PILOT TESTING OF FERTILIZER-MANURE BLOCKS IN OKRA

(*Abelmoschus esculentus* L. Moench.)

By INDUJA M. (2017-11-031)

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF HORTICULTURE

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THESIS

Submitted in partial fulfilment of the requirements for the degree of

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COLLEGE OF HORTICULTURE

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KERALA, INDIA

2020

DECLARATION

I, hereby declare that this thesis entitled **'Pilot testing of fertilizer-manure blocks in Okra (*Abelmoschus esculentus* L. Moench.)'** is a bonafide record of the research work done by me during the course of research and 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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Certified that this thesis entitled **'Pilot testing of fertilizer-manure blocks in Okra (*Abelmoschus esculentus* L. Moench.)'** is a bonafide record of the research work done independently by Ms. Induja M. (2017-11-031) 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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Induja M

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS

% - Per cent

B – Boron

C - Control

Ca – Calcium

CD – Critical difference

CEC – Cation exchange capacity

cm - centimeter

Cu – Copper

dS m^{-1}- Deci Siemens per centimeter

DAP – Days after planting

EC – Electrical conductivity

et al. – Co-workers

Fig. – Figure

g - gram

mg - milligram

K- Potassium

KAU – Kerala Agricultural University

kg – kilogram

Mg – Magnesium

mg kg^{-1} – milligram per kilogram

N – Nitrogen

NS – Non

NUE- Nutrient Use efficiency

OC – Organic Carbon

P – Phosphorus

POP- Package of Practices

S – Sulphur

T- Treatment

Zn – Zinc

Introduction

1. INTRODUCTION

Increase in population and food insecurity are the main threats that the society will endure during this century. For feeding the growing population there must be corresponding increase in the agricultural production from the existing level in a sustainable way. The challenge of sustainable agriculture involves the production of economically viable and environment friendly food and food products. Productivity enhancement is the major thrust area for sustainability of agriculture and nutrient management is one of the most important components attributing to productivity of the crops.

There are different nutrient delivery techniques for ensuring adequate plant nutrition which include soil application, foliar application of nutrients and nutrient mixtures, fertigation by using water soluble fertilizers etc. Effective fertilizer use is the key factor that determine agricultural production. Direct application of fertilizer nutrients to the soil cannot ensure high nutrient use efficiency (NUE) and nutrient security for the crops due to the physico-chemical properties of the soil as well as the environmental factors which may lead to nutrient loss from the system.

Tropical humid climate and heavy rainfall in Kerala results poor soil fertility due to faster organic matter decomposition and leaching of bases. Kerala soils exhibit low cation exchange capacity and thus low nutrient retention properties. The laterite and associated soils which constitute more than 70 % of cultivated area in Kerala have shown low status in terms of available micro nutrients. All soils of Kerala except black cotton soils of Palakkad districts exhibited deficiency of available magnesium. Majority of the soils of Kerala are acidic in reaction and thus the efficiency and uptake of the added nutrient sources from soil is very low. Fertilizers are one of the costlier inputs in agriculture and thus the loss from the fertilized fields not only cause environmental issues but also affects the socio-economic situation of the farmers. To overcome this, targeted application of plant nutrients is necessary. The concept of slow or controlled release technology of fertilizer is based on gradual release of nutrients to meet plant demand which in turn reduce loss of nutrients to the environment. Slow or controlled release fertilizers are prepared by coating fertilizers with natural or synthetic polymers or by mixing with different chemicals/ components which slow down the release of nutrients. Fertilizer forms with less exposed surface area also exhibit release of nutrients at a slow pace. Hence pelleted fertilizers are recognized in this category. Prasad *et al*. (1971) found that rate of release of nutrients from fertilizers is a function of their exposed surface area.

Presently, the slow/controlled release fertilizers available in the market are too costly and cannot be affordable to the farmers. Kumar *et al*. (2012) had formulated organic matrix based fertilizers by mixing inorganic fertilizer nutrient along with some organic base materials. Raj (2019) developed matrix based slow release fertilizer by mixing locally available low cost organic agro waste materials such as rice husk ash, cow dung, rice husk, coir pith compost, vermi compost, neem cake along with inorganic fertilizers in the form of granules as well as disk for increasing nutrient use efficiency in the Onattukara sandy plains of Kerala and reported that growth, yield and quality of tomato increased significantly due to the application of organic matrix based fertilizers.

Okra, *Abelmoschus esculentus* (L.) Moench. is an important vegetable crop widely grown in tropical, subtropical and warm temperate regions of the world. The fruits or pods are harvested when immature and used as vegetables. Okra is a fertilizer responsive vegetable crop.

This project envisages the development of fertilizer-manure blocks (slow release fertilizer) using natural organic/filler materials with high ion exchange capacity as well as slow release properties and its evaluation in okra. The project is envisaged with the following objectives:

1. Standardization of fertilizer –manure blocks for slow release of nutrients
2. Study the effect of fertilizer-manure blocks on growth and yield of okra

Review of Literature

2. REVIEW OF LITERATURE

The day by day increase in the population as well as food requirement is the main issue faced by the world. Sustainable soil productivity is the main limitation in tropical agriculture. Since there is no scope for extending the cultivable area, increasing production per unit area is the only option. Fertilizer is one of the key inputs for agricultural production and thus the limitations in agricultural production can be overcome to some extend by improved fertilizer efficiency. So environment friendly as well as economically feasible agricultural production technologies are yet to be designed. Thus it is important to design nutrient management practices that minimize nutrient losses as well as maximizes the nutrient recovery by the crops. Okra is an important vegetable consumed worldwide. Usually okra is eaten in cooked and processed form and contain protein, phosphorous, calcium, magnesium, and iron. Decline in soil fertility is the major constraint in crop production. Hence the project was envisaged to modify the nutrient delivery techniques and inputs so as to achieve high nutrient use efficiency (NUE) in okra. The review of literature is detailed under the following headings.

2.1. Soil fertility status in Kerala soils

2.2. Nutrient requirements of okra

2.3. Nutrient use efficiency (NUE) and nutrient delivery techniques

2.4. Slow release fertilizers

2.5 Fertilizer-manure blocks/ Organic matrix based slow release fertilizer

2.6 Component materials in fertilizer-manure block

2.1. Soil fertility status in Kerala soils

Soil fertility is one of the most important factors that determines crop productivity (Shukla *et al.,* 2018). Majority of the agricultural soils of the world are deficient in one or more of the essential plant nutrients and due to intensive cultivation practices majority of the arable soils exhibit poor soil fertility. Estimates of overall efficiency of soil applied fertilizers have been reported to be lower than 50% for nitrogen, less than 10 % for phosphorus, and about 40% for potassium (Baligar *et al*., 2015).

Kerala is a narrow strip of land between Western Ghats on the east and Arabian sea on the west. During most part of the time, the state experiences tropical humid climate and the major soil forming process is laterization. In general, Kerala soils are poor in soil fertility. The highly weathered laterite soil occupying majority of the areas (70%) of the state are relatively less fertile, acidic, gravelly clay, depleted of basic cations and have low water and nutrient retention capacity (Rajasekharan *et al*., 2014). In tropical acid soil, acidity is the most important constraint for availability and uptake of nutrients by annual crops, and this will ultimately leads to lower crop yields. Factors that contribute to low nutrient use efficiency in these soils also includes low natural levels of most essential plant nutrients and unfavorable soil and plant environments which lead to losses from the sites of application (Fageria *et al*., 2001).

Moreover in Kerala there is growing awareness that micronutrient deficiencies limit crop yields even though exceedingly small amounts are required by plants. Various reasons can be attributed to the increased recognition of micronutrient needs in crop production. These include (i) improved soil test and tissue analysis methods for diagnosis of micronutrient deficiencies; (ii) accumulated data on crop responses to micronutrient applications in diverse soil types; (iii) micronutrient removal from long-term crop production; (iv) increased use of high-analysis fertilizers with low amounts of micronutrients; (v) higher micronutrient requirements accompanying higher crop yields; (vi) less use of organic manures in crop production. The laterite and associated soils which constitute more than 70% of the cultivated soil in Kerala have low status of micronutrients. Copper and zinc deficiency is observed in 31 and 34% respectively in soils in Kerala. In general Kerala 5 are found to be deficient in boron (Kerala Agricultural University, 2011).

2.2. Importance of okra in Kerala

Okra is an economically important vegetable crop of tropics and the immature fruit is used as vegetable. Iron, magnesium, phosphorus, calcium, protein, oil and carbohydrates are the nutritional components present in okra. Okra is mainly eaten in cooked or processed form (Akinfasoye and Nwanguma, 2005). During 2017, 63.3 lakh metric tonnes of okra was produced in India. Okra is cultivated in almost all states of India. Okra start to bear fruits at 30-35 days after sowing onwards. In Kerala okra was cultivated in an area of about 1415 ha and average production was 22.50 tonnes (Farm Guide, 2018). In Kerala okra is mainly used for the culinary purpose. Arka Anamika is the popular variety usually preferred by the farmers of Kerala due to its high yield (Singh *et al*., 2018), excellent cooking and keeping quality as well as high tolerance to yellow vein mosaic disease which is a major threat for okra cultivation.

2.2.2 Nutrient requirements of Okra

Generally high yielding varieties require large quantities of nutrients for attaining the potential yield. Since okra is a vegetable crop with indeterminate growth pattern it has simultaneous vegetative as well as reproductive growth. Thus it needs continuous supply of nutrients for good growth as well as for attaining high yield (Abbasi *et al*., 2010). According to KAU POP 2016, okra is one of the vegetable crop with highest fertilizer recommendation (110:35:70 kg ha $^{-1}$ N, P_2O_5 , K_2O, FYM- 20 t ha^{-1})

2.2.3 Impact of fertilizer application in okra

There are different nutrient management techniques usually followed in okra such as direct application of chemical fertilizers in soil, fertigation, foliar application etc. Abbasi *et al.* (2010) found that foliar application of multi-nutrients supplement plant nutrition in integration with soil applied chemical fertilizers and improved growth trait of okra such as days to flowering, plant height, number of branches per plant, number of fruits per plant, fruit length etc. Okra is a fertilizer responsive crop.

Foliar application of nutrients at specific vegetative and fruiting stages of okra is an effective method for meeting the nutrient demands of okra (Haytova, 2013). Occurrence of flowering in okra is directly related to the soil fertility(Shukla *et al*., 2018)

Foliar spraying of $ZnSO_4$ @ 7.5 kg ha^{-1}significantly increased fruit yield per plant, number of fruits per plant, fruit length as well as fruit diameter (Sharma, 2017). According to Nishidha (2018) foliar application of multi nutrient mixture (0.5 % Sampoorna KAU multimix for vegetables) is an effective management strategy for improving vegetative and reproductive traits of okra.

2.3. Nutrient use efficiency (NUE) and nutrient delivery techniques

2.3.1 Nutrient use efficiency (NUE)

In agriculture use of plant nutrients is essential to increase productivity of the cropping system. Application and use of nutrients is influenced by various factors such as climate, soil, plant, socio-economic condition of the farmers. Overall, nutrient use efficiency by crop plants is lower than 50 % under all agro-ecological conditions (Baligar and Fageria, 2015). Under normal condition, major part of the applied nitrogen is either lost to the atmosphere in gaseous form or leached to lower part of the soil profile. Likewise major part of the applied phosphatic fertilizers gets fixed in the soil and the phosphorus becomes unavailable to the plants. Hence, major portion of the applied fertilizer nutrients is lost from the soil-plant system. Due to many environmental factors the applied nutrients get lost from the system and lower NUE. The poor nutrient use efficiency will ultimately lead to yield reduction as well as environmental pollution. Thus improvement of nutrient use efficiency is essential for sustainable agricultural production. According to Cassman *et al*. (2002), for attaining nitrogen use efficiency in crop production systems synchronization between nitrogen demand and nitrogen supply is essential. Nutrient use efficiency is calculated in terms of agronomic efficiency, physiological efficiency, agro-physiological efficiency, apparent recovery efficiency, and utilization efficiency (Thyagi *et al*., 2018). Improvement in nutrient use efficiency is possible only by adopting appropriate strategies such as use of effective nutrient source, rate of application, time and method of application. In addition, use of nutrient efficient and high yielding crop varieties with resistance to both abiotic as well as biotic stresses are also important for attaining better nutrient use efficiency.

Nitrogen is one of the essential plant nutrient elements and plants require nitrogen in large quantities. Nitrate (NO_3^-) and ammonium ions (NH_4^+) are the plant available forms of nitrogen in soil. Since nitrate and ammonium ions are highly mobile in soil, they get lost from the soil soon after application. According to Powlson and Addiscott, (2005) the period immediately after N fertilizer application is the time of high risk of nitrate loss because nitrate concentration in soil is high soon after application of the nitrogenous fertilizer in soil.

