split), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 split) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).

4.2.1.2 Number of branches per plant

Influence of organic matrix based slow release fertilizer on number of branches per plant is given in table 21. There was no significant influence on number of branches per plant due to the application of various treatments.

4.2.1.3 Days to first flowering

Data on the influence of matrix based slow release fertilizer on days to first flowering in tomato was recorded and are presented in table 21. There was no significant difference between the treatments on days to first flowering.

4.2.1.4 Days to fruit set

Influence of matrix based slow release fertilizer on days to fruit set was recorded and are given in table 22. The data revealed that there was no significant difference in days to fruit set among treatments.

4.2.1.5 Fruit set per cent

Results on the influence of matrix based slow release fertilizer on fruit set per cent are given in table 22. A significant difference among the treatments were observed. The maximum value for fruit set per cent (80.3%) was recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and it was on par with T_1 (POP), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).

Table 21.Effect of matrix based slow release fertilizers on biometric characters of tomato

Treatment	Plant height (cm)	Number of branches per plant	Days to first flowering
T_1-POP 3 split	31.8	1.8	27.6
T_2 –POP basal	30.0	1.7	30.6
T_3- POP 2split	31.7	1.3	27.3
T_4- *100% fertilizer entrapped - basal	30.5	2.3	27.6
T_5- 100% fertilizer entrapped - two split	32.9	2.0	26.3
T_6- 75% fertilizer entrapped - basal	29.8	2.0	26.6
T_7- 75% fertilizer entrapped – two split	34.6	2.3	25.6
T_8- 50% fertilizer entrapped - basal	30.6	1.7	25.3
T_9- 50% fertilizer entrapped – two splits	35.6	2.3	25.0
T_{10}- matrix alone	30.6	1.3	30.3
CD (0.05)	3.851	NS	NS

Note:* POP NPK (KAU, 2014)

Table 22. Effect of matrix based slow release fertilizers on days to flowering and fruit set per cent in tomato

Treatment	Days to fruit set	Fruit set per cent
T_1-POP 3 split	31.6	75.3
T_2 –POP basal	32.0	62.6
T_3- POP 2split	34.6	63.0
T_4- *100% fertilizer entrapped - basal	33.3	62.5
T_5- 100% fertilizer entrapped - two split	33.6	75.0
T_6- 75% fertilizer entrapped - basal	35.3	54.8
T_7- 75% fertilizer entrapped – two split	35.3	75.7
T_8- 50% fertilizer entrapped – basal	30.3	62.4
T_9- 50% fertilizer entrapped – two splits	31.0	80.3
T_{10}- matrix alone	37.0	60.0
CD (0.05)	NS	5.694

Note:* POP NPK (KAU, 2014)

4.2.2 Yield and yield attributes

4.2.2.1 Fruits per plant

Influence of matrix based slow release fertilizer on number of fruits per plant was recorded and are given in table 23. The maximum number of fruits per plant was 32.3 for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and which was on par with T_1 (POP), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).

4.2.2.2 Fruit weight

The effect of matrix based slow release fertilizer on fruit weight (g) is given in table 23.The statistical analysis of the data proved that organic matrix based slow release fertilizers had a significant influence on fruit weight. The highest fruit weight

(24.5 g) was recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and which was on par with all other treatments except T_{10} (matrix alone).

4.2.2.3 Yield per plant (kg plant^{-1})

Data on the influence of matrix based slow release fertilizer on yield per plant is given in table 23. The critical evaluation of data revealed that matrix based fertilizer application had significant influence on yield per plant. The highest yield per plant of 0.79 kg (Plate 12) was recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and lowest yield was recorded for T_{10} (0.46 kg plant^{-1}) (Plate 13).

Table 23. Effect of matrix based slow release fertilizers on number of fruits per plant, fruit weight (g) and yield (kg plant^{-1}) of tomato

Treatment	Number of fruits per plant	Fruit weight	Yield
T_1-POP 3 split	30.7	23.7	0.70
T_2 –POP basal	28.0	22.8	0.64
T_3- POP 2split	29.7	22.3	0.66
T_4- *100% fertilizer entrapped - basal	28.3	21.3	0.65
T_5- 100% fertilizer entrapped - two split	31.3	22.3	0.70
T_6- 75% fertilizer entrapped - basal	29.3	21.0	0.65
T_7- 75% fertilizer entrapped – two split	31.0	23.7	0.73
T_8- 50% fertilizer entrapped - basal	29.0	23.3	0.68
T_9- 50% fertilizer entrapped – two splits	32.3	24.5	0.79
T_{10}- matrix alone	24.0	19.0	0.46
CD (0.05)	1.867	3.569	0.095

Note:* POP NPK (KAU, 2014)

Plate 12. Highest yielding treatment – T_9

Plate 13. Lowest yielding treatment - T_{10}

4.2.3 Quality parameters

4.2.3.1 Lycopene (μg g^{-1})

Results on the influence of matrix based slow release fertilizers on lycopene content is given in table 24. The data revealed that there was no significant difference among the treatments. The lycopene content ranged from 0.094 to 0.117 μg g^{-1}.

4.2.3.2 Ascorbic acid content (mg $100g^{-1}$)

Data on the influence of matrix based slow release fertilizer on ascorbic acid content of tomato is given in table 24. The critical assessment of data showed that the maximum ascorbic acid content of 22.3 mg $100g^{-1}$ was recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits).Treatment T_8 recorded the lowest ascorbic acid content (18.0 mg $100g^{-1}$).

Table 24. Effect of matrix based slow release fertilizers on quality parameters of tomato

Treatment	TSS (%)	Lycopene (μg g^{-1})	Ascorbic acid (mg $100g^{-1}$)
T_1-POP 3 split	4.63	0.106	22.0
T_2 –POP basal	4.00	0.106	20.3
T_3- POP 2 split	4.07	0.100	21.3
T_4- *100% fertilizer entrapped - basal	3.67	0.112	18.7
T_5- 100% fertilizer entrapped - two split	4.67	0.101	21.7
T_6- 75% fertilizer entrapped - basal	3.67	0.098	20.0
T_7- 75% fertilizer entrapped – two split	4.7	0.117	22.0
T_8- 50% fertilizer entrapped - basal	3.17	0.113	18.0
T_9- 50% fertilizer entrapped – two splits	5.33	0.117	22.3
T_{10}- matrix alone	3.33	0.094	22.0
CD (0.05)	0.746	NS	1.675

Note:* POP NPK (KAU, 2014)

4.2.4 Influence of matrix based slow release fertilizers on soil parameters after harvest

4.2.4.1 pH

The influence of matrix based fertilizers on soil pH is presented in table 25. The statistical analysis revealed a significant difference in soil pH among the various treatments. The treatments with matrix entrapped fertilizers recorded a higher pH as compared to the treatments without matrices. Strong acidity is reduced to moderate acidity as pH increased from 5.2 to 5.98.

4.2.4.2 Electrical conductivity

The influence of organic matrix based fertilizers on electrical conductivity is mentioned in table 25. There was a significant difference in electrical conductivity due to various treatments. The highest value for EC was recorded for T_5 (100% fertilizer entrapped matrix in two splits).

4.2.4.3 Organic carbon

The effect of organic matrix based slow release fertilizers on soil organic carbon is presented in table 25. The critical appraisal revealed that there was no significant difference in soil organic carbon content after the experiment.

4.2.4.4 Available primary nutrients

The NPK status of soil from the experimental pots were analysed and the results are given in table 26. The critical evaluation revealed that the application of organic matrix entrapped NPK fertilizers had significant influence on the NPK status of soil after harvest. The highest content for available nitrogen (250.9 kg ha^{-1}), and potassium (215.8 kg ha^{-1}) was recorded by T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and was found to be on a par with all other matrix entrapped fertilizer treatments except T_8 (50% fertilizer entrapped matrix basal) and T_{10} (matrix alone) , but in case of phosphorus highest value (53.39 kg ha^{-1}) was recorded for T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and it was on par with all matrix entrapped treatments except T_{10}.

Table 25.Effect of matrix based slow release fertilizers on pH, EC and organic carbon of soil after harvest

Treatment	pH	EC (dS m^{-1})	Organic carbon (%)
T_1- POP 3 split	5.44	0.41	0.51
T_2 - POP basal	5.23	0.36	0.50
T_3- POP 2 split	5.5	0.38	0.46
T_4- *100% fertilizer entrapped - basal	5.88	0.58	0.60
T_5- 100% fertilizer entrapped - two split	5.91	0.75	0.59
T_6- 75% fertilizer entrapped - basal	5.8	0.47	0.56
T_7- 75% fertilizer entrapped – two split	5.82	0.74	0.63
T_8- 50% fertilizer entrapped - basal	5.65	0.54	0.61
T_9- 50% fertilizer entrapped – two splits	5.8	0.68	0.58
T_{10}- matrix alone	5.98	0.23	0.64
CD (0.05)	0.354	0.158	NS

Note:* POP NPK (KAU, 2014)

4.2.4.5 Available secondary nutrients

Data on available secondary nutrient status after the experiment is given in table 27. The statistical analysis of data revealed that the treatments had a significant influence on Ca and Mg status and did not have any significant effect on S status of soil. The highest Ca (248.9 mg kg^{-1}) and Mg (60 mg kg^{-1}) status were recorded for T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and were found to be on par with all matrix based fertilizer treatments.

Table 26. Effect of matrix based slow release fertilizers on N, P and K status of soil after harvest, kg ha^{-1}

Treatment	N	P	K
T_1-POP 3 split	204.9	36.2	105.3
T_2 –POP basal	184.0	33.71	98.8
T_3- POP 2 split	188.2	38.65	126.3
T_4- *100% fertilizer entrapped - basal	242.5	46.70	202.4
T_5- 100% fertilizer entrapped - two split	250.9	53.39	215.8
T_6- 75% fertilizer entrapped - basal	227.4	49.62	171.2
T_7- 75% fertilizer entrapped – two split	238.3	52.52	167.2
T_8- 50% fertilizer entrapped - basal	213.3	44.75	155.5
T_9- 50% fertilizer entrapped – two splits	223.5	45.38	169.0
T_{10}- matrix alone	169.8	32.41	69.0
CD (0.05)	36.79	8.68	51.78

Note:* POP NPK (KAU, 2014)

Table 27. Effect of matrix based slow release fertilizers on Ca , Mg and S status of soil after harvest, mg kg^{-1}

Treatment	Ca	Mg	S
T_1-POP 3 split	213.3	41.7	2.23
T_2 –POP basal	210.0	47.0	2.30
T_3- POP 2 split	229.8	48.7	2.28
T_4- *100% fertilizer entrapped - basal	235.3	54.3	3.53
T_5- 100% fertilizer entrapped - two split	248.9	60.0	2.45
T_6- 75% fertilizer entrapped - basal	236.1	53.7	2.60
T_7- 75% fertilizer entrapped – two split	245.7	58.3	2.35
T_8- 50% fertilizer entrapped - basal	231.7	54.4	2.76
T_9- 50% fertilizer entrapped – two splits	238.9	56.7	2.34
T_{10}- matrix alone	235.7	51.5	2.30
CD (0.05)	18.36	8.85	NS

Note:* POP NPK (KAU, 2014)

4.2.4.6 Available micronutrients

The effect of treatments on the available micronutrient status were recorded and are given in tables 28 and 29.The critical appraisal of the data showed that only B and Zn content were significantly influenced by the treatments. The treatment T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) recorded the maximum B (0.281 mg kg^{-1}) and Zn (0.519 mg kg^{-1}) status. The treatments did not show significant influence on available Fe, Mn and Cu status in soil.

Table 28. Effect of matrix based slow release fertilizers on B, Fe and Mn status of soil after harvest, mg kg^{-1}

Treatment	B	Fe	Mn
T_1-POP 3 split	0.187	12.61	3.63
T_2 –POP basal	0.199	12.87	4.13
T_3- POP 2 split	0.179	12.74	4.27
T_4- *100% fertilizer entrapped - basal	0.255	14.22	5.51
T_5- 100% fertilizer entrapped - two split	0.281	14.27	6.99
T_6- 75% fertilizer entrapped - basal	0.253	13.51	4.59
T_7- 75% fertilizer entrapped – two split	0.271	13.65	6.36
T_8- 50% fertilizer entrapped - basal	0.219	13.18	5.40
T_9- 50% fertilizer entrapped – two splits	0.271	13.20	4.93
T_{10}- matrix alone	0.227	13.57	4.71
CD (0.05)	0.059	NS	NS

Note:* POP NPK (KAU, 2014)

Table 29. Effect of matrix based slow release fertilizers on Zn and Cu status of soil after harvest, mg kg^{-1}

Treatment	Zn	Cu
T_1-POP 3 split	0.391	0.87
T_2 –POP basal	0.358	0.89
T_3- POP 2 split	0.428	0.84
T_4- *100% fertilizer entrapped - basal	0.461	0.89
T_5- 100% fertilizer entrapped - two split	0.519	0.79
T_6- 75% fertilizer entrapped - basal	0.477	0.87
T_7- 75% fertilizer entrapped – two split	0.495	0.86
T_8- 50% fertilizer entrapped - basal	0.469	0.86
T_9- 50% fertilizer entrapped – two splits	0.491	0.85
T_{10}- matrix alone	0.468	0.87
CD (0.05)	0.065	NS

Note:* POP NPK (KAU, 2014)

4.2.5 Effect of matrix based slow release fertilizer on the nutrient content of index leaf

4.2.5.1 Primary nutrients

Nutrient content of index leaf reflects the actual nutrient status of crop at its critical growth stages. The NPK content in the index leaf was analysed and presented in table 30.The statistical analysis revealed that the matrix entrapped fertilizer application had significant influence on NPK content of index leaf. The highest N (2.78%), P (0.195%) and K (1.77%) status were recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and they were on par with T_1 (POP), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).

Table 30. Effect of matrix based slow release fertilizers on content of N, P and K of the index leaf of tomato, %

Treatments	N	P	K
T_1-POP 3 split	2.57	0.182	1.64
T_2 –POP basal	2.24	0.145	1.56
T_3- POP 2 split	2.26	0.160	1.57
T_4- *100% fertilizer entrapped - basal	2.26	0.163	1.50
T_5- 100% fertilizer entrapped - two split	2.59	0.177	1.62
T_6- 75% fertilizer entrapped - basal	2.22	0.143	1.42
T_7- 75% fertilizer entrapped – two split	2.76	0.192	1.65
T_8- 50% fertilizer entrapped - basal	1.72	0.143	1.37
T_9- 50% fertilizer entrapped – two splits	2.78	0.195	1.77
T_{10}- matrix alone	1.70	0.128	1.22
CD (0.05)	0.220	0.031	0.186

Note:* POP NPK (KAU, 2014)

4.2.5.2 Secondary nutrients

The findings on the effect of treatments on Ca, Mg and S content of the index leaf is depicted in table 31. Treatments showed a significant influence on Ca and Mg content but it was not significant in the case of S. T_9 recorded the highest value for Ca (0.186%) and Mg (0.168%) and was on par with all other treatments except T_1 (POP), T_2 (POP- basal) and T_3 (POP-2 split).

4.2.5.3 Micronutrients

The micronutrient content (Fe, Mn, Zn, B and Cu) of the index leaf was analysed and presented in table 32 and 33. Only available Zn (16.15 mg kg^{-1}) and B (4.9 mg kg^{-1}) were significantly influenced by the treatments. The highest values were recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and were on par with all other treatments except T_1 (POP), T_2 (POP- basal) and T_3 (POP-2 split).

Table 31. Effect of matrix based slow release fertilizers on content of Ca, Mg and S of the index leaf of tomato, %

Treatment	Ca	Mg	S
T_1-POP 3 split	0.137	0.115	0.127
T_2 –POP basal	0.129	0.101	0.121
T_3- POP 2 split	0.130	0.133	0.124
T_4- *100% fertilizer entrapped - basal	0.172	0.150	0.117
T_5- 100% fertilizer entrapped - two split	0.174	0.161	0.115
T_6- 75% fertilizer entrapped - basal	0.173	0.147	0.133
T_7- 75% fertilizer entrapped – two split	0.180	0.165	0.120
T_8- 50% fertilizer entrapped - basal	0.184	0.153	0.128
T_9- 50% fertilizer entrapped – two splits	0.186	0.168	0.116
T_{10}- matrix alone	0.173	0.151	0.100
CD (0.05)	0.042	0.032	NS

Note:* POP NPK (KAU, 2014)

Table 32. Effect of matrix based slow release fertilizers on content of Fe, Mn and Zn of the index leaf of tomato, mg kg^{-1}

Treatment	Fe	Mn	Zn
T_1-POP 3 split	3.23	1.20	13.72
T_2 –POP basal	3.09	0.82	14.84
T_3- POP 2 split	3.34	1.02	15.04
T_4- *100% fertilizer entrapped - basal	3.13	0.48	15.24
T_5- 100% fertilizer entrapped - two split	3.27	1.57	15.42
T_6- 75% fertilizer entrapped - basal	3.03	1.05	15.41
T_7- 75% fertilizer entrapped – two split	3.34	1.42	16.14
T_8- 50% fertilizer entrapped - basal	3.09	1.29	15.30
T_9- 50% fertilizer entrapped – two splits	3.34	1.57	16.15
T_{10}- matrix alone	3.21	0.822	15.28
CD (0.05)	NS	NS	0.931

Note:* POP NPK (KAU, 2014)

Table 33. Effect of matrix based slow release fertilizers on content of Cu and B of the index leaf of tomato, mg kg^{-1}

Treatment	Cu	B
T_1-POP 3 split	0.066	3.2
T_2 –POP basal	0.059	3.3
T_3- POP 2 split	0.071	3.4
T_4- *100% fertilizer entrapped - basal	0.057	4.0
T_5- 100% fertilizer entrapped - two split	0.075	4.4
T_6- 75% fertilizer entrapped - basal	0.076	3.9
T_7- 75% fertilizer entrapped – two split	0.069	4.4
T_8- 50% fertilizer entrapped - basal	0.057	4.0
T_9- 50% fertilizer entrapped – two splits	0.052	4.9
T_{10}- matrix alone	0.063	4.1
CD (0.05)	NS	1.007

Note:* POP NPK (KAU, 2014)

4.2.6 Effect of matrix based slow release fertilizer on the nutrient content of plant

4.2.6.1 Primary nutrients

The NPK content of plant sample was analysed and depicted in table 34. The statistical analysis proved that the application of organic matrix entrapped chemical fertilizers had significant influence on NPK content in plant. The treatment T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) recorded the highest value for N (2.14%), P (0.538%) and K (2.62%) content and were on par with T_1 (POP), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).

4.2.6.2 Secondary nutrients

Influence of organic matrix entrapped chemical fertilizers on Ca, Mg and S content in plant were analysed and presented in table 35. The data revealed that the treatments had a significant influence on Ca and Mg content in plant. The maximum Ca content (0.149%) and Mg content (0.165%) were reported for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and were on par with all other treatments except T_1 (POP), T_2 (POP- basal) and T_3 (POP-2 split). The matrix entrapped NPK fertilizers did not show any significant influence on S content of plant.

4.2.6.3 Micronutrients

The effect of organic matrix entrapped chemical fertilizers on micronutrient content in plant sample was analysed and presented in table 36 and 37. The statistical evaluation proved that only Zn and B content were significantly influenced by the treatments and Fe, Mn and Cu content were not significantly influenced. The highest value for Zn (15.81 mg kg^{-1}) and B (4.4 mg kg^{-1}) were recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and were on par with all other treatments except T_1 (POP), T_2 (POP- basal) and T_3 (POP-2 split).

Table 34. Effect of matrix based slow release fertilizers on content of N, P and K in the tomato plant, %

Treatment	N	P	K
T_1-POP 3 split	2.07	0.499	2.40
T_2 –POP basal	1.79	0.452	1.80
T_3- POP 2 split	1.84	0.463	2.02
T_4- *100% fertilizer entrapped - basal	1.73	0.444	1.84
T_5- 100% fertilizer entrapped - two split	1.88	0.504	2.36
T_6- 75% fertilizer entrapped - basal	1.71	0.444	1.74
T_7- 75% fertilizer entrapped – two split	2.10	0.523	2.41
T_8- 50% fertilizer entrapped - basal	1.60	0.433	1.65
T_9- 50% fertilizer entrapped – two splits	2.14	0.538	2.62
T_{10}- matrix alone	1.58	0.429	1.42
CD (0.05)	0.266	0.066	0.269

Note:* POP NPK (KAU, 2014)

Table 35. Effect of matrix based slow release fertilizers on content of Ca, Mg and S in the tomato plant, %

Treatments	Ca	Mg	S
T_1-POP 3 split	0.112	0.115	0.301
T_2 –POP basal	0.112	0.105	0.196
T_3- POP 2 split	0.115	0.106	0.243
T_4- *100% fertilizer entrapped - basal	0.141	0.144	0.365
T_5- 100% fertilizer entrapped - two split	0.147	0.150	0.264
T_6- 75% fertilizer entrapped - basal	0.124	0.132	0.118
T_7- 75% fertilizer entrapped – two split	0.147	0.153	0.290
T_8- 50% fertilizer entrapped - basal	0.144	0.150	0.162
T_9- 50% fertilizer entrapped – two splits	0.149	0.165	0.392
T_{10}- matrix alone	0.144	0.131	0.377
CD (0.05)	0.033	0.035	NS

Note:* POP NPK (KAU, 2014)

Table 36. Effect of matrix based slow release fertilizers on content of Fe, Mn and Zn in the tomato plant, mg kg^{-1}

Treatment	Fe	Mn	Zn
T_1-POP 3 split	3.05	1.02	14.18
T_2 –POP basal	3.33	1.20	14.29
T_3- POP 2 split	3.09	0.83	14.85
T_4- *100% fertilizer entrapped - basal	3.21	0.49	15.29
T_5- 100% fertilizer entrapped - two split	3.13	1.20	15.71
T_6- 75% fertilizer entrapped - basal	3.02	1.57	15.42
T_7- 75% fertilizer entrapped – two split	3.26	1.43	15.77
T_8- 50% fertilizer entrapped - basal	3.34	1.30	15.33
T_9- 50% fertilizer entrapped – two splits	3.09	1.06	15.81
T_{10}- matrix alone	3.23	0.82	15.19
CD (0.05)	NS	NS	0.756

Note:* POP NPK (KAU, 2014)

Table 37. Effect of matrix based slow release fertilizers on content of B and Cu in the tomato plant, mg kg^{-1}

Treatment	B	Cu
T_1-POP 3 split	3.0	0.085
T_2 –POP basal	3.0	0.079
T_3- POP 2 split	3.1	0.091
T_4- *100% fertilizer entrapped - basal	3.7	0.076
T_5- 100% fertilizer entrapped - two split	3.8	0.084
T_6- 75% fertilizer entrapped - basal	3.5	0.086
T_7- 75% fertilizer entrapped – two split	3.7	0.081
T_8- 50% fertilizer entrapped - basal	3.9	0.077
T_9- 50% fertilizer entrapped – two splits	4.4	0.072
T_{10}- matrix alone	3.8	0.083
CD (0.05)	1.009	NS

Note:* POP NPK (KAU, 2014)

4.2.7 Effect of matrix based slow release fertilizers on the nutrient content of fruit

4.2.7.1 Effect of treatments on content of primary nutrients in fruit

The effect of organic matrix entrapped chemical fertilizers on primary nutrient content of fruit was analysed and presented in table 38. The critical evaluation of data showed that the treatments significantly influenced the NPK content in fruit. The highest values for N (3.69%), P (0.555%) and K (2.2%) were reported for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and were on par with T_1 (POP), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).

4.2.7.2 Effect of treatments on content of secondary nutrients in fruit

The influence of organic matrix entrapped chemical fertilizers on Ca, Mg and S content of fruit was analysed and presented in table 39. The data revealed that the treatments had a significant influence only on Ca and Mg content and it was non-significant for S content in fruit. The highest values for Ca (0.157 %) and Mg (0.149 %) were reported for T_9 (50 % recommended dose entrapped matrix based fertilizer in 2 splits) and was on par with all other treatments except T_1 (POP), T_2 (POP-basal) and T_3 (POP-2 split).

4.2.7.3 Effect of treatments on content of micronutrients in fruit

The effect of organic matrix entrapped chemical fertilizers on micronutrient content of fruit was analysed and depicted in tables 40 and 41. The data revealed that the treatments had a significant influence on available Zn and B content and Fe, Mn and Cu content were non-significant. The highest value for Zn (16.89 mg kg^{-1}) and B (1.35 mg kg^{-1}) were recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and was on par with all other treatments except T_1 (POP), T_2 (POP-basal) and T_3 (POP-2 split).

Table 38. Effect of matrix based slow release fertilizers on content of N, P and K in fruit of tomato, %

Treatment	N	P	K
T_1-POP 3 split	3.54	0.517	1.95
T_2 –POP basal	3.18	0.421	1.54
T_3- POP 2 split	3.26	0.438	1.68
T_4- *100% fertilizer entrapped - basal	3.16	0.437	2.12
T_5- 100% fertilizer entrapped - two split	3.48	0.465	2.12
T_6- 75% fertilizer entrapped - basal	3.27	0.434	1.66
T_7- 75% fertilizer entrapped – two split	3.59	0.528	2.17
T_8- 50% fertilizer entrapped - basal	3.16	0.415	2.20
T_9- 50% fertilizer entrapped – two splits	3.69	0.555	2.20
T_{10}- matrix alone	2.80	0.398	1.38
CD (0.05)	0.245	0.105	0.333

Note:* POP NPK (KAU, 2014)

Table 39. Effect of matrix based slow release fertilizers on content of Ca, Mg and S in fruit of tomato, %

Treatment	Ca	Mg	S
T_1-POP 3 split	0.128	0.128	0.139
T_2 –POP basal	0.111	0.125	0.141
T_3- POP 2 split	0.128	0.128	0.144
T_4- *100% fertilizer entrapped - basal	0.148	0.139	0.129
T_5- 100% fertilizer entrapped - two split	0.155	0.142	0.134
T_6- 75% fertilizer entrapped - basal	0.140	0.142	0.132
T_7- 75% fertilizer entrapped – two split	0.155	0.146	0.137
T_8- 50% fertilizer entrapped - basal	0.148	0.145	0.137
T_9- 50% fertilizer entrapped – two splits	0.157	0.149	0.138
T_{10}- matrix alone	0.134	0.141	0.128
CD (0.05)	0.024	0.012	NS

Note:* POP NPK (KAU, 2014)

Table 40. Effect of matrix based slow release fertilizers on content of Fe, Mn and Zn in fruit of tomato, mg kg^{-1}

Treatment	Fe	Mn	Zn
T_1-POP 3 split	2.45	1.41	14.56
T_2 –POP basal	2.78	1.50	14.42
T_3- POP 2 split	3.29	1.62	14.57
T_4- *100% fertilizer entrapped - basal	3.50	1.58	15.96
T_5- 100% fertilizer entrapped - two split	3.36	1.39	16.12
T_6- 75% fertilizer entrapped - basal	3.54	1.35	15.96
T_7- 75% fertilizer entrapped – two split	3.45	0.91	16.16
T_8- 50% fertilizer entrapped - basal	3.56	0.85	16.00
T_9- 50% fertilizer entrapped – two splits	3.59	1.36	16.89
T_{10}- matrix alone	3.67	1.63	15.93
CD (0.05)	NS	NS	1.071

Note:* POP NPK (KAU, 2014)

Table 41. Effect of matrix based slow release fertilizers on content of B and Cu in fruit of tomato, mg kg^{-1}

Treatment	B	Cu
T_1-POP 3 split	0.84	0.065
T_2 –POP basal	0.81	0.067
T_3- POP 2 split	0.83	0.086
T_4- *100% fertilizer entrapped - basal	1.21	0.074
T_5- 100% fertilizer entrapped - two split	1.24	0.073
T_6- 75% fertilizer entrapped - basal	1.29	0.082
T_7- 75% fertilizer entrapped – two split	1.30	0.086
T_8- 50% fertilizer entrapped - basal	1.19	0.067
T_9- 50% fertilizer entrapped – two splits	1.35	0.085
T_{10}- matrix alone	1.11	0.081
CD (0.05)	0.50	NS

Note:* POP NPK (KAU, 2014)

4.2.8 Pest and disease incidence

Effect of organic matrix entrapped NPK fertilizers on pest and disease incidence was recorded. There was not much incidence of pest and disease except minor incidence of leaf miner.

4.2.9 NPK uptake in plant and fruit

4.2.9.1 NPK uptake in plant

Data on the effect of NPK uptake of plant is presented in table 44. The treatments showed significant difference in NPK uptake in plant. The highest N (0.683g plant^{-1}), P (0.172 g plant^{-1}) and K uptake (0.815 g plant^{-1}) was shown by T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and was on par with T_1 (POP), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).

Table 42. Effect of matrix based slow release fertilizers on N,P and K uptake by the tomato plant, g plant^{-1}

Treatment	N	P	K
T_1 -POP-3 split	0.679	0.163	0.797
T_2-POP- Basal	0.370	0.093	0.427
T_3-POP-2 Splits	0.454	0.114	0.454
T_4-100% Fertilizer entrapped matrix - basal	0.435	0.111	0.461
T_5-*100% Fertilizer entrapped matrix-2 split	0.581	0.159	0.740
T_6-75% fertilizer entrapped matrix - basal	0.485	0.126	0.495
T_7-75% fertilizer entrapped matrix- 2 split	0.673	0.168	0.771
T_8-50% fertilizer entrapped matrix- basal	0.427	0.116	0.440
T_9-50% fertilizer entrapped matrix- 2 split	0.683	0.172	0.815
T_{10}-matrix alone	0.241	0.065	0.213
CD (0.05)	0.076	0.014	0.085

Note:* POP NPK (KAU, 2014)

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4.2.9.2 NPK uptake in fruit

Data on the effect of NPK uptake in fruit is given in table 43. The treatments had a significant influence on NPK uptake in fruit. The highest N and K uptake was reported in T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits). It was on par with T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).In case of phosphorus the fruit uptake was highest for T_9 and was on par with T_1 (POP), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits).

Table 43. Effect of matrix based slow release fertilizers on NPK uptake by the tomato fruit, g plant^{-1}

Treatment	N	P	K
T_1-POP-3 split	2.58	0.376	1.60
T_2-POP- Basal	2.11	0.279	1.02
T_3-POP-2 Splits	2.21	0.279	1.07
T_4-100% Fertilizer entrapped matrix -basal	2.28	0.286	1.38
T_5-*100% Fertilizer entrapped matrix- 2 split	3.27	0.365	1.88
T_6-75% fertilizer entrapped matrix - basal	2.49	0.255	1.07
T_7-75% fertilizer entrapped matrix- 2 split	3.38	0.388	1.88
T_8-50% fertilizer entrapped matrix- basal	2.79	0.279	1.64
T_9-50% fertilizer entrapped matrix- 2 split	3.59	0.425	2.07
T_{10}-matrix alone	1.73	0.182	0.63
CD (0.05)	0.504	0.068	0.200

Note:* POP NPK (KAU, 2014)

4.2.10.1 Effect of treatments on nutrient use efficiency

The effect of organic matrix entrapped NPK fertilizer on Nutrient use efficiency (NUE) of Onattukara soil is presented in table 44. The nutrient use efficiency of T_1

(POP- KAU) was calculated as 18% while the highest NUE of 44% was recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits). The lowest NUE was shown by T_2 (12%).

Table 44. Effect of matrix based slow release fertilizers on nutrient use efficiency in tomato plant, %

Treatment	Nutrient use efficiency
T_1-POP-3 split	18.0
T_2 -POP- Basal	12.0
T_3-POP-2 Splits	13.3
T_4-*100% Fertilizer entrapped matrix - basal	12.7
T_5-100% Fertilizer entrapped matrix- 2 split	16.0
T_6-75% fertilizer entrapped matrix - basal	16.9
T_7-75% fertilizer entrapped matrix- 2 split	24.0
T_8-50% fertilizer entrapped matrix- basal	29.3
T_9-50% fertilizer entrapped matrix- 2 split	44.0

Note:* POP NPK (KAU, 2014)

4.2.10.2 Effect of treatments on apparent recovery efficiency (%) of N, P and K

The influence of matrix entrapped NPK fertilizers on apparent recovery efficiency of N, P and K are given in table 45. The highest apparent recovery efficiency for N (53.29%), P (22.96) and K (55.5%) were reported by T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits).

4.2.11 Economic analysis

4.2.11.1 Net income

The influence of organic matrix entrapped NPK fertilizer on net income is expressed in table 46 a and 46 b. Among the treatments, T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) recorded the highest net income of Rs.230097/- per ha and the lowest net income (Rs.45084/-) was recorded for T_{10}

(Matrix alone) (Table 46 a). Net income was worked out based on per plant yield also and the highest net income of Rs.14.29/- per plant was recorded by T_9 (Table 46 b).

Table 45.Effect of matrix based slow release fertilizers on apparent recovery efficiency in tomato plant, %

Treatment	N	P	K
T_1-POP-3 split	21.32	14.62	37.35
T_2-POP- Basal	9.86	7.31	19.14
T_3-POP-2 Splits	10.09	9.30	25.66
T_4-*100% Fertilizer entrapped matrix - basal	12.29	10.48	30.32
T_5-100% Fertilizer entrapped matrix- 2 split	32.78	12.82	40.34
T_6-75% fertilizer entrapped matrix - basal	28.33	10.63	39.68
T_7-75% fertilizer entrapped matrix- 2 split	46.21	20.56	43.71
T_8-50% fertilizer entrapped matrix- basal	41.35	14.71	45.84
T_9-50% fertilizer entrapped matrix-2 split	53.29	22.96	55.50

Note:* POP NPK (KAU, 2014)

4.2.11.2 B: C ratio

Results on the effect of organic matrix entrapped NPK fertilizer on benefit cost ratio of treatments presented in table 46. Among various treatments T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) recorded the highest B: C ratio of 2.1 and lowest B: C ratio (1.17) was recorded for T_{10} (Matrix alone) (Table

46 a). B: C ratio was worked out based on per plant yield also and the highest B: C ratio of 1.62 was recorded by T_9 (Table 46 b).

Table 46(a). Effect of matrix based slow release fertilizers on net income and B: C ratio (based on per hectare yield)

Treatment	Net income (Rs./ha)	B:C ratio
T_1-POP -3 split	165784	1.69
T_2 –POP -basal	147450	1.65
T_3- POP -2 split	166062	1.73
T_4- *100% fertilizer entrapped - basal	160378	1.70
T_5- 100% fertilizer entrapped - two split	174320	1.75
T_6- 75% fertilizer entrapped - basal	156682	1.70
T_7- 75% fertilizer entrapped – two split	193625	1.80
T_8- 50% fertilizer entrapped - basal	175988	1.80
T_9- 50% fertilizer entrapped – two splits	230097	2.10
T_{10}- matrix alone	45084	1.17

Note:* POP NPK (KAU, 2014)

Table 46 (b). Effect of matrix based slow release fertilizers on net income and B: C ratio (based on per plant yield in pot)

Treatment	Net income (Rs./plant)	B:C ratio
T_1-POP -3 split	7.52	1.34
T_2 –POP –basal	7.77	1.32
T_3- POP -2 split	8.20	1.40
T_4- *100% fertilizer entrapped - basal	8.30	1.35
T_5- 100% fertilizer entrapped - two split	8.50	1.42
T_6- 75% fertilizer entrapped - basal	8.23	1.40
T_7- 75% fertilizer entrapped – two split	9.60	1.50
T_8- 50% fertilizer entrapped - basal	11.34	1.58
T_9- 50% fertilizer entrapped – two splits	14.29	1.67
T_{10}- matrix alone	1.54	1.02

DISCUSSION

5. DISCUSSION

An investigation entitled "Matrix based slow release fertilizer for increasing nutrient use efficiency in the Onattukara sandy plains" was carried out during 2017-19 in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. Pot culture experiment was carried out at Onattukara Regional Agricultural Research Station, Kayamkulam for evaluating the efficiency of organic matrix based slow release fertilizers under Onattukara condition. The results of the study are discussed in this chapter.