Plants require potassium in large quantities next to nitrogen. Potassium deficiency is a common plant disorder in light textured soil as potassium is highly soluble and easily washed out from soils with less clay content. Sourabh and Akhilesh (2016) reported that split application of nutrients increased nutrient use efficiency.

2.3.2 Different nutrient delivery techniques

The way by which fertilizers are applied have a direct influence on the nutrient use efficiency of the crop as well as potential impact on the environment. In all instances, we try to improve fertilizer use efficiency by increasing production per unit area with use of minimum quantity of fertilizer nutrient and without compromising potential yield of the crop. The different nutrient delivery techniques practiced nowadays include soil application, foliar application, fertigation and use of slow and controlled release fertilizers. Efficiency of fertilizer application depends on right rate and balance of nutrients, right fertilizer form, right fertilizer placement technique and finally right time of application (Thyagi *et al*., 2018). According to Cochran *et al*. (1978) response of crop to nitrogen fertilization is related to the rate, time and method of application.

2.3.2.1. Soil application

Soil application of fertilizers is the most common method of application. In this method fertilizers are applied directly to the soil in which the crops are grown. Mainly farmers will go for broadcast application of fertilizers. This is mainly true for phosphatic and potassic fertilizers. If phosphatic and potassic fertilizers come in contact with a large volume of soil particles, phosphorus and potassium fixation will be proportionately high. In such situation placement of fertilizers to definite depth will make sure the availability of nutrient to a greater extent. According to Omotoso and Shittu (2007) soil application of N, P, K fertilizers significantly increased yield, yield attributes and biometric parameters of okra.

2.3.2.2. Foliar application

Nowadays foliar feeding plays an important role in crop production. Some crops are fed almost exclusively by means of foliar spraying. In almost all crops, foliar nutrition plays an important role at one time or another in their growth and development. In foliar application foliar fertilizers are applied directly to the leaves and the nutrient solution is taken up by leaves through stomatal opening. Absorption also takes place through the epidermis. In foliar application fertilizers are applied in small concentration. Thus this method is mainly used for the application of secondary and micronutrients. Major nutrients can also be applied by this method when there is no adequate moisture in top layer of soil. Usually foliar feeding of nutrients is mainly adopted for horticultural crops rather than field crops. This method is applicable only for the application of water soluble fertilizers. Foliar nutrition has several advantages such as it helps in rapid correction of nutrient deficiency, foliar spraying can be combined with other chemical sprayings like insecticides based on the compatibility of chemicals and quick response during adverse conditions like root diseases and drought conditions. Foliar feeding of nutrients have some disadvantages too such as, it will leads to scorching or burning effect if the concentration of spray solution is high, only small quantities of fertilizers can be applied during single spraying and cost of multiple applications are high (Pattil and Chethan, 2016).

2.3.2.3. Fertigation

Application of all forms of water soluble fertilizers along with irrigation water is called fertigation. Efficient use of water as well as fertilizers is possible by means of fertigation. According to Vasu and Reddy (2013) in case of fertigation techniques soil is not considered as a storage reservoir for applied fertilizers; in fact fertilizer is applied to soil to match the nutrient uptake by the crop. Required quantity of fertilizer nutrients is mixed with irrigation water daily. They found that highest N and K use efficiency was observed with fertigation techniques in cabbage.

2.3.2.4. Slow release fertilizers

Slow release fertilizers (SRF) are fertilizers which release nutrients over an extended period of time. Slow release fertilizers releases nutrients gradually with time and it can be in organic or inorganic form. A SRF contains nutrients in a form that makes it unavailable for plant uptake and use for some time after the fertilizer is applied. Such a fertilizer extends its bioavailability significantly longer than quick release fertilizers such as ammonium nitrate, urea, ammonium phosphate, or potassium chloride.

Manures like farmyard manure, poultry manure, compost, green manures and other plant based manures are generally considered as slow release materials. Due to their organic nature these materials must be broken down by microbial activity before the release of nutrients.

Slow/ Controlled release fertilizer formulations offer agricultural producers the opportunity to increase nutrient use efficiency, especially in soils with very low cation exchange capacity (Morgan *et al*., 2009).

Conventional fertilizer formulations such as single super phosphate (SSP), mono ammonium phosphate(MAP) and diammonium phosphate (DAP) were developed with the goal of minimizing the production costs per unit of soluble P. The study of SSP, MAP and DAP modification to reduce susceptibility to P runoff and leaching has been limited (Hart *et al*., 2004). Slow release fertilizers (SRFs) have been employed to reduce direct fertilizer runoff losses. Nutrient leaching from SRFs is reduced through degradation of an organic or inorganic coating around a core of inorganic fertilizer (Quin *et al*., 2003)

Excessive application of nitrogenous fertilizer result in large loss of nitrogen to the environment which affects air and water quality, biodiversity and human health. The excess nitrogen applied in the soil enters in to the air as nitrous oxide and ammonia. Nitrous oxide is a potential degrader of stratospheric ozone as well as one of the greenhouse gas which result in global warming. Controlled release fertilizer is an alternative to the conventional fertilizer. Zhao *et al.* (2013) tested the efficiency of resin coated controlled release fertilizer and sulphur coated controlled release fertilizer to that of common compound fertilizer in maize. Significantly higher yield, net photo synthesis rate, agronomic nitrogen use efficiency, apparent nitrogen recovery, was obtained in the controlled release fertilizer treatments than from conventional fertilizers. They also found that the ammonia volatilization rates from the controlled release fertilizers is significantly lower as compared to controlled release fertilizers

Controlled release fertilizers (CRFs) are fertilizer materials intercalated within carrier molecules commonly known as excipients to control nutrient release thereby improving nutrient supply to crops and minimize environmental, ecological, and health hazards. Controlled release fertilizers include organic or inorganic low solubility nutrient sources and fertilizers in which physical barrier control the release(Sempeho *et al*., 2014).

Tian *et al*. (2016) conducted a field experiment to study the effect of a controlled release fertilizer on yield, nutrient uptake, and fertilizer usage efficiency in early ripening rapeseed *(Brassica napus* L.). Higher seed yield is recorded for the controlled release fertilizer applied treatment by 14.51 per cent than soluble fertilizers and the N, P, K uptakes and usage efficiencies of controlled release fertilizer is significantly higher than that of soluble fertilizer. Nitrogen accumulation and nitrogen usage efficiency of controlled release fertilizer applied treatment was 13.66 and 9.74 % respectively higher as compared to soluble fertilizer applied treatment.

Nitrogen is one of the vital element found in all living organisms. Even though nitrogen is present in abundance in the universe, nitrogen deficiency is the most common nutritional problem found in plants worldwide. In soil nitrogen is present in inorganic(nitrite, nitrate, and ammoniacal) and organic forms (residues of plant and animal). Usually the inorganic nitrogen component in the soil gets easily depleted and hence cannot supply the nitrogen to plants for a long time. Urea is one of the most common nitrogenous fertilizer using worldwide. Since urea is a water soluble fertilizer, once we apply urea in the root zone of a crop it gets rapidly solubilized. But due to the poor nutrient retention capacity as well as lower organic matter content in the soil, the inorganic nitrogen gets leached out from the root zone of a crop by means of either rain fall or irrigation water. Coating of urea with materials like neem and sulphur can improve nutrient use efficiency. Coating of urea with these materials will result in reduced rate of release of nitrogen as compared to the ordinary urea. Shilpha *et al*. (2017) conducted an incubation study in sandy clay loam soils for identifying the nitrogen release pattern from different urea fertilizers coated with natural oils such as neem oil, pongamia oil and castor oil. The results of their incubation study revealed that, slow and steady release of nitrogen was observed in the soil treated with neem coated urea and little faster release of nitrogen in soil was observed in the soil treated with castor oil coated urea as well as pongamia oil coted urea. This may be attributed to the difference in the regulation efficiency of nitrification and mineralization process by different oils.

According to Kiran *et al.* (2010) fertilizer-use efficiency could improve to some extent by using slow release fertilizer technology.

Use of coated KCl fertilizers reduced the leaching loss of nutrients and hence increased productivity in corn (Bley *et al*., 2017). Commercial SRFs can be classified into two basic groups: low solubility and polymer coated water soluble fertilizers (Blaylock *et al*., 2005).

Ahmad *et al*. (2001) studied the influence of slow release sulphur fertilizer, sulphur glass fritz on sulfur and nitrogen assimilation potential of mustard and found that poor assimilation of sulphur and nitrogen by the mustard plant when slow release materials were used due to the initial non availability of sulphur.

The polymer coated SRFs are water soluble and can exhibit consistent nutrient release rates. Entry and Sojka (2008) developed matrix based fertilizer formulation by combining varying amounts of starch, chitosan and lignin to reduce nitrogen and phosphorus leaching from soils.

There are many slow release fertilizers presently available in the market. The main reason for the lack of use of slow release fertilizers in agriculture has been the high cost. Hence slow release fertilizers with less cost and high efficiency are yet to be designed.

Fertilizer manure blocks/ Organic matrix based slow release fertilizer

Organic matrix based slow release fertilizers are developed by combining different organic materials in various proportions along with chemical fertilizers. Fertilizer-manure blocks are the physically compacted forms of organic matrix based slow release fertilizers which offer physical control on release of nutrients. Organic manures are source of both macro and micro nutrients for plants. In addition to this, incorporation of organic manures have some additional advantages like improving the physical, chemical and biological properties of soil. Akter *et al*. (2017) reported that use of fertilizers and organic manures in combination improved growth and yield of tomato. According to Balasubramanian *et al*. (1972) application of organic manures in soil promote microbial activity and maintain soil health. Sharma and Singh (2011) studied the effect of organic matrix based slow release fertilizer on enhancement of plant growth, nitrate assimilation and seed yield of Indian mustard and found significant increase in the plant growth, nitrate assimilation and seed yield under organic matrix based slow release fertilizer applied plants. According to Singh *et al*. (2013) use of organic matrix entrapped fertilizer formulations could significantly influence soil physical properties by increasing the organic matter status in the soil.

Since these organic matrix based fertilizer-formulation is made up of agro-waste materials it is cost effective too. Researchers ought to design controlled release fertilizers by using natural excipient materials to come up with efficient, effective, reliable, and cost effective controlled release fertilizer formulations (Sempeho *et al*., 2014). Kumar *et al*. (2012) developed ecofriendly organic matrix entrapped urea in granular form by mixing natural materials such as cow dung, rice bran, neem leaf powder and clay in 1:1:1:1 along with half of the recommended dose of commercially available soluble urea and studied its effect on growth, productivity and nutritional Status of Rice (*Oryza sativa* L. cv. Basmati) and enrichment in soil fertility. They found that single basal application of organic matrix entrapped urea exhibited an increase in plant growth in terms of fresh and dry weights, root length, root, leaf and tiller numbers, soluble protein, total N and ammonium in leaves, productivity in terms of grain and straw yield, and nutritional and microbial activities of field soil over free form of urea and no fertilizer application. Nutritional status of rice grains was also improved over the free urea applied treatment and no fertilizer treatment (control). They suggested that organic matrix entrapped urea, a biodegradable slow release fertilizer, can be attempted to replace the conventional use of soluble urea in rice. Since organic-matrix entrapped urea is formulated by using locally available agro waste materials it is cost effective too.

Raj (2019) developed organic matrix entrapped slow release fertilizer using locally available organic materials along with recommended fertilizers in disc and granule form for tomato crop and tested the nutrient use efficiency in onattukara sandy plains of Kerala. Onattukara sandy plains have soils with poor nutrient and water retention properties. The results of the experiment revealed that organic matrix entrapped slow release fertilizer possess the ability to ensure prolonged supply of nutrients and hence this fertilizer has the ability to improve nutrient use efficiency and crop productivity.

Component materials in fertilizer-manure blocks

The component material used for developing fertilizer-manure blocks are coir pith, cow dung, vermicompost, neem cake, ground nut cake, humic acid and zeolite. The peculiarities of the different component materials are given below.