5.1 DEVELOPING MATRIX BASED SLOW RELEASE FERTILIZER

Onattukara sandy loam soils are generally coarse textured with immature profiles and low nutrient and water retention capacity and major share of applied fertilizers are lost through leaching especially N and K (Mini and Mathew, 2015). Hence nutrient use efficiency of these fertilizers has to be enhanced for economic crop production in this area. Organic matrix entrapped NPK fertilizers is a new technology to the farmers in Onattukara region to achieve maximum fertilizer use efficiency in a cost effective manner.

The locally available agro waste materials like rice husk ash, clay, cow dung, rice husk, coir pith compost, vermicompost and neem cake were combined in various proportions to develop the organic matrix entrapped with NPK fertilizers. Singh *et al.* (2012) reported that granular OMEU (Organic matrix entrapped urea) was prepared from biodegradable agro waste materials like cow dung, rice bran, neem leaf powder and clay soil in 1:1:1:1 ratio, respectively. Among the various components cow dung, vermicompost (Vig *et al.*, 2013) and neem cake (Ketkar, 1974) will increase the availability of nitrogen and rice husk ash will serve as a major source of potassium (Priyadharshini and Seran, 2009). Coir pith compost will enhance the water holding capacity of the matrix (Chowdhury and Fatema, 2016). Clay was used as a binding agent and rice husk was added to get proper consistency for the matrix. From the various organic matrix entrapped NPK fertilizer combinations, 1:1:0.5:0.5:0.5:0.5:0.5 proportion was selected based on the high pH (6.02), low electrical conductivity(0.37 dS m^{-1}), low dissolution rate and low cost of production (Rs.5.64/- per kg) (Table 3). This is because the nutrient availability from such matrices mainly depend upon the pH, electrical conductivity and dissolution rate of matrix. Heikal and Khalil (2015) reported similar results in the study on controlled release fertilizers.

5.2 INCUBATION STUDY

From the first part of the study, organic matrix with 1:1:0.5:0.5:0.5:0.5:0.5 proportion was selected for entrapping NPK fertilizers. An incubation study was conducted using granular and disc forms of 0.5: 1, 1: 1 and 2: 1, matrix: fertilizer combinations to study the nutrient release pattern and changes in various soil properties at 15 days interval up to two months. Since only urea, rajphos and MOP were entrapped as nutrient sources, major thrust was given for nutrient release pattern of N, P and K. Since the organic matrix contains various nutrient sources like cow dung, vermicompost, neemcake, rice husk ash, coir pith compost etc. availability of secondary and micronutrients were also studied.

5.2.1 Soil pH and electrical conductivity

During period of incubation pH increased (Fig. 3) in all the treatments, which ranged from 5.31 to 5.6 and there was not much variation in electrical conductivity (Fig. 4). Even though, there was no significant difference between the treatments, there was an increase in pH and electrical conductivity between different intervals of sampling. Rice husk ash in the matrix may be the reason for increasing trend noted in the soil pH (Lekshmi and Mini, 2018).

5.2.2 Available nitrogen

The direct application of conventional urea is not efficient because of excessive N loss from Onattukara sandy soil. Thus it is necessary to increase the efficiency of

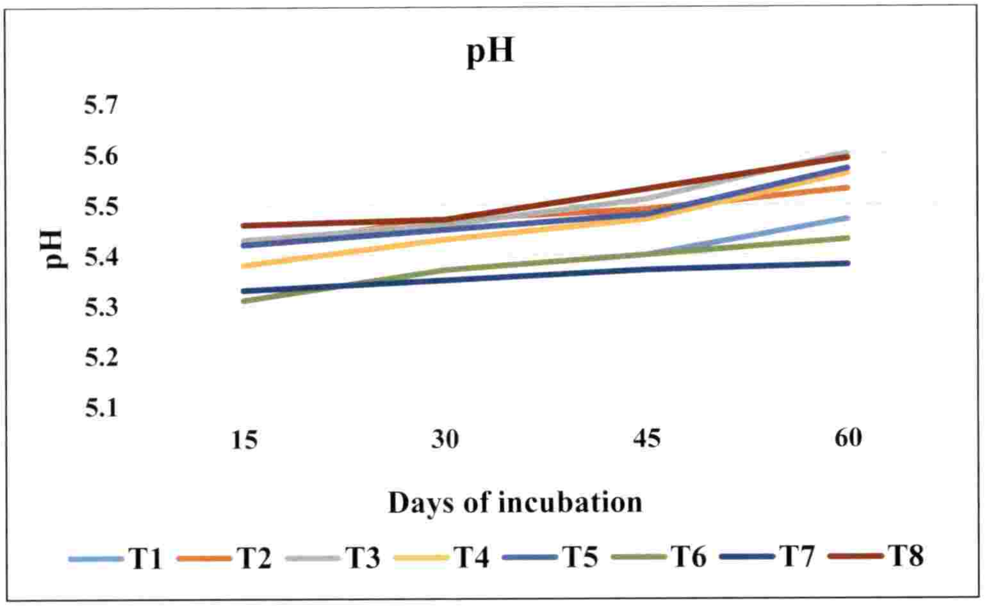

Fig. 3 Effect of different matrices on pH on incubation

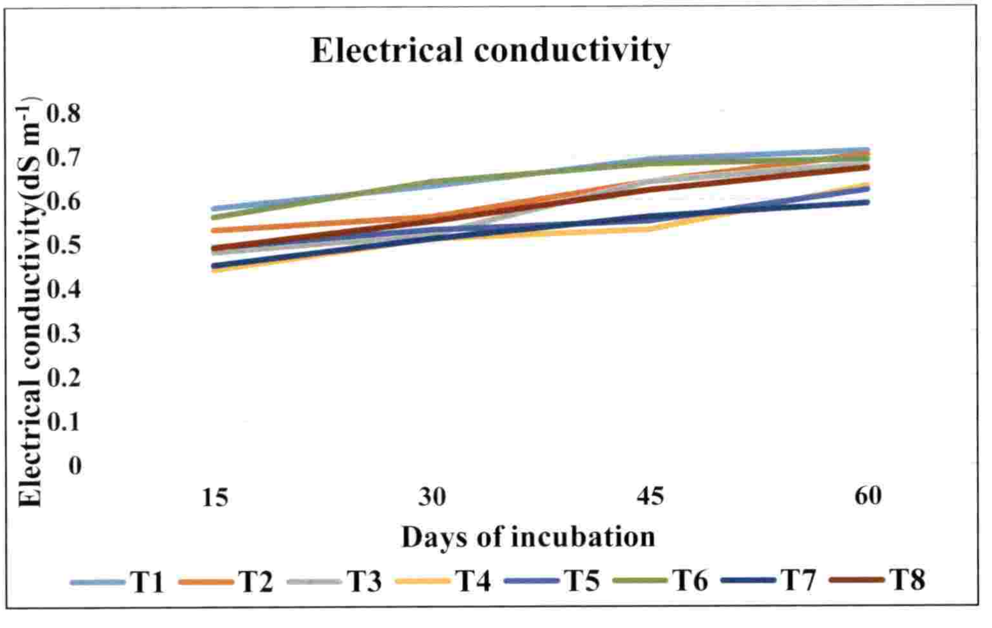

Fig 4. Effect of different matrices on electrical conductivity on incubation

conventional urea. The slow release / controlled release technology considered as a new technique for improving the gradual and synchronized release of nutrients with the nutritional requirement of the crop (Naz and Sulaiman, 2016). The 2:1 granular matrix recorded the highest peak values at 30th day, 45th day and 60th day of sampling (Fig. 5)(Table 10) and the values were 0.678g kg^{-1}, 0.484 g kg^{-1} and 0.442 g kg^{-1} respectively and this release pattern coincide with the nutrient requirements at the critical growth stages of the crop. Since the N fertilization had a significant influence on both vegetative and reproductive traits of tomato the time of peak release according to the crop requirement improved the yield in tomato (Baloch *et al.,* 2017). The matrix based slow release fertilizer containing matrix: fertilizer in the ratio of 2:1 gave the maximum release at the 60th day of sampling, thus this matrix was selected as the best for slow release of nitrogen due to the ability to retain their release even after 2 month of incubation. Singh *et al.* (2014) reported that organic matrix entrapped form of fertilizer can release nutrients in a slow release manner as compared to free soluble fertilizers. Singh and Sharma (2011) reported that organic matrix based SRF (Boron (1.5 kg ha^{-1})+Sulfur (7.5 kg ha^{-1})+ Nitrogen (40 kg ha^{-1})+ Phosphorus (7.5 kg ha^{-1})+Potassium (50 kg ha^{-1})+Matrix; cow dung, clay soil, neem leaf powder and rice bran in 2:2:1:1 ratio (483.8 kg ha^{-1}) immobilized with 15% gum Acacia) released ammonium ions maximum up to 50 days in soil at field capacity under laboratory conditions. The release pattern of nitrogen from organic matrix based fertilizers revealed that the relative rate of release of N is slower and are capable of retaining the availability for a long period of time by reducing the leaching and runoff losses of nitrogen in the soil (Ţolescu and Iovu, 2010).

5.2.3 Available Phosphorus

Phosphorus release was increasing up to 45 days after incubation and later it decreased for all treatments. The highest value was observed on 45th day after incubation for all treatments and among which the highest value (0.160 g kg^{-1}) was shown by 2:1 granule. Phosphorus is essential for the initial growth and establishment

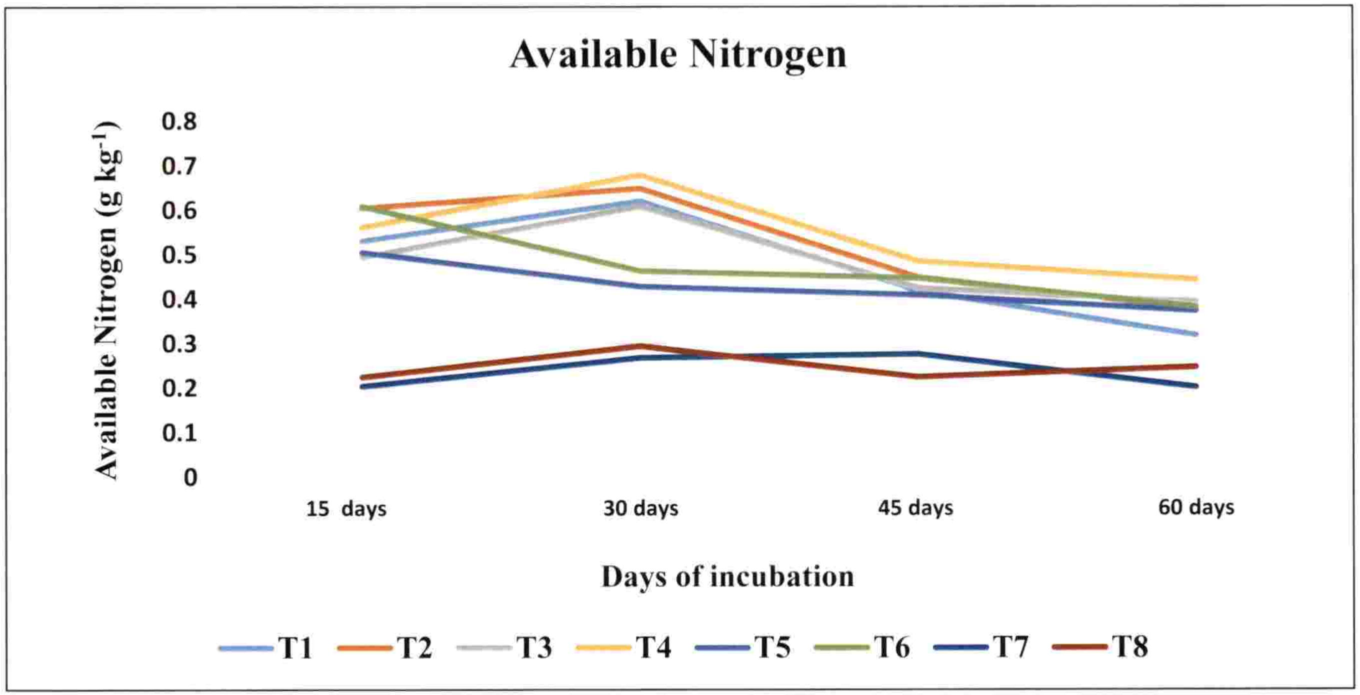

Fig 5. Effect of different matrices on available N on incubation

of the crop. Here also we can see that P release is more in the initial period of incubation which will help in crop growth. Even though there was a decreasing trend (Fig. 6) after 45th day in all the treatments, the 2:1 granule showed the highest value (0.130 g kg^{-1}) on 60th day and it was selected for further study. In acidic soil generally phosphorus availability is affected by P fixation in the soil. The organic matrix could also act as an electrostatic barrier to obstruct the fixation of phosphate ions in soil (Wang *et al.*, 2011). The entrapment of rock phosphate in the organic matrix will gradually release the P into the soil, which will reduce the fixation and increase the availability for longer period of time. Liu and Lal (2015) examined the application of hydroxyapatite nanoparticles dispersed into carboxymethyl cellulose enhanced efficiency than conventional P fertilizers.

5.2.4 Available Potassium

Potassium release from organic matrix entrapped slow release fertilizer showed a gradually increasing pattern (Fig. 7) up to 60th day of incubation. The 2:1 granular matrix recorded highest release rate (0.136 g kg^{-1}) in the 60th day of incubation. The highest release peak was seen in 60th day of incubation in all the treatments and hence the potassium availability will be synchronizing with the crop requirement during fruit setting and developing stage. Woldemariam *et al.* (2018) reported that potassium fertilizers had a significant role in yield and quality of tomato. The treatment with organic matrix alone also recorded considerable amount of K availability which showed that the matrix itself contributed K to the soil. The slow mineralization of potassium from the rice husk ash may be the reason for the increasing trend of potassium from the organic entrapped fertilizer. Priyadharshini and Seran (2009) reported that potassium fertilizers can be substituted by rice husk ash as a source of potassium.

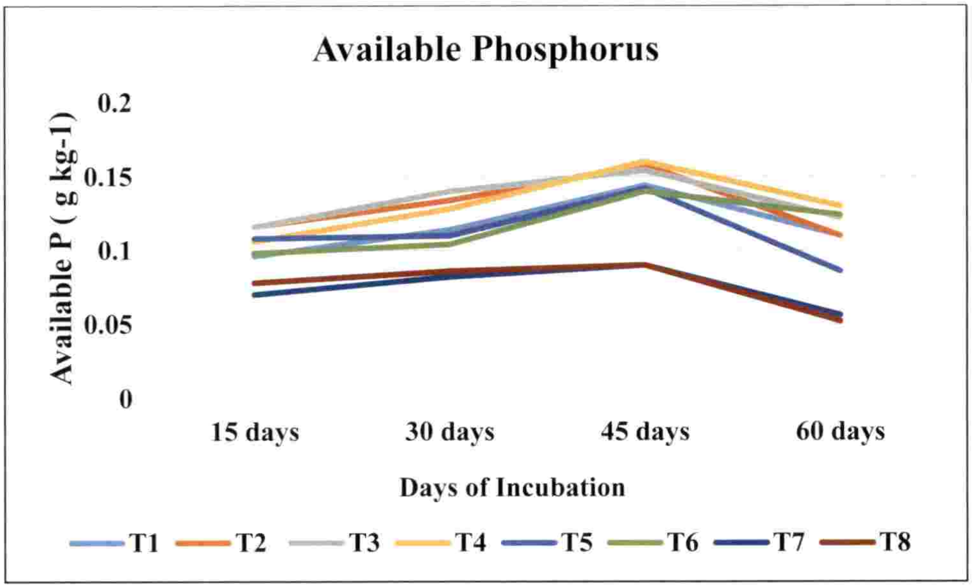

Fig 6. Effect of different matrices on available P on incubation

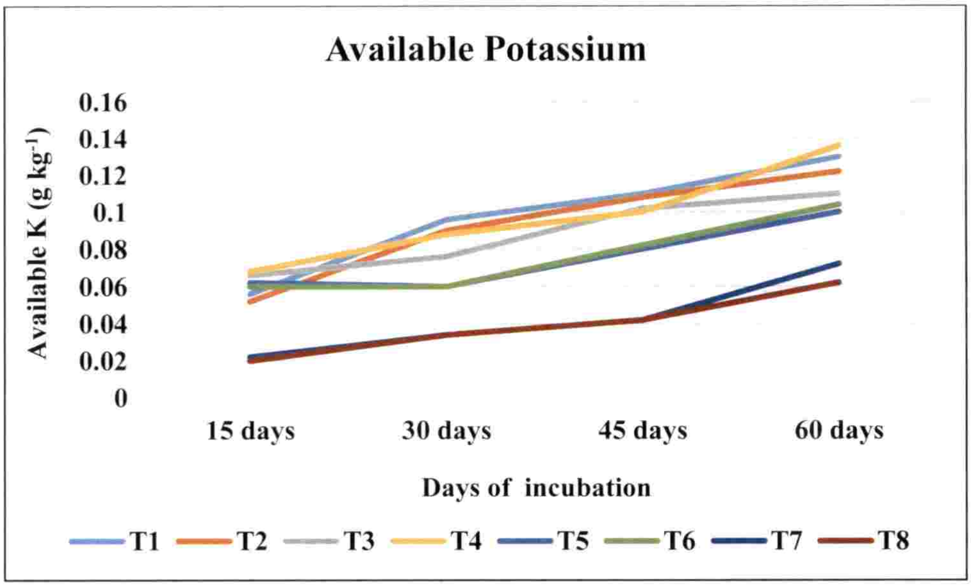

Fig 7. Effect of different matrices on available K on incubation

5.2.5 Available secondary nutrients

The available Ca, Mg and S status in soil revealed that there was no significant difference between the treatments (Tables 13, 14 and 15). But there was an average increase in Ca, Mg and S (Fig. 8, 9 and 10) between different intervals of sampling. This might be due to the presence of secondary nutrients in vermicompost (Atiyeh *et al.*, 2002), rice husk ash (Kurniastuti, 2018) and cow dung.

5.2.6 Available micronutrients

Perusal of the data revealed that the treatments had no significant influence on available micronutrients *viz.*, Fe, Mn, Zn, Cu and B (Tables 16, 17, 18, 19 and 20). All micronutrients, except Fe recorded an average increase in concentration per interval (Fig. 11, 12, 13, 14 and 15). This might be due the effect of vermicompost, rice husk ash and cow dung used in the matrix. Fe recorded an average decrease per interval and this may be due to the availability of silica from the rice husk ash. Higher silica content in rice husk ash reduced Fe toxicity in soil (Lakshmi and Mini, 2018).

5.3 EVALUATION OF THE EFFECT OF MATRIX BASED SLOW RELEASE FERTILIZER IN INCREASING NUTRIENT USE EFFICIENCY

Based on the results from the incubation study the 2:1 granular matrix was selected for conducting the pot culture experiment to evaluate the nutrient use efficiency of matrix based slow release fertilizer.

5.3.1 Effect of matrix based fertilizer on biometric characters

Biometric observations such as plant height, number of branches per plant, days to first flowering, days to fruit set and fruit set percent were recorded(Tables 21 and 22) from the pot culture experiment. Plant height and fruit set percentage were significantly influenced by the treatments whereas there was no significant influence on number of branches per plant, days to first flowering and days to fruit set. The results revealed that the treatment T_9 (50% recommended dose entrapped matrix based

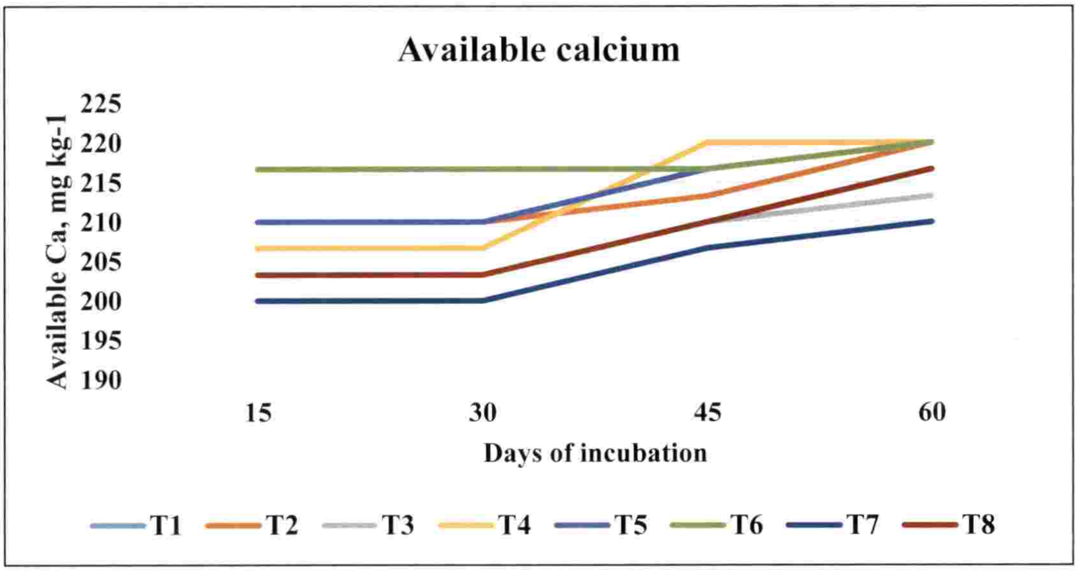

Fig 8. Effect of different matrices on available Ca on incubation

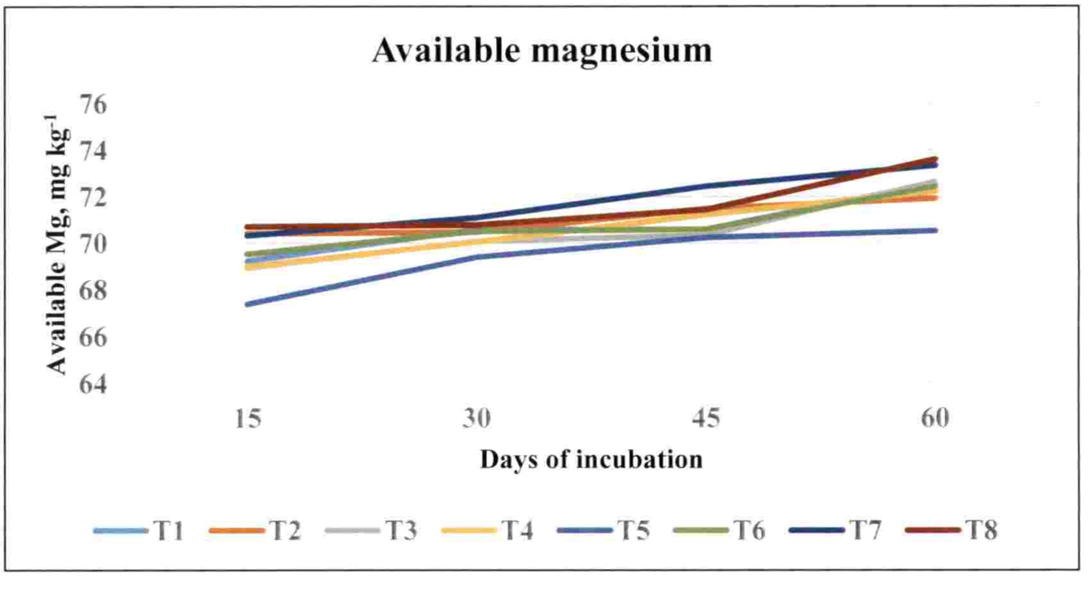

Fig 9. Effect of different matrices on available Mg on incubation

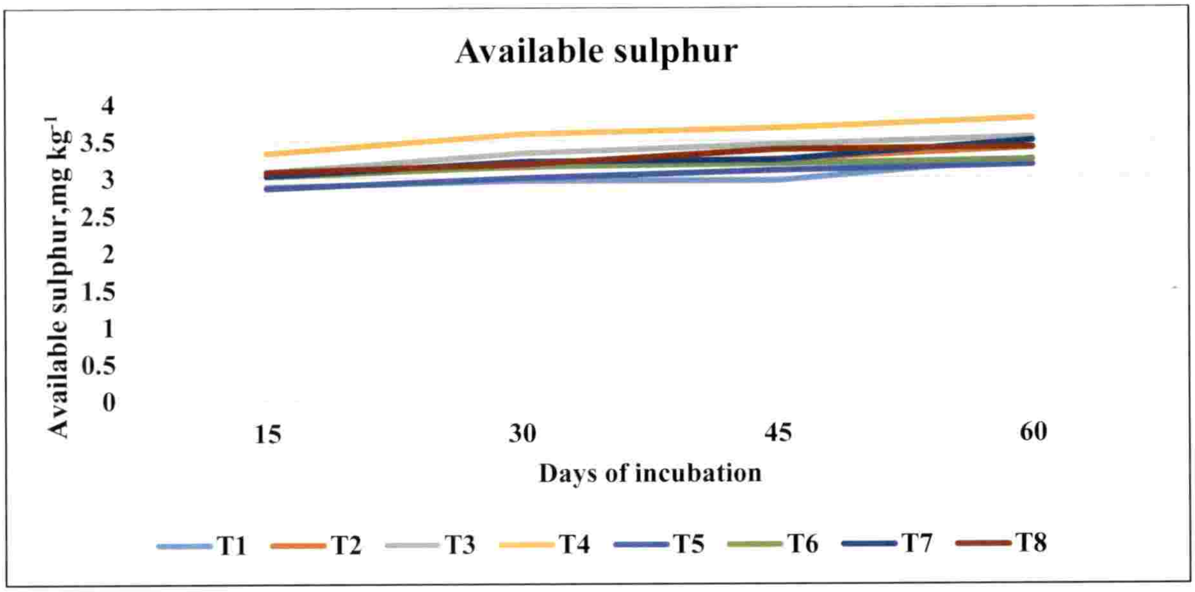

Fig 10. Effect of different matrices on available S on incubation

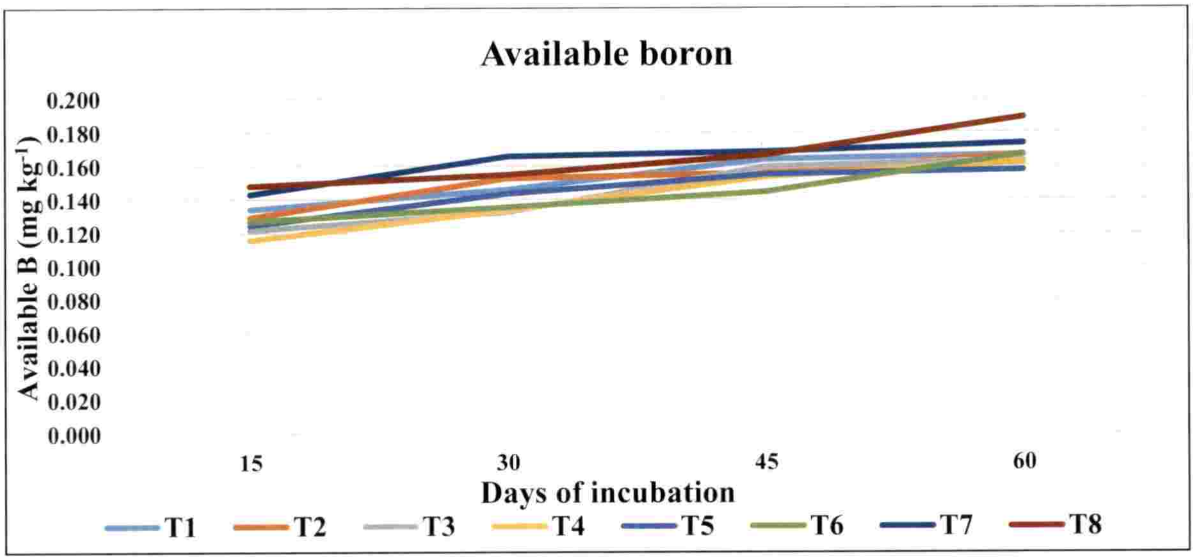

Fig 11. Effect of different matrices on available B on incubation

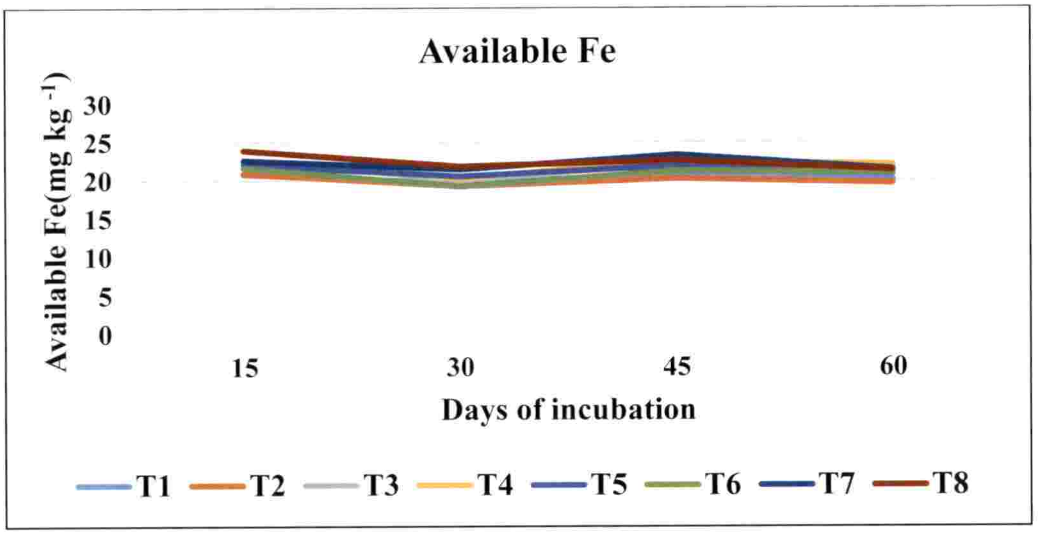

Fig 12. Effect of different matrices on available Fe on incubation

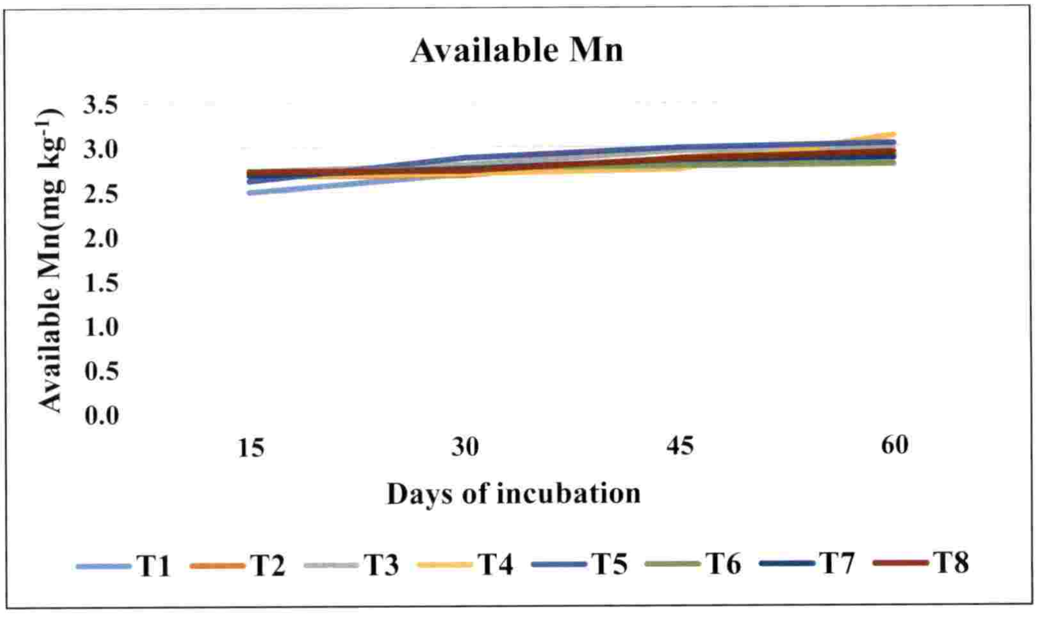

Fig 13. Effect of different matrices on available Mn on incubation

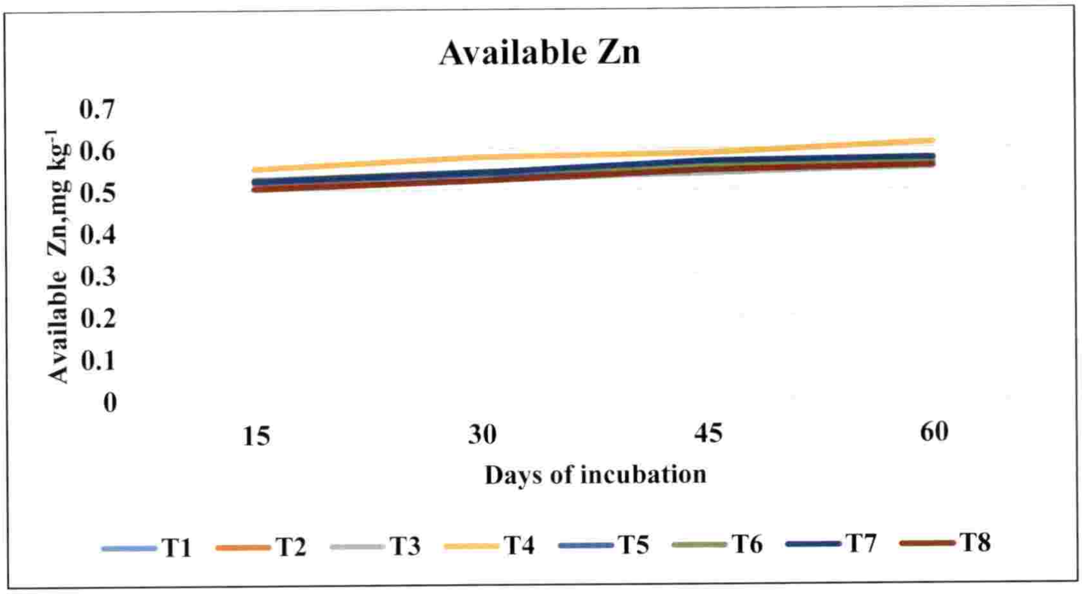

Fig 14. Effect of different matrices on available Zn on incubation

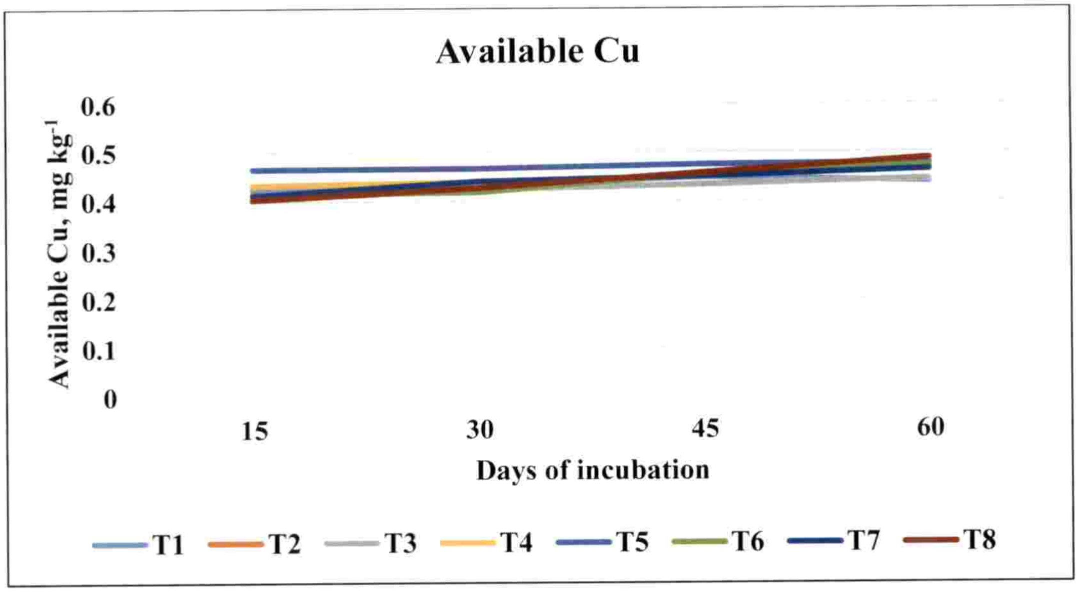

Fig 15. Effect of different matrices on available Cu on incubation

fertilizer in 2 splits) recorded the highest value for plant height (35.6 cm) and fruit set percentage (80.3%). T_9 was on par with T_1 (POP), T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and T_7 (75% recommended dose entrapped matrix based fertilizer in 2 splits). This may be due to the greater availability of nitrogen at the vegetative growth stage resulted from the slow release nature of matrix based fertilizers. Shoji *et al.* (2001) reported that controlled release fertilizer technology could enhance the nitrogen use efficiency by timely meeting the crop requirement. Singh and Sharma (2011) reported the similar results in organic matrix based fertilizer application in *B. juncea.* Organic matrix contains cow dung, rice husk and clay retain ammonium for longer duration (Verkaik *et al.*, 2006), and neem act as a nitrification inhibitor, which stabilizes the degradation of organic nitrogen forms (Puri, 1999). Akter *et al.* (2017) reported that the combined application of organic and inorganic fertilizers produced best result on plant growth and yield parameters of tomato. Kurniastuti (2018) reported that provision of rice husk ash as a potassium source gave the significant effect on plant growth parameters such as plant height and the number of leaves of red chilli.