Coir pith

According to Coir Board (2016), Coir pith is a calcitrant agro residue containing high amount of cellulose and lignin resisting decomposition by microorganisms under natural condition. The recalcitrant nature is due to the presence of lignin content of coir pith which varies based on place of extraction method of retting, rate of decomposition and storage. Coir pith is a waste product from coir industry and could be used as an organic amendment. Coir pith possess water retention ability and store the moisture for a long period of time in the soil and it is a biodegradable and a renewable resource. Water holding capacity of coir pith is 6 to 8 times than its weight had high porosity and greater physical resilience that withstand compression better. Coir pith possess the ability to store nutrients and releases nutrients over extended periods of time. It also contain natural substances which are beneficial for the growth of plants. Generally coir pith is utilized for making soil-less medium for the cultivation of vegetable crops. Coir pith possess the ability to exchange ions from the inner matrix which consists of minute pores. The exchangeable ions slowly get released from the exchange sites of coir pith and it can be utilized by the plants. Paramanandham and Ross (2018) conducted an investigation on cation exchange capacity of sieved coir pith by using different concentrations of calcium phosphate, calcium nitrate, magnesium phosphate and magnesium nitrate. They found that the univalent cations like Na^+, K^+, were knocked out from the exchange sites of the coir pith and these sites were replaced with the divalent cations such as Ca^+ and Mg^+. Though the exchange or replacement of such polyvalent ions would normally be difficult in other materials, the capacity of the coir pith to exchange such cations was an index of its cation exchange capability.

Cow dung

Cow dung is a common, ecofriendly organic fertilizer and application of cow dung increased the fresh weight and dry weight of carrot (Lebata and Jebessa,2019) . Cow dung has the ability to improve soil health, soil fertility and hence productivity of crops. Thus application of cow dung as a nutrient source is an ecofriendly and sustainable method (Raj *et al*., 2014). Organic nutrient sources like cow dung will release nutrients slowly and will be stored in the soil for a longer time hence ensuring residual effect with respect to various plant nutrients. Gudugi, (2013) reported that combined application of inorganic fertilizers and cow dung increased individual fruit weight and total fruit yield in okra. Organic carbon status increased significantly in farm yard manure treated plot (Saha *et al*., 2010).

Vermicompost

Vermicompost is an organic manure formed as a result of activity of earth worms on bio waste and contains high amount of humus. Vermicompost contains worm casts which is a source of both macro and micro nutrients as well as several enzymes and growth regulating substances. Vermicompost is a potential organic manure having the potential for improving physical, chemical and biological properties of soil. Application of vermicompost will give quick response as compared to ordinary compost or farmyard manure. Vermicompost have the potential to activate microbial activity in soil, improvement in soil aeration, soil infiltration rate, porosity, nutrient content of soil and improves growth and yield of crops as well as quality of the products (Arora *et al*., 2011). Accordingly Rekha *et al*. (2018) found that application of vermicompost have great potential to performance and growth of chilly plants and improvement in soil quality. Zaman *et al*. (2015) reported that vermin compost application significantly increased micro nutrient status of both acidic and non-calcareous soil grown with stevia. Chilli plants grown in Vermicompost amended treatment exhibited enhanced growth rate compared to growth regulator treated plants. Ali and Kashem (2018) found that application of vermicompost along with chemical fertilizers improved yield, head diameter and head thickness of cabbage. Application of vermi compost had shown positive influence on growth and yield of okra by supplying secondary and micro nutrients (Abdulla and Sukhraj, 2010).

Neem cake

Neem cake is a non-edible oil cake and used as a concentrated organic manure. Neem cake is the residue obtained after extraction of oil from fresh fruits of neem. It contains around 5.2 % N, 1.0 % P, 1.4 % K (Tyagi *et al*., 2018). In addition to this neem cake possess insect repellent, nematicidal and fungicidal properties. According to Baboo (2014), urea is one of the commonly used nitrogenous fertilizer worldwide. After the application of urea in soil, the nitrogen in the urea get released when it contacts with water. Nitrifying bacteria such as Nitrosomonas and Nitrobactor plays important role in this process. During this transformation by the activity of these microorganism, first nitrite and then nitrate is formed. Both nitrite and nitrate are highly mobile in soil and they get leached away from the root zone of the crops soon after application. To avoid this problem coating of urea fertilizer with a substance that prevent or slows down the activity of nitrifying bacteria is needed and thus slow down the process of nitrification. Neem cake possess nitrification inhibition properties and thus slows down the process of nitrogen release from urea. Neem cake act as a nitrogen inhibitor and thus reduce the rate of nitrification process in soil. Thus it supplies available nitrogen for a long time in soil. According to Puri, (1999) neem possess nitrification inhibition property.

Sharma and Prasad (1995) conducted field experiment for evaluating the nitrification inhibition properties of neem cake as well as dicyandiamide (DCD) in maize wheat cropping system. They used prilled urea (PU), neem coated urea (NCD) and dicyandiamide coated urea (DCDU) as the nitrogen source. Prilled urea increased maize yield by 1.03 t ha^{-1}, whereas NCU and DCDU increased maize yield by 1.55 and 1.18 t ha^{-1} over the control, which equivalent to an application of 127 and 94 kg N ha^{-1} as PU, respectively. Furthermore, when the results were averaged over two years of study, residual N from the application of NCU and DCDU at 60 kg N ha^{-1} left after maize cropping and increased the grain yield of the succeeding wheat crop grown with 60 kg N ha^{-1} as PU by 1.97 and 1.68 t ha^{-1}, respectively, over a no nitrogen control or 60 kg N ha^{-1} as PU applied to the maize. This was equal to an application of 96 and 82 kg N ha^{-1} as PU to wheat. Thus, neem cake increased the efficiency of urea N applied to maize and benefits were also seen in the succeeding wheat yield in the maize-wheat cropping system.

Yadav *et al*. (2019) conducted field experiment to study the effect of combined application of NPK and neem cake on soil properties. The results of the experiment revealed that different levels of NPK fertilizers when applied along with neem cake improved available nitrogen, phosphorus, and potassium status in post harvest soil.

Groundnut cake

Groundnut cake is an edible oil cake and commonly used as cattle feed and organic fertilizer. According to Oko *et al*. (2015), it is a source of proteins and minerals. Groundnut cake is a byproduct obtained after extraction of oil from groundnut and it is rich in plant nutrients especially nitrogen (7%). Vipitha and Geethakumari (2016) found that use of groundnut cake in bio-organic composite manures increased its nitrogen content.

Zeolites

Zeolites are alumino silicate minerals. Zeolites possess molecular sieve action due to their open channel network and the negative charges in the structure is neutralized by alkaline metals (Na^+, K^+, Rb^+, Cs^+), alkaline earth metals (Ca^{2+}, Mg^{2+}). Zeolites are used in agriculture as slow release fertilizers, soil conditioner, heavy metal remover and increasing the nutrient and water use efficiency along with increasing crop yield (Jakkula and Wani, 2018). Nitrate contamination in crop lands from water bodies can be rectified by applying zeolites as a fertilizer amendment to the soil. The widespread abundance and their selectivity for certain cations(i.e. $NH_4^+$and K^+) makes them suitable carrier material for the preparation of slow/ controlled release fertilizers.

In addition to slow release properties, zeolites have the ability to improve soil physico-chemical properties and hence it is used as a soil conditioner. Application of zeolites to soil helps to control soil pH and increase ammonium retention. Addition of zeolites to the soil will improve soil CEC, act as reservoir of K^+ ions and improve the water holding capacity of soil especially loamy and sandy soils (Nakhli *et al*., 2017).

Humic acid

Humic acid is a naturally occurring organic compound and is polymeric in nature. It is formed as a result of decay of organic materials and present in soils, lignites and peats. Schnitzer and Khan (1972) found that humic substances exhibit diversity of functions. The two important properties of humic acid are complexing ability and cation exchange capacity. Niaz *et al*. (2016) found that humic acid (HA) extracted from poorly weathered Pakistani coal finds effective use in crop production and soil fertility management against low organic matter and soil nutrient depletion problems. They applied urea along with humic acid in maize crop. The results of the experiment revealed that the combined application of urea and humic acid exhibits synergistic effects and increased the economic yield and nitrogen use efficiency of maize crop. Application of urea along with humic acid will ensure the synchrony between the nitrogen demand of the crop and supply thus ensuring a prolonged supply of nitrogen in comparison to the treatment where urea is applied alone.

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Pilot testing of fertilizer-manure blocks in Okra (*Abelmoschus esculentus* L. Moench.) was aimed to develop fertilizer-manure blocks (organic matrix based slow release fertilizer) and testing its effect in Okra. With this view, a laboratory incubation experiment and pot culture experiment were conducted during the year 2018-19 in the Department of Soil Science and agricultural Chemistry, Regional Agricultural Research Station Pattambi. The materials and methods adopted for the experiments are detailed below under different headings :

3.1 Development of fertilizer-manure blocks

3.2. Laboratory incubation experiment

3.3. Pot culture experiment

3.4. Laboratory studies

3.5. Statistical analysis

3.1 Development of fertilizer-manure block

Fertilizer-manure blocks were developed by mixing different organic materials along with chemical fertilizers. Coir pith, cow dung, vermi compost, neem cake, groundnut cake, zeolite (alumino silicate clay) and humic acid were taken as the component materials for formulating fertilizer-manure block for facilitating controlled release of nutrients. The nutrient content in the filler/organic manures are given in the Table 3.1. After mixing the chemical fertilizers with the matrix materials, the mixture was pressed by using specially fabricated machine and fertilizer manure blocks were developed. For the incubation experiment fertilizer-manure blocks were developed using seven different component materials in 5 different proportions along with per plant dosage of chemical fertilizers including macro and micronutrients calculated based on KAU POP recommendation. The quantity of chemical fertilizers used for formulating the fertilizer-manure blocks are given in the Table 3.5. Fertilizer alone placement (sole fertilizer placement) was taken as a check. The fertilizer manure blocks were prepared with the dimension of 7.5 cm diameter and 3 cm height. Many number of trials were taken for formulating the blocks with different proportions to attain consistency and shape retention. The different proportions were fixed based on the shape retention and consistency of the product. Thus fertilizer-manure blocks were prepared in 5 different proportions as given in the Table.3.2.

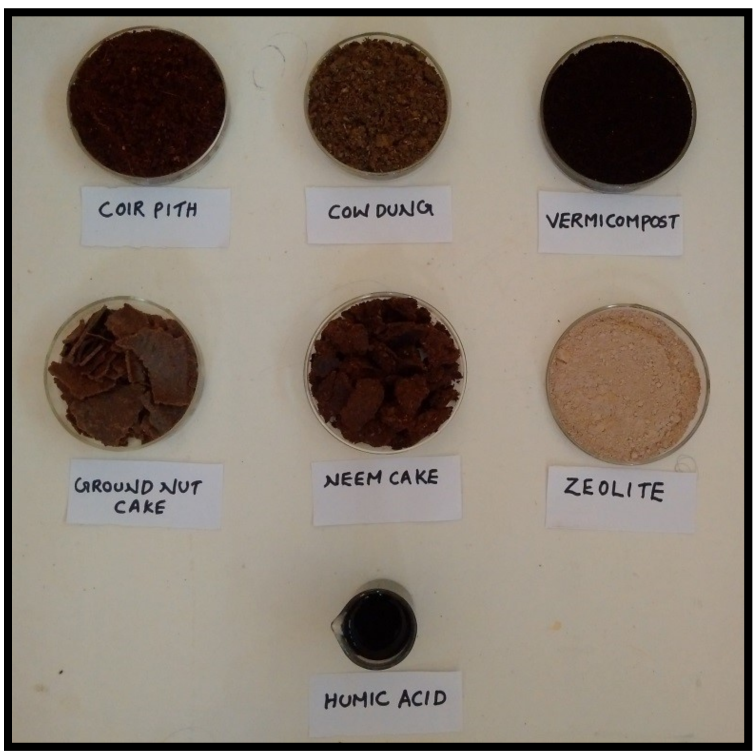
3.2.Laboratory incubation experiment

The laboratory incubation experiment was conducted at the Regional Agricultural Research Station, Pattambi for identifying the best proportion out of different combinations of organic manures/filler materials used for formulating fertilizer manure blocks for slow release of nutrients. The experiment was laid out in a completely randomized design with 6 treatments and 4 replications. Treatment details are given in the Table 3.2.

Relatively less fertile soil was collected from the garden lands of Regional Agricultural Research Station, Pattambi. Surface soil was collected at 0-15 cm depth for conducting the experiment .The soil was air dried, ground with wooden mallet, passed through 2 mm sieve and used for the laboratory incubation experiment. Initial soil analysis was done for pH, Electrical conductivity (EC), Organic carbon (OC), available nutrients such as N, P, K, Ca, Mg, S, Zn, Cu and B in soil before conduct of the incubation experiment as per the procedure detailed in Table. 3.4. The basic parameters of the experimental soil are given in the Table.3.3.

Litter bag technique was followed for incubation study. One kg each of 2mm sieved soil was filled in polythene covers (size : Height- 26 cm, Diameter- 20.5 cm) without any drainage holes and used for the incubation study. The fertilizer-manure blocks prepared with five different proportions and fertilizers alone were taken in nylon cloth bags. The nylon cloth bags of 60 mesh size and plastic twines was used for preparing the nylon cloth bags. The nylon cloths was cut into square pieces (size- 20 cm x 20 cm) and 100g fertilizer manure block was placed on the centre of the cloth piece, made in to bags by folding from all sides and tied with the help of plastic threads. In the case of sole fertilizer-placement treatment calculated quantities of fertilizers alone were taken inside the nylon cloth bag. The fertilizer-manure blocks/ fertilizers were wrapped with the nylon cloth bag for preventing the direct mixing of the materials with the soil. These individual nylon cloth bags with blocks/fertilizers were inserted into centre of the polythene cover containing soil. Sufficient quantity of soil was added to cover the blocks/fertilizer from all sides. The soil was brought to field capacity (30% w/w) by adding measured quantity of water and the moisture content was restored gravimetrically at an interval of 3 days throughout the experiment. Destructive sampling was done at 1, 3, 6, 10, 20, 40, and 60 days of incubation for studying the pattern of release of nutrients. The nylon cloth bags with blocks/ fertilizer were pulled out carefully from each polythene cover and the remaining soil was mixed well, dried under shade and analyzed for available nutrients such as N, P, K, Ca, Mg, S, Zn, Cu and B at 1, 3, 6, 10, 20, 40, and 60 days of incubation. Absolute release of each nutrient during during various intervals of incubation was calculated by subtracting the available nutrient content of two consecutive days of sampling. Based on the nutrient release pattern, best proportion of fillers was selected on the basis of slow release of nutrients and its concurrence with the pattern of crop growth with respect to different stages as well as the cost of the fertilizer-manure blocks. The nutrient composition of five different combinations of fertilizer-manure blocks and its cost are given in the Table. 3.5 and 3.6.respectively. The best proportion (Treatment) selected based on the laboratory incubation experiment was used for the pot culture study (Experiment-II).

Fertilizer-manure blocks made in two different dimensions (100g and 25 g)



Component materials in Fertilizer-manure blocks

Plate 1. Fertilizer-manure blocks and component materials

Machine for making 100 g fertilizer-manure block

Machine for making 25 g fertilizer-manure block

Plate 2. Machines for developing fertilizer-manure block

Mixing

Air drying

Pressing

Plate 3. Process of development of fertilizer-manure block

Fertilizer-manure blocks taken inside nylon cloth bags

Fertilizers taken inside nylon cloth bags

Samples kept for incubation

Destructive sampling

Plate 4. Experimental view of incubation study

Table.3.1. Nutrient content of component material used for formulating fertilizer-manure blocks

Components	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})
Vermi compost	0.987	0.100	0.304	0.501	0.154	0.270	620.0	28.25	19.97
Coir pith	0.330	0.075	0.975	0.322	0.233	0.210	10.20	22.25	16.20
Cow dung	0.700	0.399	0.254	0.308	0.184	1.520	38.00	10.50	9.450
Zeolite	0.530	0.007	0.0445	11.43	3.015	0.010	0.800	15.90	6.150
Neem cake	0.990	0.456	0.475	0.202	0.890	0.290	42.00	9.000	6.975
Groundnut cake	6.400	0.500	0.328	0.200	0.243	0.350	50.00	9.750	5.900
Humic acid	0.170	0.0012	0.240	0.005	0.003	0.00250	2.500	3.750	0.105

Table 3.2. Proportion of Fillers/ organic manures in fertilizer-manure blocks (Treatments) designed for the incubation experiment

Treatments	Proportion of fillers/organic manure
T_1 (Proportion 1)	Coirpith- 35%, Cowdung- 25%, Vermicompost-13%, Groundnutcake- 10%, Neem cake 10%, Zeolite- 2%, Humic acid- 5%
T_2 (Proportion 2)	Coirpith- 35%, Cowdung- 22.5%, Vermicompost-18% , Groundnutcake- 7.5%, Neem cake 7.5%, Zeolite- 2%, Humic acid- 7.5%
T_3 (Proportion 3)	Coirpith- 35%, Cowdung- 20%, Vermicompost-18%,Groundnutcake- 7.5%, Neem cake 7.5%, Zeolite- 2%, Humic acid- 10%
T_4 (Proportion 4)	Coirpith- 35%, Cowdung- 20%, Vermicompost- 12.5%,Groundnutcake- 7.5%, Neem cake 7.5%, Zeolite- 5%, Humic acid- 12.5%
T_5 (Proportion 5)	Coirpith- 40%, Cowdung- 30%, Vermicompost- 20%, Groundnutcake- 5%, Neem cake 5%
T_6- Control (check)	Fertilizer alone taken in a nylon cloth bag

Table.3.3 . Basic parameters of the soil taken for the incubation study

Sl. No.	Parameter	Value
1	pH	5.34
2	Electrical conductivity ($dS\ m^{-1}$)	0.019
3	Organic carbon(%)	0.62
4	Available nitrogen ($kg\ ha^{-1}$)	300.9
5	Available phosphorus ($kg\ ha^{-1}$)	5.740
6	Available potassium ($kg\ ha^{-1}$)	273.2
7	Exchangeable calcium ($mg\ kg^{-1}$)	424.4
8	Exchangeable magnesium ($mg\ kg^{-1}$)	148.5
9	Available sulphur ($mg\ kg^{-1}$)	3.200
10	Available zinc ($mg\ kg^{-1}$)	3.250
11	Available copper ($mg\ kg^{-1}$)	1.360
12	Available boron ($mg\ kg^{-1}$)	0.580

Table.3.4. Procedures used for chemical analysis of soil

Parameter	Method used for extraction and estimation	Reference
pH	The H^+ ion activity in 1:2.5 soil water suspension was measured using pH meter	Jackson (1958)
Electrical conductivity (EC)(dS m^{-1})	The electrical conductivity of the supernatant solution after soil pH estimation was measured using conductivity meter.	Jackson (1958)
Organic carbon (OC)(%)	Wet digestion method	Walkely and Black (1935)
Available nitrogen(Av. N) (kg ha^{-1})	Alkaline permanganometry	Subbiah and Asija (1956)
Available phosphorus (Av. P) (kg ha^{-1})	Bray No. I solution was used for extracting available phosphorus and after ascorbic acid blue colour method estimated by using spectrophotometer	Bray and Kurtz (1945) Watanabe and Olsen 1956)
Available potassium (Av. K) (kg ha^{-1})	Neutral normal ammonium acetate was used as extractant and measurement was done by using flame photometer	Jackson (1958)
Exchangeable calcium (Ex. Ca) (mg kg^{-1})	Neutral normal ammonium acetate was used as extractant and estimation by Atomic absorption spectro photometry	
Exchangeable magnesium (Ex. Mg) (mg kg^{-1})	Neutral normal ammonium acetate was used as extractant and estimation by Atomic absorption spectro photometry	
Available sulphur	0.15 % calcium chloride was used as	Tabatabai (1982)

(Av. S) (mg kg^{-1})	extractant and followed by turbidimetric analysis using spectrophotometer at 440 nm	Massoumi and Cornfield (1963)
Available zinc (Av. Zn) (mg kg^{-1})	0.1 N Hydrochloric acid was used as extractant and estimation was done by using Atomic Absorption Spectrophotometer	Sims and Jhonson (1991)
Available copper (Av.Cu)(mg kg^{-1})	0.1 N Hydrochloric acid was used as extractant and estimation was done by using Atomic Absorption Spectrophotometer	
Available boron (Av. B) (mg kg^{-1})	Hot water extractable boron was determined calorimetrically by using azomethane-H reagent at 420 nm	Berger and Troug(1939) Gupta (1972)

Table 3.5. Per plant recommended dose of fertilizers in Okra for incubation experiment

Sl. No.	Name of fertilizer	Quantity(g)
1.	Urea	4.304
2.	Rajphos	3.500
3.	Muriate of potash	2.100
4.	Dolomite	4.130
5.	Magnesium sulphate	1.440
6.	Zinc sulphate	0.360
7.	Copper sulphate	0.036
8.	Borax	0.180

Table. 3.6. Nutrient content (%) of fertilizer-manure blocks (with fertilizers) designed for incubation experiment

Nutrient (%)	T_1 Proportion 1	T_2 Proportion 2	T_3 Proportion 3	T_4 Proportion 4	T_5 Proportion 5
N	3.164	3.007	2.969	2.935	2.889
P	0.541	0.5117	0.448	0.4427	0.5233
K	1.583	1.578	1.868	1.8789	1.6132
Ca	1.391	1.398	1.442	1.757	1.2994
Mg	0.17	0.434	0.475	0.5567	0.3741
S	0.638	0.748	0.479	0.465	0.7122
Zn	0.079	0.089	0.0882	0.0778	0.0789
Cu	0.0106	0.0104	0.0109	0.01081	0.0104
B	0.0201	0.0202	0.0205	0.02041	0.0203

Table. 3.7. Cost of fertilizer-manure blocks of different proportions

Treatments	Cost (Rs.) per block
T_1 (Proportion-1)	1.572
T_2 (Proportion-2)	1.6895
T_3 (Proportion-3)	1.9225
T_4 (Proportion-4)	1.9225
T_5 (Proportion-5)	1.195

3.3. Pot culture experiment

A pot culture experiment was undertaken in grow bags to investigate the efficiency of fertilizer-manure blocks on growth and yield of okra. The proportion of filler materials selected based on the results of the laboratory incubation experiment was used for formulating fertilizer-manure blocks for the pot culture experiment conducted at Regional Agricultural Research Station, Pattambi, during the summer season 2019.

3.3.1 Climate and soil

Typical humid tropical climate was experienced in this area. The laterite soil was collected from the garden lands of Regional Agricultural Research station, Pattambi and used for conducting pot culture experiment in grow bags. The initial soil analysis data of soil used in the pot culture study are given in the Table. 3.8.

3.3.2. Variety

Okra variety Arka Anamika with duration of 130-135 days was used for the experiment. This variety is a heavy yielder with an average yield of 20 t ha^{-1} and highly tolerant to yellow vein mosaic virus. Plants are tall in general, well branched, with lush green, tender long fruits. Fruits are born in two flushes. Purple pigment is present on both sides of the petal base, green stem with purple shade. Fruits free from spines having 5-6 ridges, delicate aroma and good keeping and cooking qualities are the main features of this variety.

3.3.3. Treatment details

The details of treatments are as follows:

Design : Completely Randomised design(CRD)

Number of Treatments : 11

Number of Replications : 3

Number of plants per replication : 5

The best proportion of fillers/organic manures selected based on experiment-I was used for formulating fertilizer-manure blocks for the pot culture experiment. Fertilizer-manure blocks was prepared in two dimensions (100g and 25 g blocks) using three different dosages (100% of POP, 50% of POP, and 25% POP) of fertilizers. The per plant dosage of fertilizers was calculated based on the POP and *ad hoc* POP recommendations of primary, secondary and micro nutrients and were used for formulating single block.

Combinations of the following treatment options taken as T_1-T_6 (3x2 = 6), along with placement of 25 g blocks with 25% recommended nutrients + 50 % nutrients as top dressing, normal blanket and soil test based recommend action of fertilizer as per POP of KAU, control and absolute control. The details of treatments followed in pot culture experiment is presented in Table 3.9.

a) Fertilizer dosages

1. Nutrients as per 100% POP
2. Nutrients as per 50% POP
3. Nutrients as per 25% POP

b) Size and placement geometry

1. The blocks of size 100 g containing per plant recommendation of fertilizers; for use @ 1 block/ grow bag, placed below the level of planting
2. The blocks of size 25g with 1/4th of the per plant recommendation of fertilizers; for use @ 4 nos /grow bag, placed at the soil surface on four sides of the plant

Table. 3.8. Basic parameters of soil selected for pot culture experiment

Sl. No.	Parameter	Value
1	pH	5.34
2	Electrical conductivity ($dS\ m^{-1}$)	0.015
3	Organic carbon (%)	0.49
4	Available nitrogen ($kg\ ha^{-1}$)	220.5
5	Available phosphorus ($kg\ ha^{-1}$)	29.95
6	Available potassium ($kg\ ha^{-1}$)	135.37
7	Exchangeable calcium ($mg\ kg^{-1}$)	529.5
8	Exchangeable magnesium ($mg\ kg^{-1}$)	118.5
9	Available sulphur ($mg\ kg^{-1}$)	3.23
10	Available zinc ($mg\ kg^{-1}$)	2.8
11	Available copper ($mg\ kg^{-1}$)	0.97
12	Available boron ($mg\ kg^{-1}$)	0.37

3.3.4 Cultivation details

The experiment was conducted in grow bags. Eight kg of air dried soil and two kg of nutrient free river sand were mixed and used for filling the grow bags. Calculated quantities of farm yard manure based on KAU POP recommendation was added to all the treatments except the absolute control. Twelve days old seedlings of Okra variety Arka Anamika were transplanted at the rate of one seedling per grow bag. Shade was provided to the seedlings for few days after transplanting.