5.3.2 Yield and yield attributes

The study on effect of matrix based slow release fertilizer on yield and yield attributes of tomato revealed that fruits per plant, fruit weight and yield per plant were significantly influenced by various treatments and T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) recorded the highest value for the yield (0.79 kg plant^{-1}) (Fig. 16) and yield attributes (Table 23.) and it was on par with T_1 in which 100% recommended dose of fertilizer was applied. 50% reduction in the recommended dose of fertilizer was achieved by this organic matrix based slow release fertilizer formulation. This is due to the reduced leaching loss of nutrients from the organic matrix based fertilizers and it act as a slow release fertilizer. Singh *et al.* (2015) also reported similar results in case of rice with 50% recommended dose of fertilizers entrapped in organic matrix. Kiran *et al.* (2010) suggested that the slow release

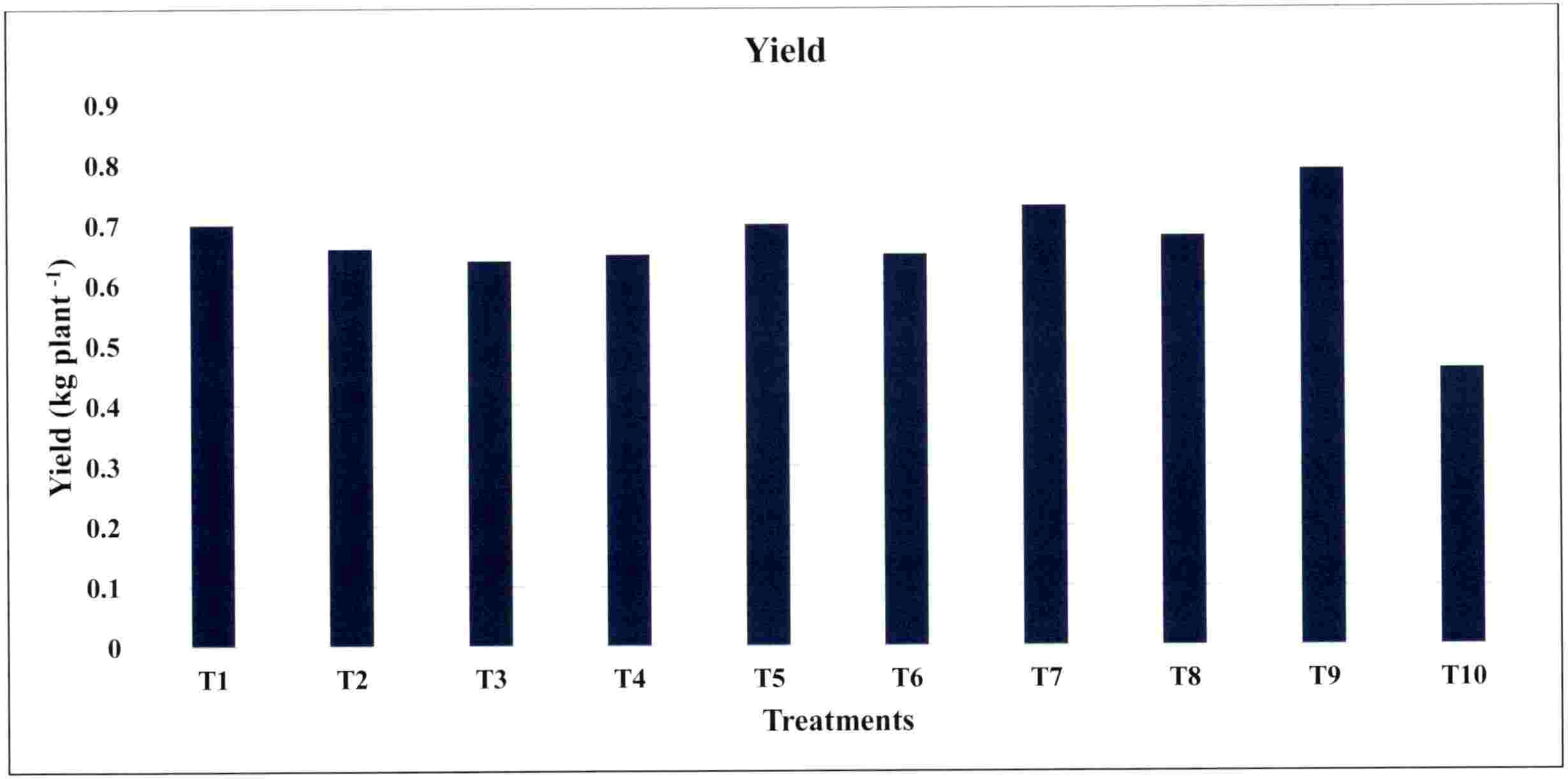

Fig 16. Effect of matrix based slow release fertilizer on yield of tomato (kg $plant^{-1}$)

fertilizer technology can enhance the efficiency of fertilizers and can improve the yield and quality of crop. Treatment T_9 was the best treatment in which yield was increased by 13% compared to T_1 in which 100% recommended dose of fertilizers as per POP was applied. Singh *et al.* (2017) reported that *R. serpentina* recorded higher biomass yield in terms of shoot and root with the application of organic matrix entrapped bio fertilizers as compared to loose application of fertilizers. They also stated that the double and triple dose of biofertilizers in entrapped form gave the same concentration of alkaloid content as that of single dose. This might be due to the proper nutrient enrichment in accordance with the crop requirement from the single dose itself due to reduced leaching and increased plant uptake. Singh and Sharma (2011) reported that organic matrix based slow release fertilizers significantly increased the seed yield of Indian mustard by 28%. Organic matrix entrapped urea and DAP containing 1/4th of the recommended dose of urea and DAP produced wheat biomass and grain yield almost equal to that obtained with full recommended dose of soluble urea and DAP (Singh *et al.*, 2013). Wu *et al.* (2018) reported that the low cost sustainable slow release matrix based urea fertilizer was an ecofriendly method of wheat (*Tritium aestivum* L.) production as it reduce the risk of nitrogen loss and increase the yield more than 11%.

5.3.3 Quality parameters

The organic matrix based slow release fertilizers had significant influence on quality parameters like TSS (%) and Ascorbic acid content. The treatment T_9 recorded the highest value for TSS (5.33%) and ascorbic acid content (22.3 mg $100g^{-1}$) (Table 24). Potassium supply determines the quality of fruits and hence the improvement in fruit quality may be due to the slow mineralization of potassium from the rice husk ash and enhanced availability of potassium from the matrix at the critical stage of fruit development. Valencia (2003) reported that the slow release nitrogen fertilizer with K source had significant effect in TSS (°Brix) in tomato. Singh *et al.* (2013) confirmed that half of the recommended dose of urea entrapped organic matrix could produce higher yield of wheat with better nutritional qualities.

5.3.4 Influence of matrix based slow release fertilizer on soil fertility parameters

5.3.4.1 Soil pH and electrical conductivity

The highest soil pH (5.98) was recorded for T_{10} (matrix alone) and T_1 recorded the highest electrical conductivity value (0.68 dS m^{-1}). The highest soil pH in T_{10} after the harvest of the crop may be due to the lack of fertilizer especially urea in the matrix. Rice husk ash with the pH of 8.02 also may be contributed to the high soil pH. Sandy soils are generally poor in nutrient concentration and the pH has to be managed carefully (Miller *et al.*, 2016). Large amount of fertilizer application increases the soil acidity (Trenkel, 2010). Hence the organic matrix which is having a pH of 6.02 is a very good alternative to avoid the fertilizer induced soil acidification. Higher values for electrical conductivity were observed in T_1, T_2 and T_3, in which 100% fertilizer was applied without entrapping in organic matrices whereas lower electrical conductivity was recorded for all organic matrix entrapped fertilizer treatments. The organic matrix recorded slow release rate of nutrients and the electrical conductivity was reduced in matrix entrapped fertilizers. Nelson *et al.* (2010) also reported similar results in the case of soybean based slow release fertilizer.

5.3.4.2 Available primary nutrients

Various treatments had a significant influence on available NPK status in soil after harvest of the crop. The highest N (250.9 kgha^{-1}), P (53.39 kg ha^{-1}) and K (215.8 kg ha^{-1}) status in the soil after harvest of the crop was recorded for T_5 (100% recommended dose entrapped matrix based fertilizer in 2 splits) and the lowest for T_{10} (matrix alone) (Table 26). The results (Fig. 17) proved that the application of organic matrix based fertilizer retained the nutrients for a prolonged time period as compared to the conventional fertilizer application. This might be due to the reduced nutrient loss and slow releasing nature of matrices. Singh *et al.* (2015) reported that the application

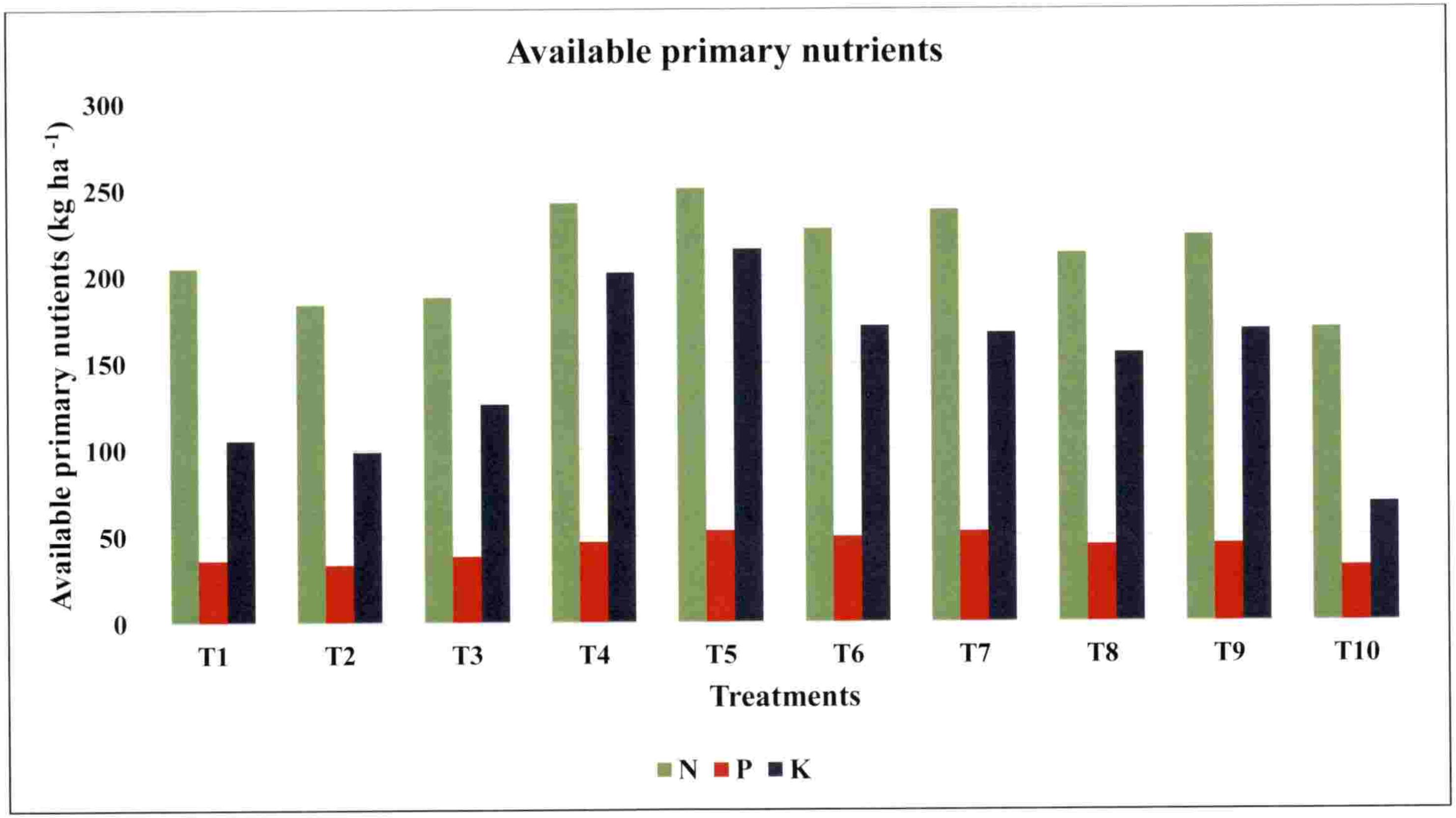

Fig 17. Effect of matrix based slow release fertilizer on primary nutrient status of soil after harvest of the crop

of organic matrix entrapped chemical fertilizers with 50% and 25% fertilizers increased the availablé N, available P and available K status in rice field as compared to the free form of chemical fertilizers. Singh *et al.* (2013) reported that organic matter, nutritional quality, microbial status of soil, nitrate, nitrite and phosphate in the rhizosphere were improved by the cow dung and other organic manures present in the matrix bounded urea and DAP . Singh *et al.* (2012) reported that OMEU (Organic matrix entrapped urea) increased % OC, total NPK in plant and available N, P and K in soil. It might be due to the agro waste materials that helped in increasing the organic matter content in soil.

5.3.4.3 Available secondary nutrients

Application of organic matrix based slow release fertilizer had a significant influence on the Ca and Mg status in soil after the harvest of the crop. There was a slight increase in Ca and Mg status in soil as compared to the initial nutrient status. The increase in calcium may be due to the soil test based application of agricultural lime. The highest values of Ca and Mg were recorded for T_5 and all matrix entrapped fertilizer treatments were on par with T_5 (Fig 18). This might be due to the effect of organic matrix which acted as a nutrient source. Generally organic sources are considered as a complete plant food as they hold all essential plant nutrients. It was reported that the application of vermicompost can significantly influence the yield of okra due to the supply of more amounts of secondary and micronutrients (Abdulla and Sukhraj, 2010). Based on the analysis of rice husk ash carried by Tamtomo *et al.* (2015) reported that the content of Ca and Mg (0.4758% and 0.0868%) in the rice husk ash is quite high and this also may be contributed for increased Ca and Mg status in soil. Treatments did not have any significant effect on S status of soil.

5.3.4.4 Available micronutrient

The organic matrix entrapped NPK fertilizer significantly influenced the B and Zn status in soil after harvest. Treatment T_5 recorded the highest value and all matrix

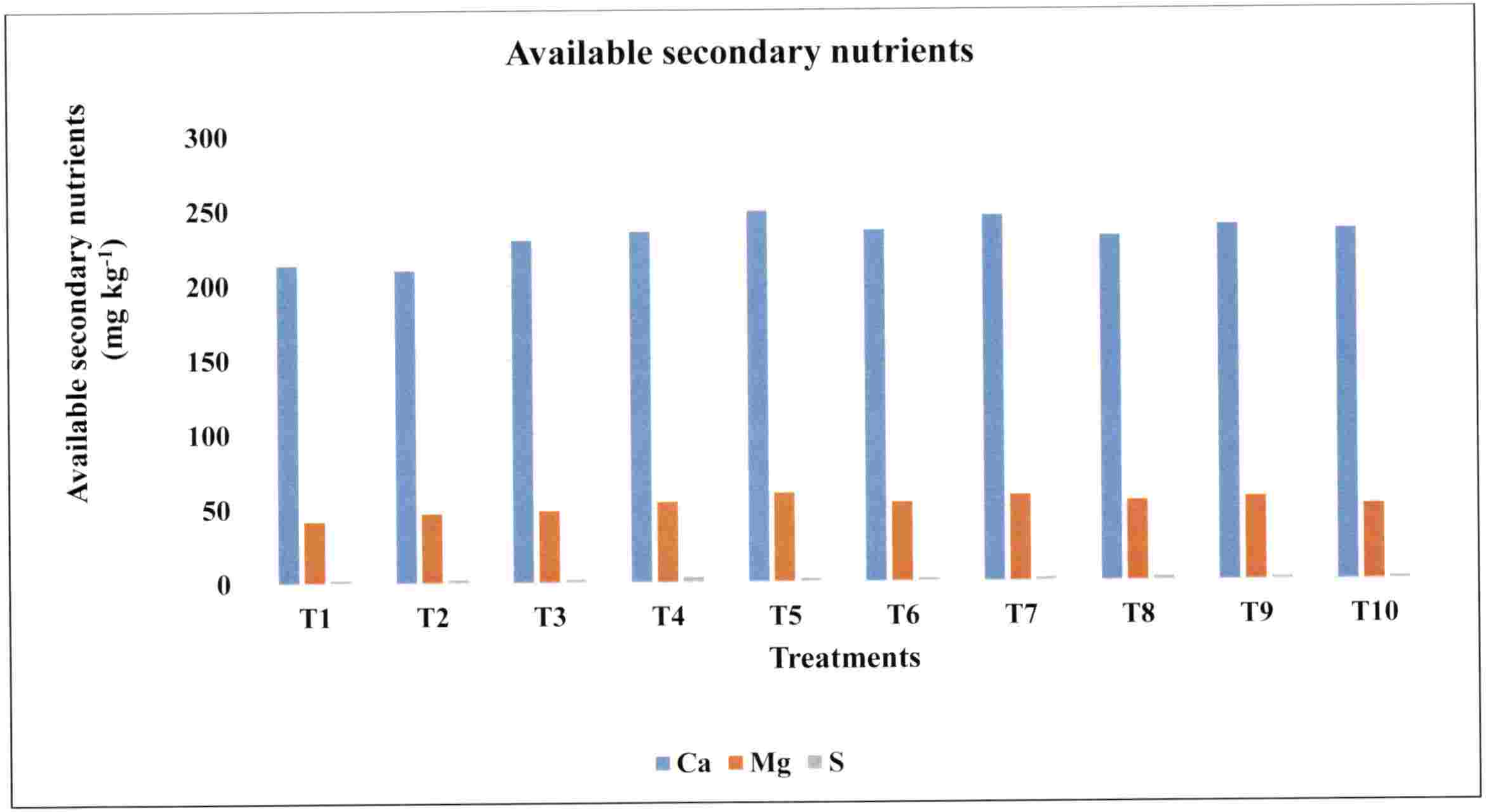

Fig 18. Effect of matrix based slow release fertilizer on secondary nutrient status of soil after harvest of the crop

entrapped fertilizer treatments were on par with T_5 (Fig 19). This may be due to the influence of the organic materials that were used in the preparation of matrix. These organic materials can supply secondary and micro nutrients up to a considerable amount (Abdulla and Sukhraj, 2010).