Table.3.9. Treatment details of pot culture experiment

Treatments	
T_1	Blocks of size 100 g with nutrients as per 100 % POP @ 1 block per grow bag, placed below the level of planting
T_2	Blocks of size 100 g with nutrients as per 50 % POP @ 1 block per grow bag, placed below the level of planting
T_3	Blocks of size 100 g with nutrients as per 25 %POP @ 1 block per grow bag, placed below the level of planting
T_4	Blocks of size 25 g with nutrients as per 100 % POP @ 4 block per grow bag, placed on 4 sides of the plant at soil surface
T_5	Blocks of size 25 g with nutrients as per 50 % POP @ 4 block per grow bag, placed on 4 sides of the plant at soil surface
T_6	Blocks of size 25 g with nutrients as per 25 % POP @ 4 block per grow bag, placed on 4 sides of the plant at soil surface
T_7	T_3 + 50 % POP recommendation as top dressing

T_8	Nutrients as per POP of KAU
T_9	Nutrients as per soil test based recommendation
T_{10}	Control (Organic manure as per POP of KAU)
T_{11}	Absolute control

3.3.5 Fertilizer application

Fertilizer application was done based on the treatments. Fertilizer-manure block of 100g size was placed 5 cm below the level of planting and fertilizer manure blocks of 25 g size placed on four sides of the plant just below the soil surface.

3.3.6. Irrigation

Daily irrigation was provided using drip irrigation system so as to ensure uniform irrigation for the entire set of plants.

3.3.7 After cultivation

Weeding and plant protection operations were carried out as and when required.

3.3.8 Biometric observations

The observations recorded during the pot culture study were listed below

- Days to first flowering - Number of days taken from planting to opening of first flower was recorded.
- Plant height (cm) - Height of the plants was recorded at 15, 30, 45, 60, and 75 days after planting.
- Number of leaves per plant - Number of leaves per plant was recorded at 15, 30, 45, 60, and 75 days after planting.
- Number of branches per plant - Number of branches per plant was recorded 15, 30, 45, 60, and 75 days after planting.

- Total number of fruits per plant – Total number of fruits per plant was found out by counting the number of fruits harvested during the entire crop growth period.
- Fruit length (cm) – Fruit length was measured from tip to bottom of the fruit and the average fruit length of total fruits were calculated harvested during the entire crop growth period.
- Fruit girth (cm) - Fruit girth (diameter) was measured by using thread and scale and average fruit girth of total fruits were calculated for the fruits harvested from the plant during the entire crop growth period.
- Total fruit yield per plant (g) – Total fruit yield per plant was calculated by adding up the weight of fruits harvested at different times during the entire crop growth period.
- Number of seeds per fruit – Average number of seeds was calculated by counting the number of seeds in individual fruit harvested during the entire crop growth period.

3.4. Laboratory studies

3.4.1. Soil analysis after final harvest of the crop

Soil samples were drawn from each treatments after final harvest. The whole soil was taken from the grow bag after harvest, properly mixed, air dried under shade and analysed for pH, Electrical conductivity, Organic carbon, Available N, P, K, Ca, Mg, S, Zn, Cu, B as per the procedure given in the Table 3.2.

3.4.2. Plant analysis after final harvest of the crop

The plant samples representing various treatments were collected after final harvest of the crop. Fresh weight was noted and kept for air drying and then the samples were dried to constant moisture at 65^0C in hot air oven. Finally the samples were ground thoroughly in mixer grinder and stored in moisture free condition. Ground plant samples were digested with di-acid mixture (2:1 nitric acid and perchloric acid) using Kelplus-KES 12L R digestion unit for determining P and K content. Concentrated sulphuric acid was used for the digestion of plant samples for determination of nitrogen content.

Digested samples were filtered and made up the volume to 100 mL and used for the analysis of different elements. Plant nutrient content was determined by following the procedures given in the Table 3.10.

3.4.2.1 Uptake of nutrients by plants.

The N, P,K, Ca, Mg, S, Zn, Cu, B contents of the plant were multiplied with their respective dry matter yield to get the uptake values. It was expressed in mg per plant dry matter.

3.4.3 Agronomic efficiency

Agronomic efficiency was computed by using the formula given below

Agronomic efficiency

= Yield in fertilized pot(g pot^{-1}) – Yield in unfertilized pot(g pot^{-1})/ Quantity of fertilizer nutrient applied

3.5 Statistical analysis

Data generated from the laboratory experiment as well as pot culture study was subjected to statistical analysis by Completely Randomized Design (CRD) and two way analysis of data. Analysis of data in CRD was done using the software WASP (Web Agri Stat Package).

Table.3.10. Methods used in analysis of the contents of various nutrients in plant samples.

Element	Method
Nitrogen	Single acid digestion using concentrated sulphuric acid followed by filtration and nitrogen content was determined by microkjeldhal method of distillation.
Phosphorus	Di-acid digestion of plant samples followed by filtration(Piper, 1966). Intensity of yellow coloured vanadomolybdate complex was determined colorimetrically at 420 nm using spectrophotometer.
Potassium	Di-acid digestion of plant samples followed by filtration. The potassium content in the plant digest was determined using flame photometer.
Calcium and Magnesium	Di-acid digestion of plant samples followed by filtration. The content in the plant digest was determined using Atomic Absorption Spectrophotometer (AAS).
Sulphur	Di-acid digestion of plant samples followed by filtration. Sulphur content in the filtrate was estimated by turbidimetric method using spectrophotometer by measuring absorbance at 420 nm.
Zinc and Copper	Di-acid digestion of plant samples followed by filtration. The content in the plant digest was determined using Atomic Absorption Spectrophotometer (AAS).
Boron	Di-acid digestion of plant samples followed by filtration. Boron content in the filtrate was determined calorimetrically by Azomethane-H reagent using spectrophotometer.

Fertilizer-manure block (100 g) placed 5 cm below the level of planting

Fertilizer-manure block (25 g) placed on four sides

Plate 5. Pot culture experiment- Placement of fertilizer manure block

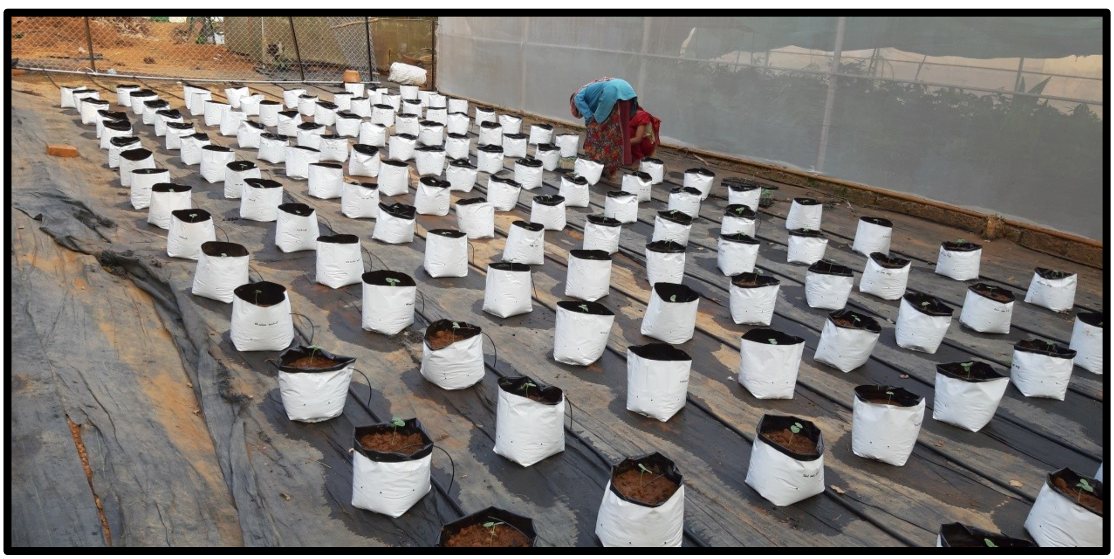


Plate 6. Pot culture experiment- Planting

Plate 7. Experimental view- pot culture study

Field observation

Impact of treatments on growth of okra

Plate 8. Experimental view- pot culture study


Root penetration under 100g fertilizer-manure block placement

Root system under conventional fertilizer application

Plate 9. Root system under various treatments

Results

4. RESULTS

Productivity enhancement is the major thrust area for sustainability of agriculture and nutrient management is one of the most important components attributing to productivity of the crops. The increase in food requirement and limitations in area expansion warrants improvement on fertilizer use efficiency. However a major portion of the soil applied nutrients is lost through leaching, runoff, and volatilization processes. To overcome these issues fertilizer-manure blocks (organic matrix based slow release fertilizer) were developed at Department of Soil Science and Agricultural Chemistry, Regional Agricultural Research Station, Pattambi and its effect on growth and yield of okra was studied. The study includes two experiments: laboratory incubation experiment and pot culture experiment. The results obtained from these experiments are presented in this chapter.

4.1. Incubation experiment

The main objective of the incubation study was to assess the nutrient (N, P, K, Ca, Mg, S, Zn, Cu, B) release pattern from five different fertilizer-manure blocks and fertilizers alone at varying intervals for 60 days.

4.1.1. Effect of treatments on available nitrogen content (mg kg^{-1}) in soil

Available nitrogen content showed significant difference among treatments. The available nitrogen content of the soil at different periods of incubation as influenced by the treatments is presented in the Table 4.1. The highest value of 1771.5 mg kg^{-1} was recorded by T_6 at 10 days of incubation and lowest value of 253.9mg kg^{-1} was observed under T_1 during the first day of incubation. At first day of incubation the treatments were significantly different and highest value was recorded by $T_6$and lowest value was recorded by T_1.The treatments T_2,T_3,T_4, and T_5 were on par with each other and significantly superior to T_1 with respect to available nitrogen content in soil at 1stday of incubation. Almost similar trend was observed up to 10 days of incubation. At twenty days of incubation highest value was recorded by T_6. The release of nitrogen from T_1 was considerably increased and was in on par with T_2. The nitrogen release from T_3, T_4, and T_5were on par. At 40 days of incubation the highest value was recorded by T_5 which was on par with T_4. Treatment, T_1showed highest release of nitrogen at 60 days of incubation and lowest by T_6.

Table 4.1. Effect of fertilizer-manure blocks/ fertilizers on available nitrogen content (mg kg^{-1}) of the soil at different periods of incubation

Treatments	Days of incubation						
	1	**3**	**6**	**10**	**20**	**40**	**60**
T_1	253.9^{c}	416.3^{d}	474.1^{d}	496.5^{c}	832.5^{c}	1153.6^{d}	1375.7^{a}
T_2	354.7^{b}	492.8^{c}	593.6^{c}	630.9^{b}	925.8^{c}	1153.6^{d}	1291.7^{a}
T_3	369.6^{b}	545.1^{b}	642.1^{c}	703.7^{b}	1183.5^{b}	1198.4^{cd}	1325.3^{a}
T_4	408.8^{b}	576.8^{b}	629.1^{c}	658.9^{b}	1093.9^{b}	1288.0^{ab}	1344.0^{a}
T_5	403.2^{b}	563.7^{b}	744.8^{b}	742.9^{b}	1187.2^{b}	1357.1^{a}	1325.3^{a}
T_6	787.7^{a}	821.3^{a}	1566.1^{a}	1771.5^{a}	1704.3^{a}	1260.0^{bc}	1024.8^{b}
CD(0.05)	**58.526**	**38.871**	**84.181**	**130.344**	**130.892**	**83.197**	**149.305**

The overall effect of the treatments on release of nitrogen was analyzed through two way analysis of the data and is presented in the Table 4.2 .The highest mean value of available nitrogen was recorded by T_6 (1276.5 mg kg^{-1}) and is significantly superior to all other treatments. As the days of incubation progressed, the available nitrogen release showed an increasing trend in all the treatments except T_6 where it was increased up to 10 th day and decreased thereafter. The interaction between treatments and period of incubation showed significantly higher available nitrogen content in T_6 (1771.5 mg kg^{-1}) at 10 days of incubation and lowest in T_1(253.87 mg kg^{-1}) at first day of incubation. As a whole, all fertilizer-manure blocks showed a slow release pattern with respect to available nitrogen in soil as compared to sole fertilizers. When compared among the fertilizer-manure blocks, peak release of available N was obtained from T_1 at 60 days of incubation, the average release was least which indicate the superiority of the block in controlling the rate of release of nitrogen from the formulation.

Table 4.2. Overall effect of fertilizer-manure blocks/ fertilizers on available nitrogen content (mg kg^{-1}) of the soil at different periods of incubation

Treatments (T)	Days of incubation(D)							
	1	**3**	**6**	**10**	**20**	**40**	**60**	**Mean**
T_1	253.87	416.27	474.13	496.53	832.53	1153.6	1375.7	714.67
T_2	354.67	492.80	593.60	630.93	925.87	1153.6	1291.7	777.60
T_3	369.60	545.07	642.13	703.73	1183.5	1198.4	1325.3	852.53
T_4	408.80	576.80	629.07	658.93	1093.9	1288.0	1344.0	857.07
T_5	403.20	563.73	744.80	742.93	1187.2	1357.07	1325.3	903.47
T_6	787.73	821.33	1566.1	1771.5	1704.3	1260.0	1024.8	1276.5
Mean	429.64	569.33	774.98	834.088	1154.5	1235.1	1281.2	
CD(0.05)- T- 35.44		**CD(0.05) - D-38.28**		**CD(0.05)- TXD- 93.77**				

4.1.2. Effect of treatments on available phosphorus content (mg kg^{-1}) in soil

Data pertaining to available P content of the soil as influenced by the various treatments are given in the Table 4.3. The treatments were significantly differed with respect to release of P in soil during incubation. At the first day of incubation, the available P content was highest (5.389 mg kg^{-1})for soil treated with sole fertilizers(T_6) and lowest (2.648mg kg^{-1}) under T_1. On third day of incubation there was an increase in the available phosphorus content irrespective of the treatments and highest value of 6.664 mg kg-1 was observed in T_6. Treatments T_1,T_2,T_3 and T_4 were found to be on par and lowest value(4.039mg kg^{-1}) was recorded in T_5. At 6thday of incubation there was an decrease in the available phosphorus content in all treatment except for T_4 and T_5. Compared among the fertilizer manure blocks, the highest available phosphorus content

(7.243mg kg^{-1}) was noticed in T_1 at 40 days of incubation. Treatments T_2 and T_6 were found to be on par with T_1. At 60thday of incubation highest available phosphorus content were noticed in T_4 and T_5.

Table 4.3. Effect of fertilizer-manure blocks/ fertilizers on available phosphorous (mg kg^{-1}) content of the soil at different periods of incubation

Treatments	Days of incubation						
	1	3	6	10	20	40	60
T_1	2.648^{e}	4.296^{b}	3.782^{c}	3.979^{d}	4.509^{c}	7.243^{a}	8.041^{b}
T_2	3.201^{d}	4.353^{b}	3.782^{c}	4.055^{cd}	5.097^{a}	6.729^{a}	5.000^{c}
T_3	3.386^{cd}	4.353^{b}	3.582^{c}	4.420^{b}	4.553^{c}	4.296^{b}	3.972^{d}
T_4	3.460^{bc}	4.353^{b}	4.353^{b}	4.274^{bc}	4.800^{b}	3.972^{b}	10.12^{a}
T_5	3.650^{b}	4.039^{c}	4.104^{b}	4.039^{d}	4.671^{bc}	4.541^{b}	10.13^{a}
T_6	5.389^{a}	5.646^{a}	5.398^{a}	5.000^{a}	5.222^{a}	6.664^{a}	5.380^{c}
CD(0.05)	**0.247**	**0.252**	**0.283**	**0.232**	**0.234**	**0.688**	**0.836**

Table 4.4. Overall effect of fertilizer-manure blocks/ fertilizers on available phosphorus content (mg kg^{-1}) of the soil at different periods of incubation

Treatments(T)	Days of incubation(D)							
	1	3	6	10	20	40	60	Mean
T1	2.648	4.296	3.782	3.979	4.509	7.243	8.041	4.927
T2	3.201	4.353	3.782	4.055	5.097	6.729	5.000	4.608
T3	3.386	4.353	3.582	4.421	4.553	4.296	3.972	4.089
T4	3.460	4.353	4.353	4.274	4.800	3.972	10.12	5.057
T5	3.650	4.039	4.104	4.039	4.671	4.541	10.13	5.027
T6	5.389	5.646	5.398	5.000	5.222	6.664	5.380	5.527
Mean	3.622	4.505	4.164	4.298	4.810	5.572	7.102	
CD(0.05)-T-0.159		**CD(0.05)-D-0.176**		**CD(0.05)-0.419**				

The overall effect of the treatments on release of P was analyzed through two way analysis of the data and is presented in the Table 4.4. Significantly highest mean value of available P was recorded in T_6 (5.527mg kg^{-1}) and superior to all other treatments. Generally as the time of incubation progresses the available phosphorus content in different treatments exhibited an increasing trend. The interaction effect of treatments and period of incubation showed significantly higher amount of available phosphorus content at 60^{th} day of incubation in T_4 and T_5 and lowest in T_1(2.648 mg kg^{-1}) at first day of incubation.

4.1.3.. Effect of treatments on available potassium content (mg kg^{-1}) in soil

Available potassium released by different fertilizer-manure blocks and fertilizers during all the incubation period showed significant and is presented in the Table 4.5. On the first day of incubation, the highest value (1049.9 mg kg^{-1}) was recorded by T_6 and lowest value of (348.18 mg kg^{-1}) was recorded by T_1.

Table 4.5. Effect of fertilizer-manure blocks/ fertilizers on available potassium content (mg kg^{-1}) of the soil at different periods of incubation

Treatments	**Days of incubation**						
	1	**3**	**6**	**10**	**20**	**40**	**60**
T_1	348.18^{d}	557.34^{d}	667.73^{d}	995.58^{d}	1072.8^{cd}	1128.4^{b}	1162.4^{b}
T_2	424.13^{c}	655.28^{c}	758.62^{c}	1084.4^{c}	1118.8^{bc}	1142.9^{b}	1165.3^{b}
T_3	450.69^{bc}	691.80^{c}	792.23^{c}	1122.9^{bc}	1148.3^{b}	1165.3^{b}	1176.5^{b}
T_4	496.75^{b}	799.70^{b}	881.46^{b}	1228.8^{a}	1250.4^{a}	1267.4^{a}	1275.7^{a}
T_5	479.74^{b}	708.40^{c}	783.10^{c}	1094.7^{c}	1117.2^{bcd}	1133.8^{b}	1145.4^{b}
T_6	1049.9^{a}	1114.7^{a}	1125.5^{a}	1176.9^{ab}	1066.5^{d}	937.69^{c}	930.84^{c}
CD(0.05)	**53.463**	**66.024**	**86.846**	**68.161**	**51.027**	**54.129**	**67.972**

At third day of incubation the highest value (1114.7 mg kg^{-1}) of available potassium was recorded by treatment T_6 and lowest (557.34 $mgkg^{-1}$) by T_1. A similar trend was observed at 6^{th} day of incubation. Treatment T_4 showed highest available potassium content at 10, 20, 40 and 60 days of incubation which was on par with the treatment T_6 at 10 days of incubation study. But T_6 showed a decreasing trend in the case of available potassium, while T_1 showed a gradual increasing trend on 20^{th} day onwards.

The overall effect of the treatments on release of potassium was analyzed through two way analysis of the data and presented in the Table 4.6. The highest mean available potassium (1057.5mg kg^{-1}) was recorded in $T_6$and which was significantly superior to all other treatments.. As the days of incubation progressed, the available potassium released from fertilizer-manure blocks/fertilizers showed an increasing trend in all the treatments except T6 between 10 and 60 days of incubation. On analyzing the effect of incubation period on available potassium, highest value was observed at 60 days of incubation (1142.7 mg kg^{-1}) and lowest at (541.57 mg kg^{-}1) first day of incubation. The interaction effect of treatments and period of incubation showed significantly higher available potassium content in T_4 (1275.7 mg kg^{-1}) at 60 days of incubation and lowest in T_1(348.18 mg kg^{-1}) at first day of incubation.

Table 4.6. Overall effect of fertilizer-manure blocks/ fertilizers on available potassium content (mg kg^{-1}) of the soil at different periods of incubation

Treatments	Days of incubation(D)							
(T)	1	3	6	10	20	40	60	Mean
T_1	348.18	557.34	667.73	995.58	1072.8	1128.4	1162.4	847.48
T_2	424.13	655.28	758.62	1084.4	1118.8	1142.9	1165.3	907.07
T_3	450.69	691.80	792.23	1122.9	1148.3	1165.3	1176.5	935.41
T_4	496.75	799.70	881.46	1228.8	1250.4	1267.4	1275.7	1028.6
T_5	479.74	708.40	783.10	1094.8	1117.2	1133.8	1145.4	923.19
T_6	1049.9	1114.7	1125.5	1176.9	1066.5	937.69	930.84	1057.5
Mean	541.57	754.53	834.77	1117.2	1129.0	1129.2	1142.7	
CD-(0.05)-T-18.27		**CD-(0.05) -D-19.73**		**CD(0.05)- TXD-48.31**				

4.1.4. Effect of treatments on exchangeable calcium content (mg kg^{-1}) in soil

The results of exchangeable calcium content of soil at different stages of incubation are presented in the Table 4.7. At first day of incubation, the highest calcium content (1128 mg kg^{-1}) was recorded by T_6 and least (506.2 mg kg^{-1}) by T_2. The exchangeable calcium content of T_2 was on par with T_1 and the other treatments T_3, T_4, and T_5 were found to be on par with each other with respect to calcium release. On third day of incubation, the highest (1005 mg kg^{-1}) calcium was released by T_6 and lowest (541.2mg kg^{-1}) by T_2 and T_3which were on par with the treatment T_1. The exchangeable calcium content of all the treatments was on par and lower except T_6 at 6thday of incubation. But at 10th day of incubation a slight decrease in the exchangeable calcium content was noticed in all treatments except T_5. Considerable increase in the available calcium content was noticed in T_1 at 20 days of incubation. At 40th day of incubation, the highest calcium content was recorded in T_6 and other treatments T_1, T_2, T_3, T_4, and T_5

were found on par with each other. Almost similar trend was noticed at 60th day of incubation also.

Table 4.7. Effect of fertilizer-manure blocks/ fertilizers on exchangeable calcium content (mg kg^{-1}) of the soil at different periods of incubation

Treatments	Days of incubation						
	1	**3**	**6**	**10**	**20**	**40**	**60**
T_1	514.6^c	565.5^c	555.2^b	509.4^c	652.7^b	621.7^b	690.5^b
T_2	506.2^c	541.2^c	537.2^b	491.7^c	456.7^d	634.2^b	661.1^b
T_3	664.3^b	541.2^c	554.6^b	512.9^c	506.5^{cd}	677.4^b	624.7^b
T_4	740.2^b	695.2^b	527.2^b	521.8^c	512.0^c	683.9^b	662.3^b
T_5	707.1^b	663.7^b	556.2^b	613.9^b	533.4^c	624.7^b	712.2^b
T_6	1128^a	1005^a	874.9^a	835.2^a	879.5^a	1395^a	1216^a
CD(0.05)	**78.052**	**67.502**	**62.069**	**60.648**	**54.99**	**83.393**	**99.116**

The overall effect of the treatments on release of calcium was analyzed through two way analysis of the data and is presented in the Table 4.8.The highest mean exchangeable calcium content of (1048 mg kg^{-1}) was recorded by T_6 and it was significantly superior to all other treatments. As the days of incubation progressed, the exchangeable calcium release showed an increasing trend. The interaction between treatments and period of incubation showed significantly higher amount of calcium in T_6 (1395 mg kg^{-1}) at 40 days of incubation. However in all the treatments the exchangeable calcium content was maintained above the critical limit (300 mg kg^{-1}) during the entire period of incubation.

Table4.8. Overall effect of fertilizer-manure blocks/ fertilizers on exchangeable calcium content (mg kg^{-1}) of the soil at different periods of incubation

Treatments (T)	Days of incubation(D)							
	1	3	6	10	20	40	60	Mean
T_1	514.6	565.5	555.2	509.4	652.7	621.7	690.5	587.1
T_2	506.2	541.2	537.2	491.7	456.7	634.2	661.1	546.9
T_3	664.3	541.2	554.6	512.9	506.5	677.4	624.7	583.1
T_4	740.2	695.2	527.2	521.8	512	683.9	662.3	620.4
T_5	707.1	663.7	556.2	613.9	533.4	624.7	712.2	630.2
T_6	1128	1005	874.9	835.2	879.5	1395	1216	1048
Mean	710.2	668.7	600.9	580.8	590.16	772.7	761.2	
CD(0.05)-T -25.09		**CD(0.05)-D-27.107**	**CD(0.05)-TXD-66.385**					

4.10. Effect of treatments on exchangeable magnesium content (mg kg^{-1}) in soil

The exchangeable magnesium content of the soil incubated with fertilizer-manure blocks for different periods is given in the Table 4.9. Exchangeable magnesium content exhibited significant difference between treatments during the entire period of incubation except 6, 10, 20 and 60 days of incubation. At first day of incubation, significantly highest exchangeable magnesium (439.2 mg kg^{-1}) was recorded by T_6 and all the other fertilizer-manure blocks were on par with each other but with reduced rate of release of magnesium in to soil. The similar trend of magnesium release was observed at 3 days of incubation. At 40 days of incubation, the highest value of exchangeable magnesium (626.4 mg kg^{-1}) was recorded by T_2 and lowest (437.1) by T_6. The treatment T_6 was on par with the treatments T_1, T_3 and T_4.