5.3.5 Effect of matrix based slow release fertilizer on the nutrient content of index leaf and plant

5.3.5.1 Content of primary nutrients in index leaf and plant

The index leaf analysis is an efficient tool for determining the nutritional status of the crop under particular soil and environmental condition during the crop period and plant analysis after the harvest shows the uptake and nutrient content after the crop period. The highest NPK content for index leaf (2.78% , 0.195% and 1.77%), plant (2.14%, 0.538% and 2.62%) sample were recorded by T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) and it was on par with T_1, T_5 and T_7 (Fig. 20) (Tables 30 and 34). The NPK content in plant and index leaf revealed that the split application of organic matrix entrapped fertilizers could supply nutrients more efficiently than that of the basal application of entrapped fertilizers and conventional application of fertilizers. In sandy loam soils split application of recommended dose of nutrients improves the nutrient use efficiency (KAU, 2014). A comparative study of different split applications of fertilizers in sandy loam soil revealed that the N and K losses were significantly reduced on three step split application of fertilizer, followed by two step split application and lastly on single application of fertilizers (Sourabh and Akhilesh, 2016). Organic matrix entrapped fertilizers act as a slow releasing fertilizer and supply nutrients according to the actual crop requirement at the critical growth stages of crop growth. Singh and Sharma (2011) reported, significantly higher nitrite levels in organic matrix based slow release fertilizer treated plant leaves which was due to the reduced nitrobacter activity in soil.

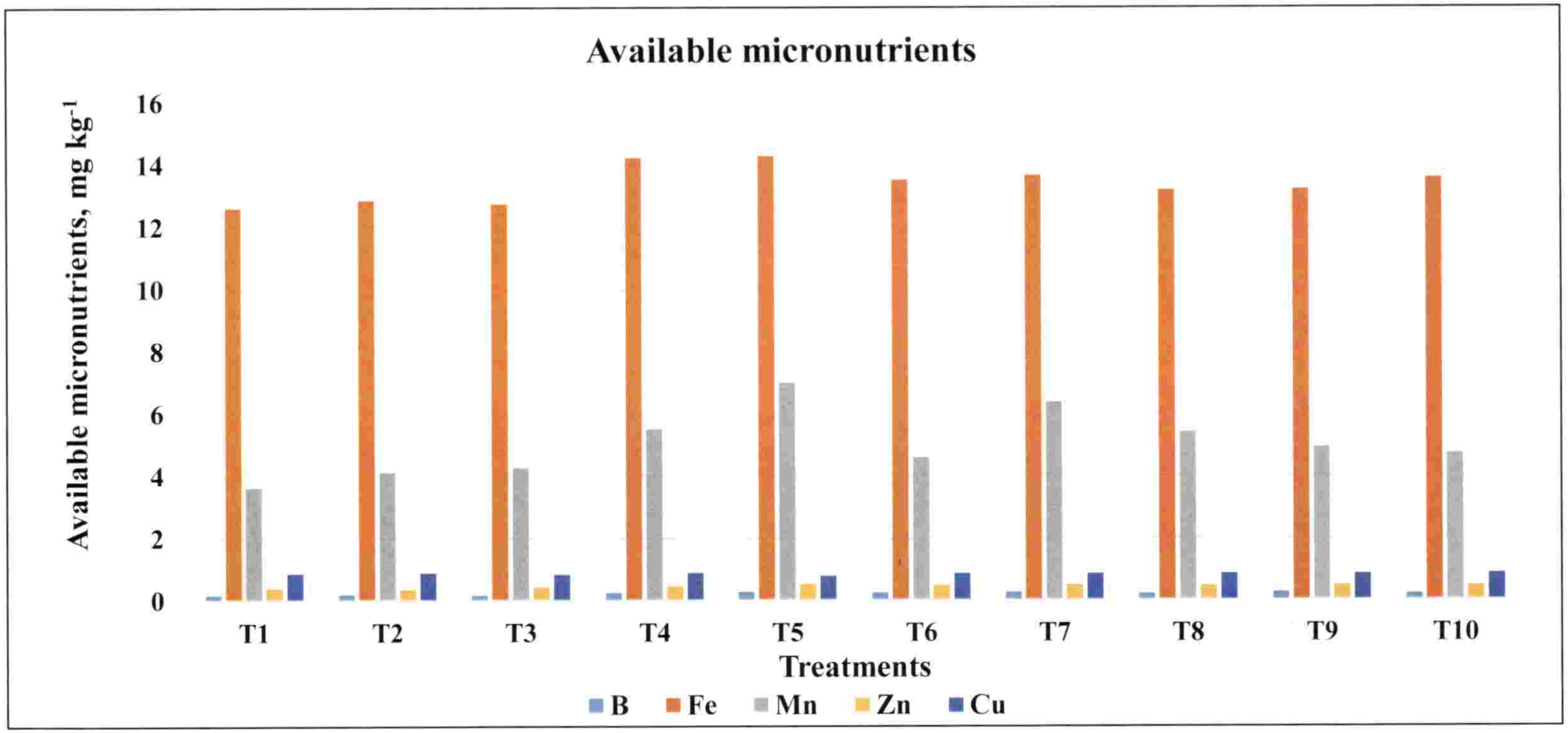

Fig 19. Effect of matrix based slow release fertilizer on micronutrient status of soil after harvest of the crop

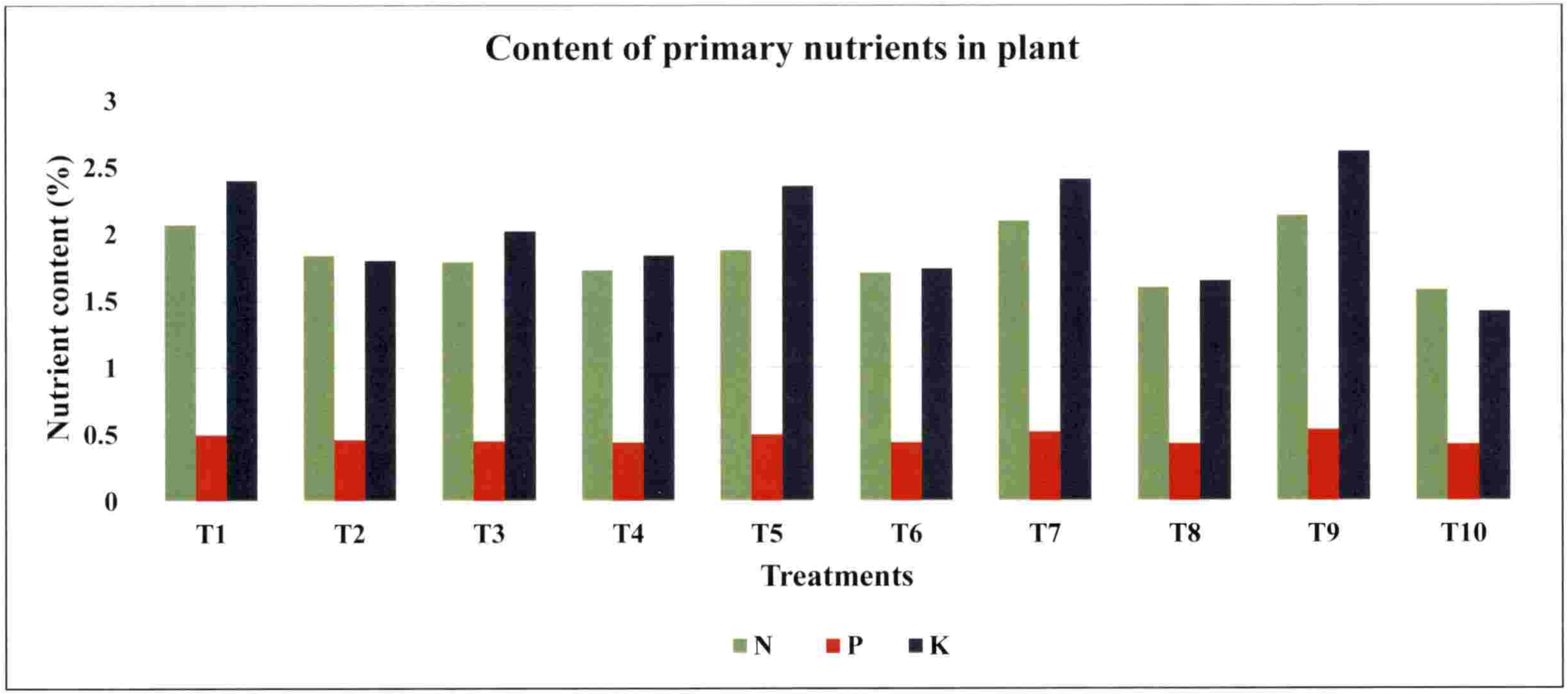

Fig. 20 Effect of matrix based slow release fertilizer on content of primary nutrients in tomato plant

5.3.5.2 Content of secondary nutrients in index leaf and plant

The Ca and Mg content in plant and index leaf were found to be significantly influenced by the treatments and the treatment T_9 recorded the highest values for Ca and Mg for index leaf (0.186 % and 0.168%) and plant (0.149% and 0.165%) and were on par with all other matrix entrapped fertilizers (Fig.21). The result may be due to the effect of organic matrix components used for matrix development over the sole application of fertilizers (Abdulla and Sukhraj, 2010). There was no significant difference in S content both in plant and index leaf.

5.3.5.3 Content of micronutrients in index leaf and plant

The application of 50% recommended dose of NPK fertilizer entrapped matrix in two split recorded the highest B and Zn content in plant and index leaf (Fig 22). The applied organic materials along with the fertilizers might be the reason for the result. The matrix materials are capable of holding nutrients tightly and are able to release in a slow manner. This is in line with the report of Swain *et al.* (2013). In their work they reported that vermicompost based NPK fertilizers supplied higher micronutrient content as compared to 100% NPK fertilizer application and 100% vermicompost application. Enhanced mineralization of manures were seen when manures were applied with NPK fertilizers as compared to their sole application (Adhikari *et al.*, 2016).

5.3.6 Effect of matrix based slow release fertilizer on the nutrient content of fruit

5.3.6.1 Content of primary nutrients in fruit

The 50% recommended dose of NPK fertilizer in organic matrix entrapped form in two split (T_9) recorded the highest values for N (2.14%), P (0.538%) and K (2.62%) content in fruit (Fig. 23) and it was on par with T_1, T_5 and T_7 (Table 38).It was due to the enhanced nutrient use efficiency of N,P and K in these treatments. Split

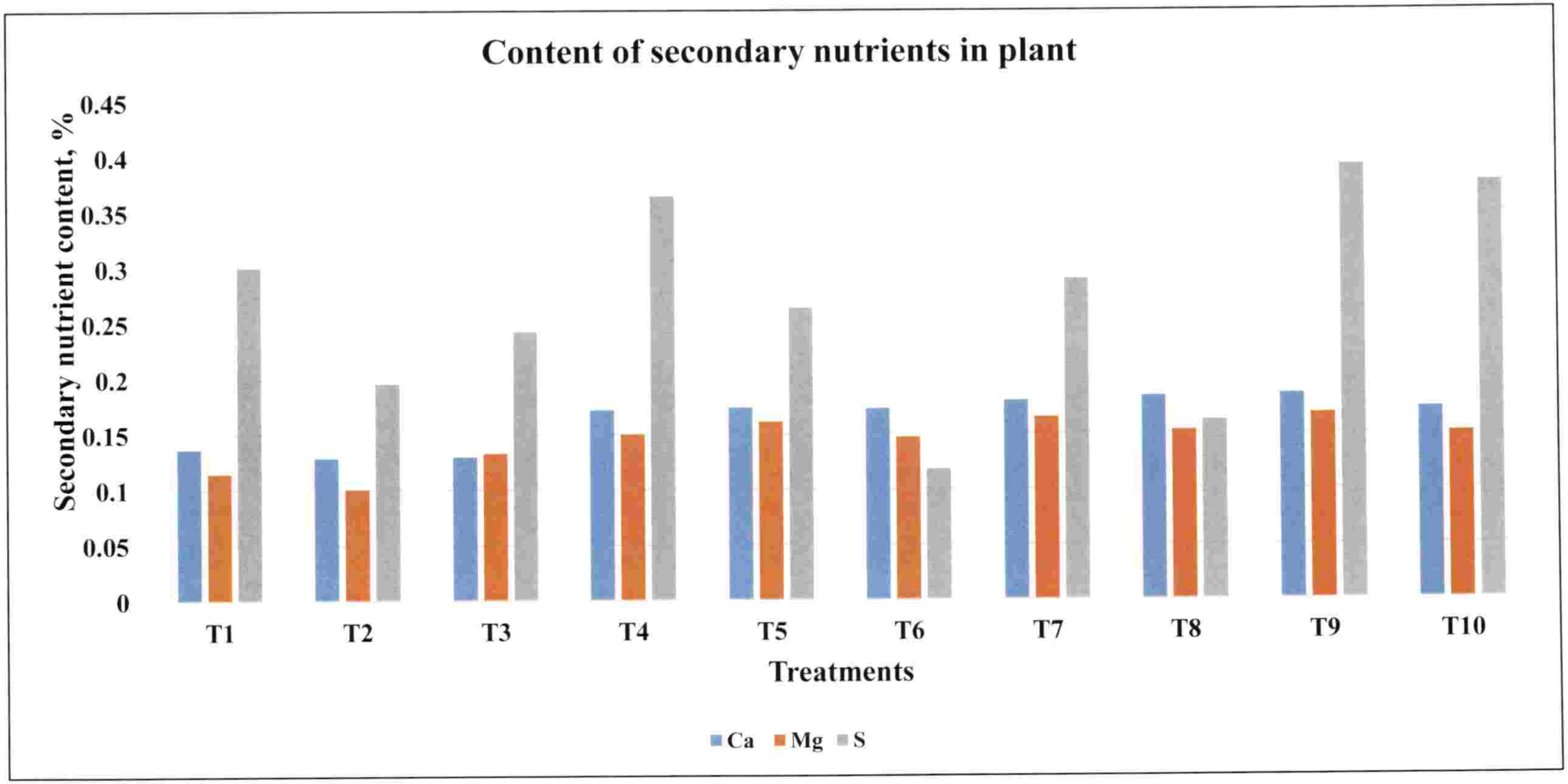

Fig. 21 Effect of matrix based slow release fertilizer on content of secondary nutrients in tomato plant

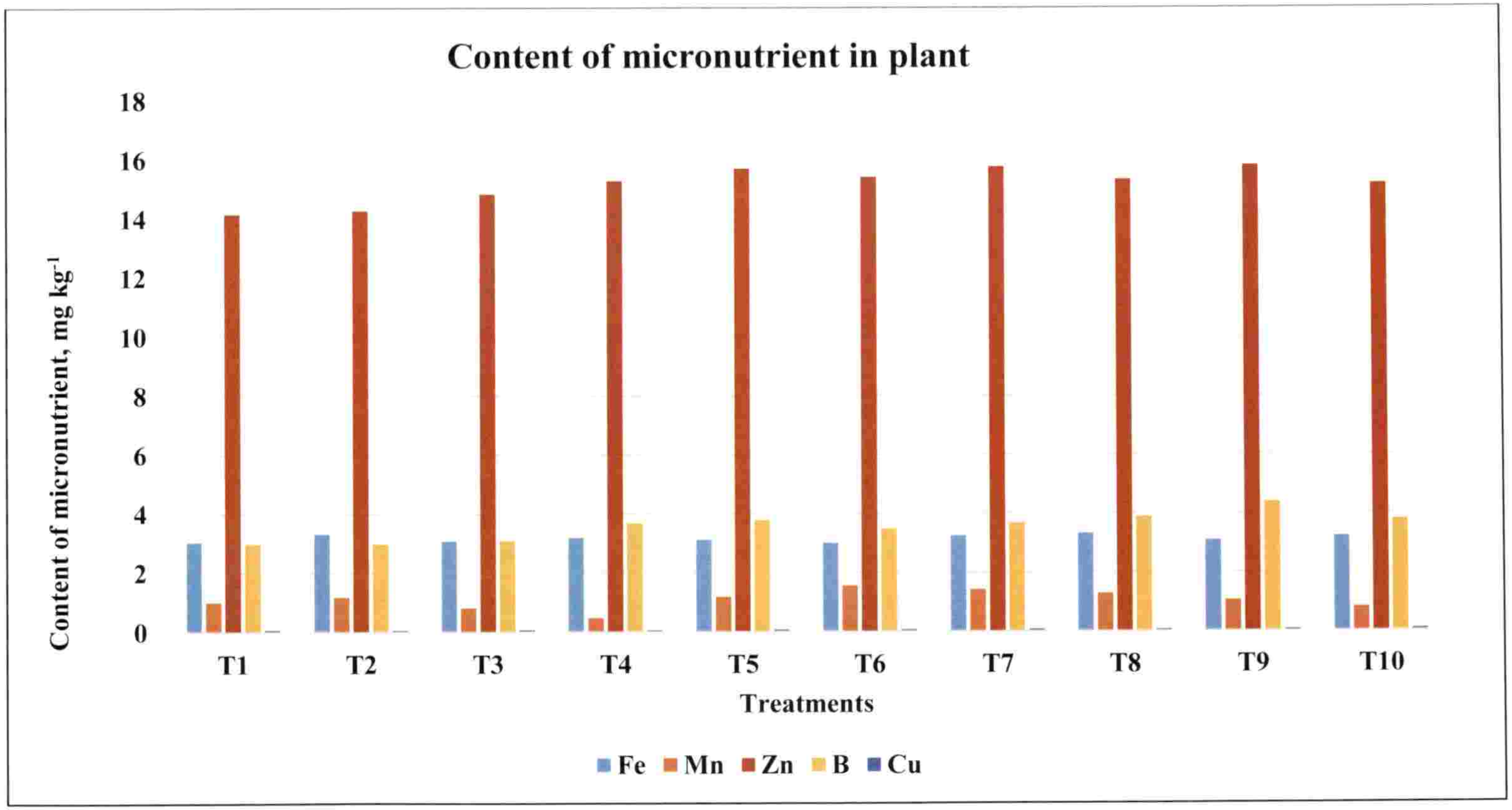

Fig. 22 Effect of matrix based slow release fertilizer on content of micronutrients in tomato plant