Table 4.9. Effect of fertilizer-manure blocks/ fertilizers on exchangeable magnesium content (mg kg^{-1}) of the soil at different periods of incubation

Treatments	Days of incubation						
	1	3	6	10	20	40	60
T_1	236.2^{b}	232.2^{b}	473.3	375.2	499.2	593.5^{ab}	530.0
T_2	234.7^{b}	214.1^{b}	441.7	518.0	435.6	626.4^{a}	551.2
T_3	232.7^{b}	253.8^{b}	467.0	527.3	453.2	615.1^{ab}	593.3
T_4	248.9^{b}	264.7^{b}	431.0	414.0	460.8	565.8^{ab}	641.6
T_5	259.5^{b}	212.6^{b}	410.2	450.2	504.3	531.0^{b}	548.0
T_6	439.2^{a}	391.8^{a}	408.4	542.4	472.7	437.1^{c}	497.9
CD(0.05)	**41.95**	**76.34**	**NS**	**NS**	**NS**	**86.35**	**NS**

Table 4.10. Overall effect of fertilizer-manure blocks/ fertilizers on exchangeable magnesium content (mg kg-1) of the soil at different periods of incubation

Treatments (T)	Days of incubation(D)							
	1	3	6	10	20	40	60	Mean
T_1	236.2	232.2	473.3	375.2	499.2	593.5	530	420
T_2	234.7	214.1	441.7	517.9	435.6	626.4	551.2	431.7
T_3	232.7	253.8	467.0	527.3	453.2	615.1	593.3	448.9
T_4	249.0	264.7	430.9	413.9	460.8	565.8	641.6	432.4
T_5	259.5	212.6	410.2	450.2	504.3	531.0	548.0	416.5
T_6	439.2	391.8	408.4	542.4	472.7	437.1	498.0	455.6
Mean	275.2	261.5	438.6	471.2	471.0	561.5	560.3	
CD(0.05) -T-34.94		**CD(0.05)-D-37.74**			**CD(0.05) -D-92.45**			

The overall effect of the treatments on release of magnesium was analyzed through two way analysis of the data and is presented in the Table 4.10.

4.1.6. Effect of treatments on available sulphur (mg kg^{-1}) content in soil

The data on available sulphur content in soil at different periods of incubation as influenced by different treatments are presented in the Table 4.11. At first day of incubation, the highest available sulphur content was recorded in T_6 (67.05 mg kg^{-1}) and lowest value (6.948 mg kg^{-1}) in T_1. There was an increase in the available sulphur content at third day of incubation and highest value was recorded in T_6 (187.4 mg kg^{-1}) and least (19.50 mg kg^{-1}) in T_1. Almost similar trend was noticed during 6, 10 and 20 days of incubation. At 40 days of incubation, highest available sulphur content was noticed in T_6 (203.5mg kg^{-1}) followed by T_3 (153.4 mg kg^{-1}) and lowest value was observed in T_2 (42.65 mg kg^{-1}). Similarly at 60 days of incubation, the highest available sulphur content was noticed T_6 (187.4 mg kg^{-1}) but was on par with T_5 (174.0 mg kg^{-1}). The available sulphur content of T_1 and T_3 were also on par at sixty days of incubation.

Table 4.11. Effect of fertilizer-manure blocks/ fertilizers on available sulphur content (mg kg^{-1}) of the soil at different periods of incubation

Treatments	Days of incubation						
	1	3	6	10	20	40	60
T_1	6.948^{b}	19.50^{c}	28.75^{f}	54.91^{d}	63.94^{d}	90.15^{d}	112.45^{b}
T_2	9.795b	29.12^{c}	45.83^{e}	77.18^{c}	43.53^{e}	42.65^{f}	31.24^{d}
T_3	12.30^{b}	50.25^{b}	98.43^{b}	123.2^{b}	97.26^{c}	153.4^{b}	120.8^{b}
T_4	8.700^{b}	47.87^{b}	68.20^{d}	110.9^{b}	108.5^{bc}	113.6^{c}	60.15^{c}
T_5	10.11^{b}	44.37^{b}	85.31^{c}	110.0^{b}	115.8^{b}	73.74^{e}	174.0^{a}
T_6	67.05^{a}	187.4^{a}	202.2^{a}	232.2^{a}	206.2^{a}	203.5^{a}	187.4^{a}
CD(0.05)	**7.398**	**12.493**	**11.004**	**13.581**	**16.713**	**14.32**	**15.963**

Table 4.12. Overall effect of fertilizer-manure blocks/ fertilizers on available sulphur content (mg kg^{-1}) of the soil at different periods of incubation

Treatments(T)	Days of incubation(D)							
	1	**3**	**6**	**10**	**20**	**40**	**60**	**Mean**
T_1	6.948	19.50	28.75	54.91	63.94	90.15	112.5	53.80
T_2	9.795	29.12	45.83	77.18	43.53	42.65	31.24	39.91
T_3	12.30	50.25	98.43	123.2	97.26	153.4	120.8	93.68
T_4	8.700	47.87	68.25	110.9	108.5	113.6	60.15	73.99
T_5	10.11	44.37	85.31	110.0	115.84	73.74	174.0	87.62
T_6	67.05	187.4	202.2	232.2	206.19	203.5	187.4	183.7
Mean	19.15	63.09	88.13	118.09	105.87	112.9	114.3	
CD(0.05) -T-4.250		**CD(0.05) -D-4.590**		**CD-TXD -11.258**				

The overall effect of the treatments on release of sulphur was analyzed through two way analysis of the data and is presented in the Table 4.12. The highest mean available sulphur was recorded by T_6 (183.7 mg kg^{-1}) and found significantly superior to all other treatments. The interaction effect of treatments and period of incubation showed significantly higher amount of available sulphur by the treatment T_6 at 10 days of incubation (232.2 mg kg^{-1}). However the available sulphur content was maintained above the critical limit throughout the incubation period.

4.15. Effect of treatments on available zinc content (mg kg^{-1})in soil during incubation

The available zinc content of the soil as influenced by different treatments during different periods incubation are presented in the Table 4.13. At first day of incubation, highest available zinc content (46.65 mg kg^{-1}) in the soil was recorded by soil applied with sole fertilizer (T_6). But lowest available zinc content (11.35 mg kg^{-1}) was recorded in T_1 and it was on par with T_2, T_3, T_4 and T_5. Similarly at third day of incubation, the highest available zinc content was observed in soil treated with T_6 (65.23mg kg^{-1}) and lowest value (9.8 mg kg^{-1}) for T_2 and which was on par with T_5 and T_1. Almost similar trend was observed during the remaining period of incubation. However the available zinc content was maintained above the critical limit (1 mg kg^{-1}) and below the toxicity level in soil treated with all fertilizer manure block applied soils during the entire period of incubation.

Table 4.13. Effect of fertilizer-manure blocks/ fertilizers on available zinc content (mg kg^{-1}) of the soil at different periods of incubation

Treatments	**Days of incubation**						
	1	**3**	**6**	**10**	**20**	**40**	**60**
T_1	11.35^{b}	10.35^{c}	14.90^{b}	9.100^{bc}	6.150^{b}	10.70^{b}	9.633^{bc}
T_2	13.75^{b}	9.800^{c}	8.000^{c}	7.250^{d}	7.766^{b}	10.07^{b}	12.80^{b}
T_3	11.30^{b}	12.00^{b}	7.766^{c}	8.166^{bcd}	7.766^{b}	10.72^{b}	9.300^{c}
T_4	11.33^{b}	11.85^{b}	7.466^{c}	7.450^{cd}	7.466^{b}	11.20^{b}	12.60^{bc}
T_5	11.23^{b}	10.00^{c}	7.000^{c}	9.500^{b}	7.966^{b}	10.60^{b}	11.25^{bc}
T_6	46.65^{a}	65.23^{a}	44.97^{a}	57.10^{a}	65.95^{a}	72.45^{a}	44.25^{a}
CD(0.05)	**4.851**	**1.124**	**1.105**	**1.721**	**3.833**	**7.335**	**3.392**

The overall effect of the treatments on release of zinc was analyzed through two way analysis of the data and is presented in the Table 4.14. Data on available zinc content in the soil during different periods of incubation as influenced by the treatments infer that, the release of zinc from soil applied with sole fertilizers was significantly superior as compared soils treated with 5 different fertilizer manure blocks (T_1, T_2, T_3, T_4, and T_5) during the entire period of incubation.

Table 4.14. Overall of fertilizer-manure blocks/fertilizers on available zinc content(mg kg^{-1}) of the soil at different periods of incubation

Treatments (T)	Days of incubation(D)							
	1	3	6	10	20	40	60	Mean
T_1	11.35	10.35	14.90	9.100	6.150	10.70	9.633	10.32
T_2	13.75	9.800	8.000	7.250	7.766	10.07	12.80	9.910
T_3	11.30	12.00	7.766	8.166	7.766	10.72	9.300	9.578
T_4	11.33	11.85	7.466	7.450	7.466	11.20	12.60	9.905
T_5	11.23	10.00	7.000	9.500	7.966	10.60	11.25	9.650
T_6	46.65	65.23	44.97	57.10	65.95	72.45	44.25	56.65
Mean	17.61	19.87	15.02	16.43	17.18	20.96	16.64	
CD(0.05) -T1.37		**CD(0.05) -D-1.482**		**CD(0.05) -TXD-3.645**				

4.18. Effect of treatments on available copper content (mg kg^{-1}) in soil during incubation

The results of available copper content of the soil at different stages of incubation are presented in the Table 4.15. The values varied from 3.186 mg kg^{-1} to 12.26 mg kg^{-1}. At first day of incubation, the highest available copper was noticed in T_6 (11.34 mg kg^{-1}) and lowest (5.756 mg kg^{-1}) in T_4 and found to be on par with T_1, T_2, T_3 and T_5. As time progress, the copper content showed decreasing trend in all the treatments. However the treatment T_6 was significantly superior in release of copper during the entire stages of incubation.

Table 4.15. Effect of fertilizer-manure blocks/ fertilizers on available copper content (mgkg^{-1}) of the soil at different periods of incubation

Treatments	Days of incubation						
	1	3	6	10	20	40	60
T_1	6.100^b	5.550^b	3.693^b	3.833^b	3.316^b	3.640^b	3.213^b
T_2	6.453^b	5.893^b	3.876^b	4.023^b	3.186^b	3.636^b	3.473^b
T_3	5.806^b	5.713^b	4.420^b	4.073^b	3.276^b	3.800^b	3.343^b
T_4	5.756^b	5.996^b	4.380^b	4.030^b	3.350^b	3.486^b	3.373^b
T_5	5.830^b	5.743^b	4.613^b	4.736^b	3.573^b	3.703^b	3.300^b
T_6	11.34^a	12.26^a	11.67^a	10.66^a	10.08^a	11.12^a	9.766^a
CD(0.05)	**1.294**	**1.021**	**1.801**	**1.692**	**0.803**	**1.571**	**0.575**

Table 4.16. Overall effect of fertilizer-manure blocks/ fertilizers on available copper content (mg kg^{-1}) of the soil at different periods of incubation

Treatments (T)	Days of incubation(D)							
	1	3	6	10	20	40	60	Mean
T_1	6.100	5.550	3.693	3.833	3.316	3.640	3.213	4.193
T_2	6.453	5.893	3.876	4.023	3.186	3.636	3.473	4.363
T_3	5.806	5.713	4.420	4.073	3.276	3.800	3.343	4.346
T_4	5.756	5.996	4.380	4.030	3.350	3.486	3.373	4.330
T_5	5.830	5.743	4.613	4.736	3.573	3.703	3.300	4.500
T_6	11.34	12.26	11.67	10.66	10.08	11.12	9.766	10.99
Mean	6.886	6.854	5.447	5.221	4.468	4.892	4.416	
CD(0.05) -T-0.463		**CD(0.05) -D-0.504**		**CD(0.05) -TXD-1.621**				

The overall effect of the treatments on release of copper was analyzed through two way analysis of the data and is presented in the Table 4.16. The highest mean available copper content was recorded in T_6 (10.99 mg kg^{-1}).The interaction between treatment and period of incubation showed significant and higher amount of available copper content was observed in T_6 (12.26 mg kg^{-1}) at 3 days of incubation.