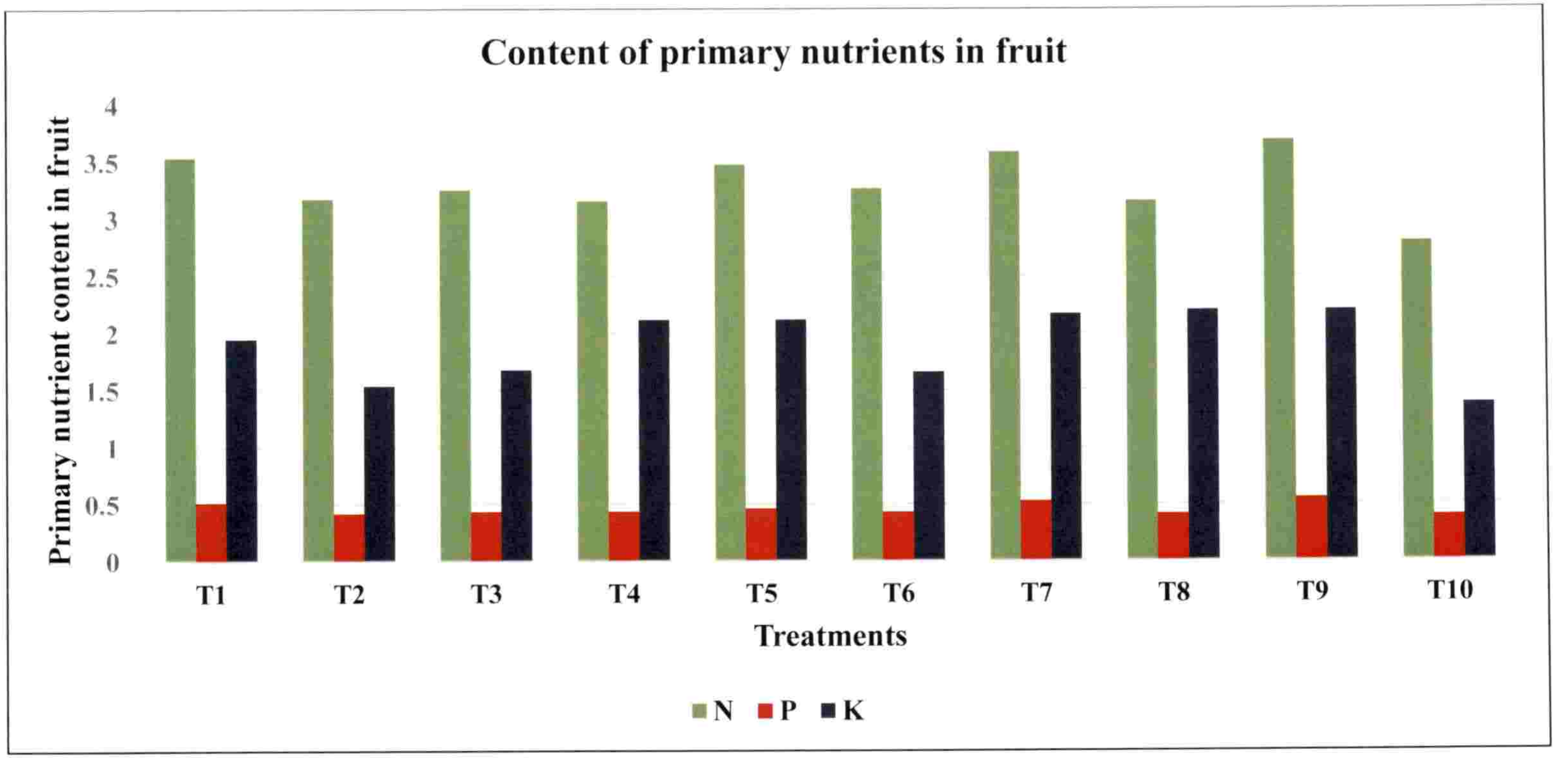

Fig 23. Effect of matrix based slow release fertilizer on content of primary nutrients in tomato fruit

application of nutrients generally enhance the nutrient use efficiency in sandy loam soil and organic matrix reduces the leaching loss of nutrients and further improves the nutrient use efficiency. Phongchanmixay *et al.* (2019) reported that split application of nitrogenous fertilizers could supply the nutrients at its critical growth stages. Hence the nutrient use efficiency can be increased. Youmbi *et al.* (2009) reported that organo-mineral treatment have a tendency to give the highest fruit concentration of P and K . Adhikary *et al.* (2016) reported that enhanced mineralization of manures were seen when manures were applied with NPK fertilizers as compared to their sole application.

5.3.6.2 Content of secondary nutrients in fruit

Application of organic matrix based slow release NPK fertilizer had a significant influence on Ca and Mg content in fruit. Treatment T_9 recorded the highest value and was on par with all organic matrix entrapped fertilizer treatments (Fig 24). This may be due to the supply of secondary nutrients from the vermicompost, rice husk ash and cow dung. Khan *et al.* (2010) reported that organic materials supplies all major nutrients (N, P, K, Ca, Mg, S,) necessary for plant growth, as well as micronutrients (Fe, Mn, Cu and Zn). Tamtomo *et al.* (2015) reported that the rice husk ash contained significant amount of bases especially Ca and Mg (0.476 % and 0.087 %) in addition to high amount of P and K. There was no significant difference in S content in fruit.

5.3.6.3 Content of micronutrients in fruit

The highest value for B and Zn were recorded by T_9 (matrix based slow release NPK fertilizer with 50% recommended dose of fertilizers) (Fig 25). All the treatments with matrix based fertilizers were on par with T_9. This is clear from the result that the presence of organic matrix affected the nutrient content in fruit positively and organic matrix helped to maintain the nutritional status of soil. Sutar (2009) reported that vermicompost contained significant amount of micronutrients *viz*., Fe, Mn, Zn, Cu and B.

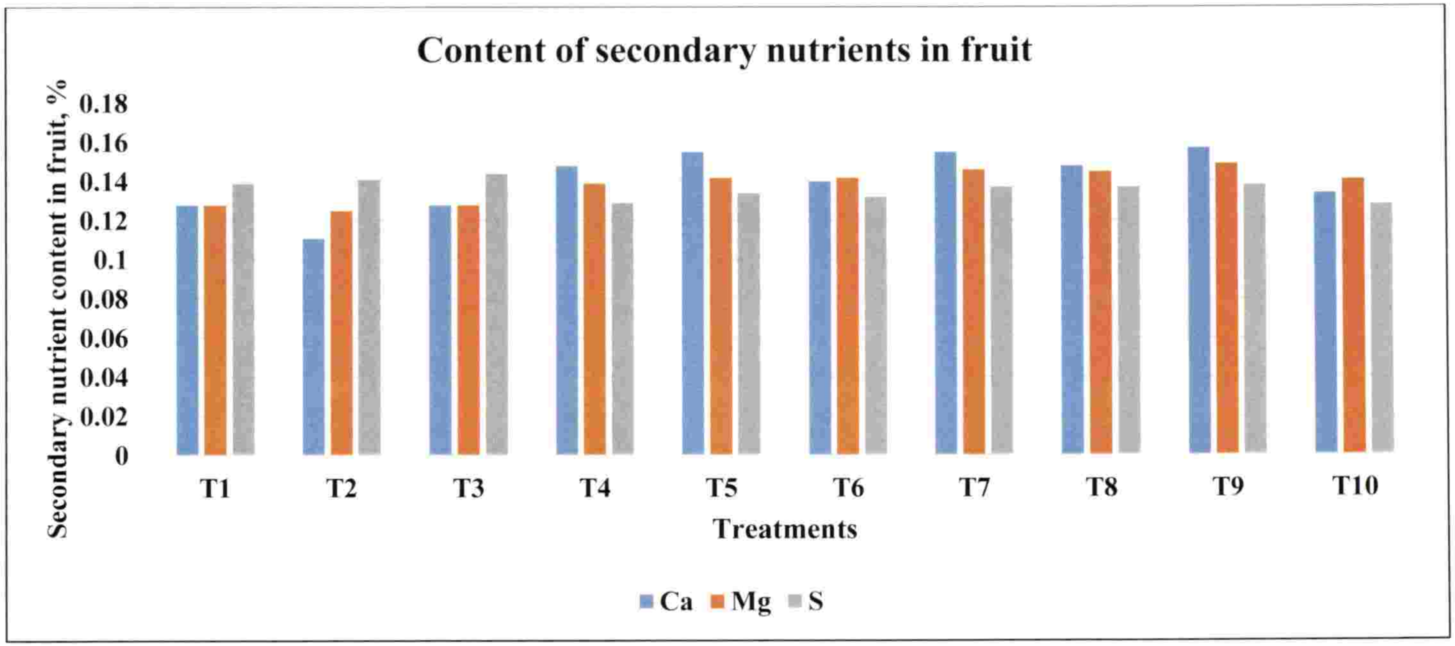

Fig 24. Effect of matrix based slow release fertilizer on content of secondary nutrients in tomato fruit

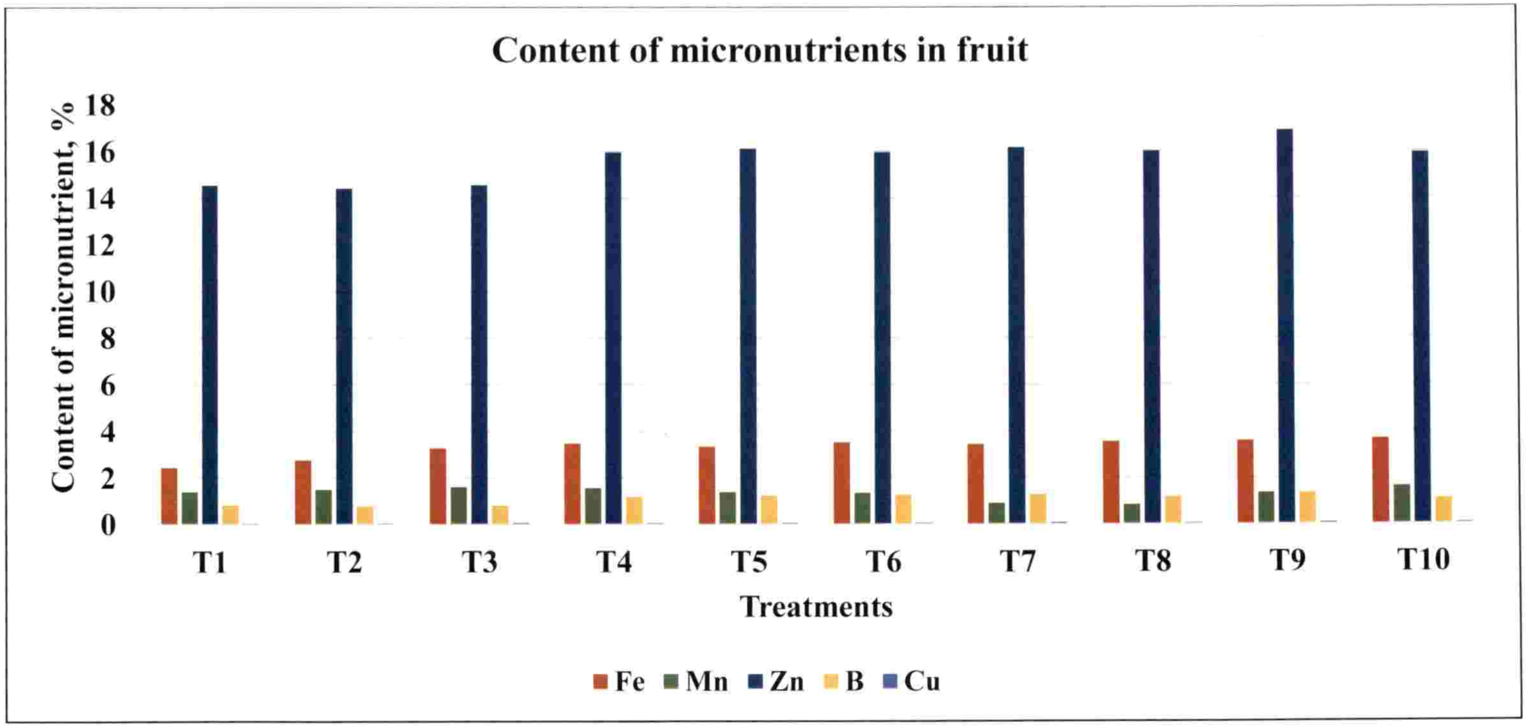

Fig 25. Effect of matrix based slow release fertilizer on content of micronutrients in tomato fruit

5.3.7 Effect of matrix based slow release fertilizer on the NPK uptake of plant and fruit

The treatments had a significant influence on NPK uptake of plant and fruit. Treatment T_9 recorded (Tables 42 and 43) the highest value for N (0.683g plant^{-1}and 3.59 g plant^{-1}), P (0.172 g plant^{-1} and 0.425 g plant^{-1}) and K (0.815 g plant^{-1} and 2.07 g plant^{-1}) uptake of plant and fruit and was on par with T_1, T_5 and T_7. This may be due to the enhanced supply of nutrients and their translocation in plants by entrapping the inorganic sources in organic matrix based systems and their split application in sandy loam soils. Addition of organic materials like rice husk ash loosen the soil so that plant roots can absorb more nutrients (Kurniastuti, 2018). Memon *et al.* (2017) reported similar results regarding the enhanced shoot NPK uptake on combining mineral fertilizers with organic manures.

5.3.8 Effect of organic matrix based slow release fertilizer on nutrient use efficiency

The organic matrix based slow release fertilizer had a significant influence on nutrient use efficiency of Onattukara sandy soil. The highest NUE of 44% was recorded (Fig. 26) in treatment T_9. The NUE of POP was calculated as 18% (Table 44.). The main limiting factor in nutrient management in sandy soil is high nutrient leaching, which is responsible for the low NUE. Slow release fertilizers can contribute to enhance the NUE and minimize environmental hazards (Trenkel, 2010). The treatment T_9 recorded the highest value for apparent recovery efficiency of N, P and K fertilizers. Azeem *et al.* (2014) reported that slow release fertilizers are designed to control the nutrient release in accordance to the crop requirement thereby increasing the nutrient adsorption efficiency, which in turn reducing the cost of cultivation and increasing the crop productivity. Wu *et al.*, (2018) reported that the organic matrix based fertilizer could increase the agronomic and apparent recovery efficiencies as compared to

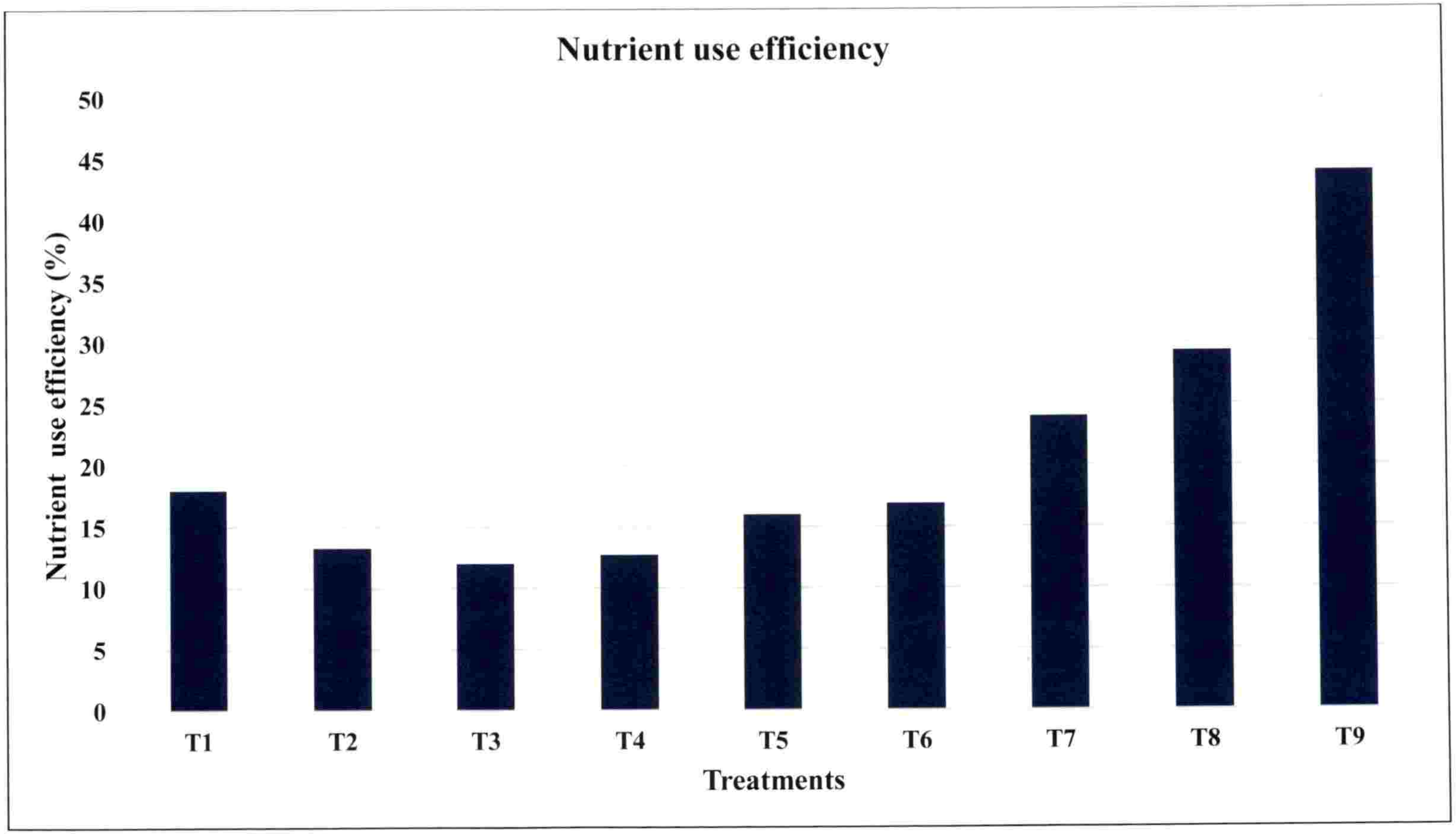

Fig 26. Effect of matrix based slow release fertilizer on Nutrient use efficiency in Onattukara soil

unentrapped conventional urea. This might be due to the reduced nitrogen loss (leaching and ammonia emission) and prolonged availability of nitrogen contributing to increased plant uptake.

5.3.9 Economic analysis

The effect of organic matrix based NPK fertilizers on benefit cost ratio and net income revealed that treatment T_9 (50% recommended dose entrapped matrix based fertilizer in two split) recorded the highest B: C ratio (2:1) and net income (Rs.230097/-). The economic analysis of Indian mustard production with the application of organic matrix based slow release fertilizer proved that this agro waste material based formulation is cost effective method (Singh and Sharma, 2011). Singh *et al.* (2012) evaluated OMEU with half of the recommended dose of urea and reported almost equal net returns as compared to the full recommended dose of free urea. Thus the reduced fertilizer cost was also confirmed. Azeem *et al.* (2014) reported that slow release fertilizers (SRFs) release nutrients in harmony with the nutritional requirements of plants, thereby enhancing the fertilizer use efficiency, ensuring the reduction in the cost of fertilizers and increasing the productivity of crop.

From the present study it was revealed that organic matrix based slow release fertilizer is a promising technology to reduce nutrient leaching and enhancing the nutrient use efficiency in Onattukara sandy plains. These organic matrix based fertilizers were capable of enhancing the growth, yield and quality of tomato. Fifty percentage reduction in the recommended dose of NPK fertilizers were achieved by entrapping these fertilizers in organic matrix prepared from low cost agro waste materials. These matrices were capable of holding nutrients tightly as compared to soluble chemical fertilizers and increased the nutrient use efficiency significantly. Since all the materials used for the matrix preparation are easily available, the technology can be popularized as a low cost technology for the production of slow release fertilizers under Onattukara condition. Thus the cost of fertilizers and fertilizer load per unit area can be reduced by the application of organic matrix based slow release fertilizers. Prolonged nutrient supplying capacity of this organic matrix based fertilizers can be effectively utilized for cultivation of crops in grow bags and pots. For the field application, large quantity of organic matrix based fertilizer is required and hence the production process has to be mechanized. Small instruments can be fabricated for this purpose. Secondary and micronutrients also can be entrapped in this organic matrix for further study. Long term effect of these matrix based fertilizers on soil and water quality in Onattukara sandy plain also has to be studied.

SUMMARY

6. SUMMARY

The study entitled "Matrix based slow release fertilizer for increasing nutrient use efficiency in the Onattukara sandy plains" was undertaken with the objective to develop low-cost sustainable matrix based slow release fertilizer using local biodegradable agro waste as matrix and to evaluate the effect of this slow release fertilizer in increasing nutrient use efficiency in the sandy loam soils of Onattukara by using tomato variety Vellayani Vijai as test crop. This study included three parts viz. development of matrix based slow release fertilizer, incubation study and evaluation of the effect of matrix based slow release fertilizer in increasing nutrient use efficiency. Pot culture experiment was carried out at Onattukara Regional Agricultural Research Station, Kayamkulam and was laid out in a completely randomized design with ten treatments and three replications *viz.,* T_1 (Recommended dose of fertilizers and organic manures as per POP), T_2 (Recommended dose of fertilizers as basal application),T_3 (Recommended dose of fertilizers in two splits), T_4 (Matrix entrapped recommended dose of fertilizers as basal application), T_5 (Matrix entrapped recommended dose of fertilizers in two splits), T_6 (Matrix entrapped 75% of recommended dose of fertilizers as basal application),T_7 (Matrix entrapped 75% of recommended dose of fertilizers in two splits), T_8 (Matrix entrapped 50% of recommended dose of fertilizers as basal application), T_9 (Matrix entrapped 50% of recommended dose of fertilizers in two splits) and T_{10} (Matrix alone).The salient findings of the experiment are given below.

A matrix based slow release fertilizer was developed by combining local biodegradable agro wastes with conventional NPK fertilizers. For developing the matrix, various agro waste materials like rice husk ash, cow dung, rice husk, coir pith compost, vermicompost and neemcake were combined in various proportions (1:1:0.5:0.5:0.5:0.5:0, 1:1:1:1:1:1:1 and 1:1:1:1:0.5:0.5:0.5). Both disc and granular shapes were developed and 1:1:0.5:0.5:0.5:0.5:0.5 combination was selected based on

their desirable characteristics such as high pH, low electrical conductivity, low dissolution rate and low cost of production.

From the first part of the study, the best matrix combination (1:1:0.5:0.5:0.5:0.5:0.5) was selected and an incubation study was conducted to study the nutrient release pattern of various matrix: fertilizer combinations *viz.*, 1:1, 2:1, 0.5:1 and matrix alone. The nutrients were estimated at 15 days interval up to two months to study the nutrient release pattern, especially N, P and K from various matrix: fertilizer combinations. Release pattern of secondary and micronutrients were also recorded.

Available nitrogen in soil recorded significant difference among treatments at different intervals of sampling. N release was increasing from 15^{th} day to 30^{th} day of sampling and from 30^{th} day to 60^{th} day, release of N recorded a decreasing pattern. Soil available P recorded an increasing pattern from 0^{th} day to 45^{th} day and then a decreasing pattern and soil available potassium status increased in all the treatments throughout the incubation period. The data revealed that the treatments had no significant influence on available secondary and micronutrients *viz*., Ca, Mg, S, Fe, Mn, Zn, Cu and B. The nutrient release pattern from incubation study revealed that 2:1 granular matrix was best for the slow release of N, P and K nutrients.

The 2:1 granular matrix combination was further used for pot culture experiment to evaluate the effect of organic matrix based slow release fertilizer in increasing the nutrient use efficiency.

In pot culture experiment, growth, yield and quality of tomato increased significantly due to the application of organic matrix based fertilizers. The plant height and fruit set percentage were significantly influenced by the treatments whereas there was no significant influence on number of branches per plant, days to first flowering and days to fruit set. Treatment T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits) recorded the highest value for plant height (35.6 cm) and fruit set percentage (80.3%), TSS (5.33%) and ascorbic acid content (22.3 mg $100g^{-1}$). The split application of 50% recommended dose of organic matrix entrapped fertilizer (T_9) also recorded the highest value for number of fruits per plant (32.3), fruit weight (24.5 g) and yield per plant (0.79 kg plant^{-1}). The yield of treatment, T_9 was on par with split application of 75% and 100% of recommended dose of fertilizer entrapped matrices and with POP recommendation.

A significant increase in pH, available N, P and K, exchangeable Ca, Mg, B and Zn were observed due to the application of this organic matrix based slow release fertilizer formulation. The soil pH increased from the initial value of 5.28 to the highest value of 5.98 (T_{10}). The treatments with matrix entrapped fertilizers recorded a higher pH as compared to the treatments without matrices. In the case of primary nutrients, for both available N and K, treatment T_5 recorded the highest status (250.9 kg ha^{-1} and 215.8 kg ha^{-1}) and was on par with T_4, T_6, T_7 and T_9. Available P status was the highest in T_5 (53.37 kg ha^{-1}) and was on par with treatment T_4, T_6, T_7, T_8 and T_9.

Application of organic matrix based slow release fertilizer had a significant influence on total N, P, K, Ca, Mg, Zn and B content in index leaf, plant and fruit . Treatment T_9 recorded the highest value for N, P and K content in index leaf (2.78% , 0.195% and 1.77%), plant (2.14%, 0.538% and 2.62%) and fruit (3.69 %, 0.555% and 2.20 %), respectively which was on par with T_1, T_5 and T_7. In the case of Ca, Mg, Zn and B content, the treatment T_9 recorded the highest value for index leaf (0.186 %,0.168% , 16.15 mg kg^{-1} and 4.9 mg kg^{-1}), plant (0.149%, 0.165% ,15.81 mg kg^{-1} and 4.4 mg kg^{-1}) and fruit (0.157%, 0.149%, 16.89 mg kg^{-1} and 1.35 mg kg^{-1}) respectively but was on par with all other treatments except T_1, T_2 and T_3 (treatments without matrix).

Application of organic matrix based slow release fertilizers also had significant influence on the NPK uptake in plant and fruit. The highest N,P and K uptake in plant (0.683 g plant^{-1}, 0.172 g plant^{-1} and 0.815 g plant^{-1}) and fruit (3.59 g plant^{-1}, 0.182 g plant^{-1} and 0.63 g plant^{-1}), respectively were recorded for T_9 (50% recommended dose entrapped matrix based fertilizer in 2 splits)

By using matrix entrapped fertilizers the NUE (Agronomic efficiency) increased from 18% to 44% under Onattukara condition. The highest value for nutrient use efficiency was recorded for T_9 and the value was 44%. Highest Apparent recovery efficiency for N (53.29%), P (22.96%) and K (55.50%) was also recorded for T_9 (50% recommended dose of fertilizer entrapped matrix).

There was no incidence of major pest and disease in the crop. Treatment T_9 recorded the highest net income (Rs.230097/- per hectare) and B: C ratio (2.1).

From this study it was revealed that organic matrix based slow release fertilizers are low cost, sustainable and efficient source of nutrient under Onattukara sandy plain. Fifty per cent reduction in the recommended dose of fertilizer was achieved by this organic matrix based slow release fertilizer formulation. Among the various treatments, T_9 was the best treatment in which yield increased by 13% compared to that with POP recommendation of conventional fertilizers with a B: C ratio of 2.1.Organic matrices were capable of holding nutrients and increased the nutrient use efficiency significantly. The nutrient use efficiency increased from 18% to 44% under Onattukara condition. The cost of fertilizers and the fertilizer load per unit area could be reduced due to the prolonged nutrient supplying capacity of these matrix based fertilizer. Hence this matrix based slow release fertilizer technology could effectively sustain supply of nutrients for a prolonged time in accordance with normal crop requirements and lower the frequency of application.

Future line of work

- Large scale preparation of organic matrix based slow release fertilizer using machines.
- Development of micronutrients entrapped organic matrix to be tried.

- Study on long term effect of organic matrix based fertilizers on soil and water quality under Onattukara sandy plain.

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MATRIX BASED SLOW RELEASE FERTILIZER FOR INCREASING NUTRIENT USE EFFICIENCY IN THE ONATTUKARA SANDY PLAINS

by

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ABSTRACT

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8. ABSTRACT

A study on "Matrix based slow release fertilizer for increasing the nutrient use efficiency in the Onattukara sandy plain" was carried out during 2017-2019 in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. The objective of the study was to develop low-cost matrix based slow release fertilizer using local biodegradable agro waste and to evaluate the effect of this slow release fertilizer in increasing nutrient use efficiency in the sandy loam soils of Onattukara. The study comprised three parts *viz.,* development of matrix based slow release fertilizer, incubation study and evaluation of the effect of matrix based slow release fertilizer in increasing nutrient use efficiency. Different combinations of biodegradable locally available materials like rice husk ash, clay, cow dung, rice husk, coirpith compost, vermicompost and neem cake were used to develop a suitable matrix. The matrix with 1: 1: 0.5: 0.5: 0.5: 0.5: 0.5 composition was selected based on its high pH, low electrical conductivity and low cost of production. The stability and dissolution was also studied under controlled condition.

The best combination of matrix (1: 1: 0.5: 0.5: 0.5: 0.5: 0.5) was selected to entrap fertilizers at various proportions of matrix: fertilizer *viz.,* 1:1, 2:1, 0.5:1 and matrix alone. Granular and disc forms of these combinations were developed and used for incubation for a period of two months to study the nutrient release pattern of N, P and K. Soil samples were collected at 15 days interval for nutrient analysis. The nutrient release pattern was different for N, P and K. The 2: 1(matrix: fertilizer) granular formulation was selected based on the gradual release pattern and the highest peak of nutrient availability of N, P and K even after 2 months.

Effect of matrix based slow release fertilizer in increasing nutrient use efficiency was evaluated by using tomato variety Vellayani Vijay as test crop and the pot culture experiment was conducted at Onattukara Regional Agricultural Research Station, Kayamkulam during November,2018 - January,2019. The 2:1 granular formulation was selected for entrapping NPK fertilizers for the pot culture

experiment.The experiment consisted of ten treatments and they were T_1 (Recommended dose of fertilizers and organic manure as per POP), T_2 (Recommended dose of fertilizers as basal application),T_3 (Recommended dose of fertilizers in two splits),T_4 (Matrix entrapped recommended dose of fertilizers as basal application), T_5 (Matrix entrapped recommended dose of fertilizers in two splits),T_6 (Matrix entrapped 75 % of recommended dose of fertilizers as basal application),T_7 (Matrix entrapped 75% of recommended dose of fertilizers in two splits),T_8 (Matrix entrapped half dose of recommended dose of fertilizers as basal),T_9 (Matrix entrapped half of recommended dose of fertilizers in two splits) and T_{10} (Matrix alone).

Growth, yield and quality of tomato increased significantly due to the application of organic matrix based fertilizers. The highest plant height (35.6 cm) was recorded in the treatment T_9 and was on par with T_1, T_3, T_5 and T_7.The treatments did not show a significant influence on number of branches per plant, days to first flowering and days to fruit set. Treatment T_9 recorded the highest fruit set percentage (80.3%) which was on par with treatments T_1, T_5, and T_7.The treatment T_9 recorded the highest value for all the yield attributes and yield. The highest number of fruits per plant (32.3) and yield per plant (0.79kg) was recorded by treatment T_9 and was on par with T_1, T_5 and T_7. For fruit weight, treatment T_9 was found to be on par with all other treatments except treatment T_{10}.The treatment T_9 recorded the highest value for the quality parameters such as TSS (5.33 %) and ascorbic acid (22.3 mg $100g^{-1}$). The treatments did not show any significant influence on Lycopene content of fruit. Soil analysis after the experiment showed that the pH increased from the initial value of 5.28 to the highest value of 5.98 which was recorded for the treatment T_{10} and was on par with all treatments except T_1, T_2 and T_3. The treatments with matrix entrapped fertilizers recorded a higher pH as compared to the treatments without matrices. The highest value of EC (0.68 dS m^{-1}) was recorded by T_5. The treatment did not show a significant influence on organic carbon content. In the case of primary nutrients, for both available N and K, treatment T_5 recorded the highest status (250.9 kg ha^{-1} and

215.8 kg ha^{-1}) and was on par with T_4, T_6, T_7 and T_9. Available P status was the highest in T_5 (53.37 kg ha^{-1}) and was on par with treatment T_4, T_6, T_7, T_8 and T_9. The highest value for exchangeable Ca (248.89 mg kg^{-1}) and Mg (60 mg kg^{-1}) was recorded for treatment T_5 which was significantly superior to all other treatments. Treatment T_5 recorded the highest value for available B (0.281 mg kg^{-1}) and Zn (0.519 mg kg^{-1}) also and was on par with T_4, T_6, T_7, T_8, T_9 and T_{10}. The results of the plant and fruit analysis revealed that the treatment T_9 recorded the highest value for N, P and K content in index leaf (2.78% , 0.195% and 1.77%), plant (2.14%, 0.538% and 2.62%) and fruit (3.69 %, 0.555% and 2.20 %), respectively, which was on par with T_1, T_5 and T_7. In the case of Ca, Mg, Zn and B content, the treatment T_9 recorded the highest value for index leaf (0.186 %,0.168% , 16.15 mg kg^{-1} and 4.9 mg kg^{-1}), plant (0.149%, 0.165% ,15.81 mg kg^{-1} and 4.4 mg kg^{-1}) and fruit (0.157%, 0.149%, 16.89 mg kg^{-1} and 1.35 mg kg^{-1}), respectively and was on par with all other treatments except T_1, T_2 and T_3. Treatments did not show any influence on S, Fe, Mn and Cu content in index leaf, plant and fruit. There was no incidence of major pest and disease in the crop. Treatment T_9 recorded the highest net income (Rs.230097/-), B: C ratio (2.1) and nutrient use efficiency.

From the investigation it can be concluded that, treatment T_9 (Matrix entrapped half of recommended dose of fertilizers in two splits) was the best treatment in which the yield increased by 13% compared to POP recommendation and B: C ratio increased from 1.69 to 2.1. Organic matrix based slow release fertilizer was found to be effective under Onattukara condition for increasing the nutrient use efficiency from 18% to 44%. Fifty per cent reduction in the recommended dose of fertilizer was achieved by this matrix based slow release fertilizer formulation. This slow release fertilizer technology reduced the cost of cultivation and leaching loss of nutrients and increased the nutrient use efficiency and yield in the Onattukara sandy plain.

APPENDIX

APPENDIX 1

Weather parameters during the cropping period, November 2018 to January 2019

Standard meteorological week (No)	Rainfall (mm)	Temperature (^0C)		Relative humidity (%)
		Max temp (^0C)	Min temp (^0C)	
Nov 5-11 (45)	7	31.10	23.80	77
Nov 12-18 (46)	21	33.70	23.00	76
Nov 19-25 (47)	74	35.60	25.10	86
Nov 26-02 (48)	49	33.90	23.00	79
Dec 03-09 (49)	13	33.20	23.10	60
Dec10-16 (50)	0	32.90	23.80	79
Dec 17-23 (51)	0	32.00	22.90	68
Dec 24-31 (52)	36	32.90	23.50	79
Jan 01-06 (01)	0	31.97	20.60	77
Jan 07-14 (02)	0	31.57	20.70	74
Jan 15-20 (03)	0	31.20	18.85	59
Jan 21-27 (04)	0	31.15	18.93	55
Jan 28-03 (05)	0	31.79	18.47	65