4.1.9. Effect of treatments on available boron content (mg kg^{-1}) in soil

The data pertaining to available boron content of the soil during different incubation periods is given in the Table 4.17. The available boron content of the soil as influenced by different treatments was significantly differed. At the first day of incubation, the highest available boron content (10.01 mg kg^{-1}) was recorded in $T_{6.}$ The lowest available boron was recorded by T_4 was on par with the treatments T_1, T_2, T_3, and T_5. As the time of incubation progressed, the available boron content in all the treatments was gradually increased. At 60^{th}day of incubation, the highest available boron content (16.17mg kg^{-1}) was recorded by T_6followed by the treatment $T_1$and lowest (10.92 mg kg^{-1}) by T_5.

Table. 4.17. Effect of fertilizer-manure blocks/ fertilizers on available boron content (mg kg^{-1}) of the soil at different periods of incubation

Treatments	Days of incubation						
	1	**3**	**6**	**10**	**20**	**40**	**60**
T_1	2.440^{b}	2.830^{d}	3.000^{e}	3.213^{d}	4.833^{d}	11.77^{ab}	12.86^{b}
T_2	2.520^{b}	2.880^{cd}	3.146^{de}	3.413^{cd}	4.620^{d}	11.02^{b}	12.12^{bc}
T_3	2.433^{b}	2.946^{bcd}	3.466^{cd}	3.880^{bc}	7.400^{c}	11.64^{b}	12.10^{bc}
T_4	2.400^{b}	3.213^{b}	3.946^{b}	4.200^{b}	9.320^{b}	10.81^{b}	11.91^{bc}
T_5	2.713^{b}	3.166^{bc}	3.826^{bc}	4.273^{b}	9.120^{b}	9.120^{c}	10.92^{c}
T_6	10.01^{a}	11.00^{a}	11.89^{a}	12.900^{a}	13.14^{a}	13.05^{a}	16.17^{a}
CD(0.05)	**0.770**	**0.305**	**0.424**	**0.607**	**0.89**	**1.336**	**1.732**

The overall effect of the treatments on release of boron was analyzed through two way analysis of the data and is presented in the Table 4.18. The highest mean available boron was recorded in T_6 (12.60 mg kg^{-1}) which was significantly superior to all other treatments.

Table 4.18. Overall effect of fertilizer-manure blocks/ fertilizers on available boron content (mg kg^{-1}) of the soil at different periods of incubation

Treatments (T)	Days of incubation							
	1	3	6	10	20	40	60	Mean
T_1	2.440	2.830	3.000	3.213	4.833	11.77	12.86	5.840
T_2	2.520	2.880	3.146	3.413	4.620	11.02	12.12	5.672
T_3	2.433	2.946	3.466	3.880	7.400	11.64	12.10	6.266
T_4	2.400	3.213	3.946	4.200	9.320	10.81	11.91	6.548
T_5	2.713	3.166	3.826	4.273	9.120	9.120	10.92	6.168
T_6	10.01	11.00	11.89	12.90	13.14	13.046	16.17	12.60
Mean	3.753	4.334	4.878	5.313	8.077	11.233	12.68	
CD(0.05) -T-0.337		**CD(0.05) -D-0.352**		**CD(0.05) -TXD-0.870**				

4.2. Pot culture Study

As per the results of the laboratory incubation study, proportion-1 was selected as the best combination of organic materials/fillers for developing slow release fertilizer-manure block. Pot culture study was conducted with the objectives to find out the effect of fertilizer-manure blocks on growth and yield and uptake of nutrients by okra. Based on the results of the incubation study a proportion(proportion-I) was selected and used for conducting the pot culture experiment in grow bags. The experiment was conducted in a completely randomized design with 11 treatments and 3 replications .The results are presented here.

4. 2. 1. Effect of different treatments of nutrient management options on Biometric parameters

4.2.1.1 Plant height (15, 30, 45, 60 and 75 DAP)

The statistical analysis of the data revealed that the plant height significantly differed between treatments at on 15, 30, 45, 60 and 75 DAP. At 15 DAP the plant was taller in (28.06 cm) in T_7 and shorter (17.59 cm) in T_{11}. T_1 and T_3 were found to be on par with T_7 and T_2. At 30 DAP, the taller plant was noticed in T_2 (52.42 cm) and shorter in T_6 (20.08 cm). Treatments T_1,T_3 and T_7 were found to be on par with T_2. At 45 DAP, the tallest plant was noticed in T_2 (95.87 cm) and shortest in T_{11}(34.36 cm). Treatment T_1 was on par with T_2. At 60 days after planting, the tallest plant was noticed in T_7 (125.6 cm) followed by T_9,T_1 and T_8in succession. At 75 DAP, the tallest plant was noticed in T_7 (183.4cm) and shortest (62.06 cm) in T_{11}.

4.2.1.2 .Leaves per plant at different growth period

The treatments were significantly different from one another with respect to number of leaves per plant at 15, 30, 45, 60 and 75 DAP. At 15 DAP, the higher number of leaves were noticed in T_2 (10.750) where fertilizer manure block with 50 % POP recommendation was placed in the grow bag and least number were noticed in absolute control (4.633). Treatment T_{11} was found to be on par with T_{10} (5.500). But at 30 DAP, higher number of leaves were noticed in T_7 (13.33) and T_8 (13.33) and least number was recorded in T_{11} (5.750). Treatment T_{11} was on par with T_{10} (6.416). At 45 days after sowing, the number of leaves varied from 6.500 (T_{11}) to 17.12 (T_7). Treatment T_7 was found on par with T_7 and T_8. Almost similar trend was noticed at 60 and 75 DAP also.

4.2.1.3. Branches per plant

The treatments significant by influenced the number of branches per plant at 75 DAP. The higher number of branches were noticed in T_7 (2.416) and it was on par with T_8 (2.166) and T_9 (2.333). No branches were observed in T_{10} (control) and T_{11} (absolute control) till 75 DAP.

Table 4.19. Effect of different treatments of nutrient management options on Biometric parameters

Treatments	Plant height (cm)					Number of eaves per plant					Number of branches per plant
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	75 DAP
T_1	26.52^{ab}	52.06^{a}	94.93^{a}	115.3^{b}	132.1^{de}	7.250^{d}	10.87^{b}	12.12^{cd}	13.50^{cd}	16.75^{d}	1.583^{b}
T_2	26.26^{b}	52.42^{a}	95.87^{a}	106.3^{c}	136.8^{d}	10.750^{a}	11.33^{b}	13.62^{b}	17.25^{b}	23.00^{b}	1.333^{bc}
T_3	27.57^{ab}	51.31^{a}	80.10^{b}	104.6^{c}	135.7^{de}	8.083^{bc}	10.62^{b}	11.33^{d}	13.50^{cd}	17.12^{d}	1.083^{cd}
T_4	24.16^{c}	24.16^{e}	70.52^{cd}	102.5^{c}	129.6^{e}	7.625^{cd}	10.37^{b}	12.62^{bc}	17.17^{b}	20.12^{c}	1.450^{b}
T_5	21.41^{de}	21.41^{f}	62.00^{e}	85.31^{d}	102.9^{g}	7.333^{d}	7.750^{c}	9.500^{c}	14.23^{c}	15.25^{e}	1.083^{cd}
T_6	20.09^{e}	20.08^{f}	49.64^{f}	67.50^{e}	112.0^{f}	6.375^{e}	7.250^{c}	9.500^{e}	13.00^{d}	14.87^{ef}	1.000^{d}
T_7	28.06^{a}	51.22^{a}	84.00^{b}	125.6^{a}	183.4^{a}	8.250^{b}	13.33^{a}	16.58^{a}	26.92^{a}	37.08^{a}	2.416^{a}
T_8	21.02^{de}	39.21^{c}	67.37^{d}	115.1^{b}	164.6^{b}	7.125^{d}	13.33^{a}	16.25^{a}	26.58^{a}	37.00^{a}	2.166^{a}
T_9	22.42^{d}	42.70^{b}	74.08^{c}	119.5^{b}	157.6^{c}	7.250^{d}	11.25^{b}	17.12^{a}	26.87^{a}	36.25^{a}	2.333^{a}
T_{10}	17.91^{f}	26.81^{d}	36.26^{g}	49.08^{f}	80.75^{h}	5.500^{f}	6.416^{cd}	7.500^{f}	11.62^{e}	13.75^{g}	0.000^{e}
T_{11}	17.59^{f}	27.25^{d}	34.36^{g}	46.75^{f}	62.06^{i}	4.633^{f}	5.750^{d}	6.500^{f}	9.250^{f}	11.42^{f}	0.000^{e}
CD (0.05)	**1.621**	**2.208**	**4.923**	**5.908**	**6.741**	**0.535**	**1.411**	**1.129**	**0.814**	**1.135**	**0.282**

4.2.2. Effect of different treatments of nutrient management options on yield and yield characteristics

The influence of treatments, fertilizer-manure block (proportion-1) incorporated with 100 %, 50 %, 25 % recommended dose of fertilizer in 100 g and 25 g size, with 100 % inorganic fertilizers applied as POP of KAU and soil test basis with organic manure application] and absolute control on yield and yield parameters such as days to flowering, number of fruits per plant, fruit yield, fruit length, fruit girth and number of seeds per fruit is presented in Table. 4.20.

4.2.2.1 Days to flowering

In general the days to flowering varied from 29.08to 36.33days after transplanting. Significantly early flowering was noticed in T_8 (29.08 DAP), T_6 (29.50 DAP), T_7 (29.50 DAP) T_9 (29.75 DAP), T_2 (29.92 DAP).

4.2.2.2. Fruits per plant

The statistical analysis of the results revealed that the number of fruits per plant significantly differed among the treatments and ranged from 2.550 (T_{11}) to 20.70 (T_7).

4.2.2.3. Fruit yield per plant

The fruit yield per plant recorded under various treatments is presented in Table 4.19. and varied from 39.83 g in T_{11} to 457.9g in T_7. Application of fertilizer-manure block(proportion-1) incorporated with 25 % POP recommended fertilizer + 50 % top dressing and application of POP recommended fertilizer and soil test based fertilizers were statistically on par with each other with the values ranging from 452.6 to 457.9 g.

Table 4. 20. Effect of different treatments of nutrient management options on yield and yield attributing characteristics of okra

Treatments	Days to flowering (DAP)	Number of fruits per plant	Fruit yield per plant (g)	Fruit length (cm)	Fruit girth (cm)	Number of seeds per fruit
T_1	31.25^{b}	11.29^{d}	238.5^{d}	15.17^{e}	5.880^{cde}	53.66^{c}
T_2	29.92^{bcd}	10.37^{e}	254.0^{c}	17.03^{b}	5.973^{bcd}	47.33^{d}
T_3	30.67^{bcd}	8.930^{f}	167.9^{f}	15.90^{d}	5.840^{de}	43.33^{e}
T_4	30.77^{bc}	10.38^{e}	348.2^{b}	16.65^{bc}	6.066^{bc}	60.66^{a}
T_5	30.00^{bcd}	7.666^{g}	209.7^{e}	16.27^{cd}	5.720^{ef}	46.33^{d}
T_6	29.50^{cd}	6.625^{h}	164.1^{f}	15.87^{d}	6.010^{bcd}	46.33^{d}
T_7	29.50^{cd}	20.70^{a}	457.9^{a}	17.90^{a}	6.326^{a}	58.67^{ab}
T_8	29.08^{d}	17.98^{c}	456.6^{a}	16.33^{cd}	6.110^{b}	56.33^{b}
T_9	29.75^{bcd}	19.14^{b}	452.6^{a}	17.90^{a}	6.326^{a}	59.00^{a}
T_{10}	34.83^{a}	4.470^{i}	81.60^{g}	13.80^{f}	5.513^{f}	41.67^{e}
T_{11}	36.33^{a}	2.550^{j}	39.83^{h}	10.70^{g}	5.266^{g}	25.00^{f}
CD (0.05)	**1.597**	**0.603**	**14.237**	**0.590**	**0.211**	**2.559**

4.2.2.4. Fruit length

The average fruit length was found to be significantly different among the treatments and it varies from 10.70cm (T_{11}) to 17.90 cm in both T_7 and T_9.

4.2.2.5. Fruit girth

The average fruit girth varied from 5.266cm in T_{11} to 6.326 cm in T_7 and T_9.

4.2.2.6. Number of seeds per fruit

Number of seeds per fruit varied from 25.00 in T_{11} to 60.66 in T_4. T_7 and T_9 were found to be on par with T_4 with respect to the number of seed per fruit.

4.3. Effect of different treatments of nutrient management options on nutrient uptake by the crop

The effect of treatments on uptake of primary, secondary and micronutrients by the test crop okra is presented here.

4.3.1. Primary nutrients

The data pertaining to primary nutrient uptake by the test crop okra is presented in the Table 4.21. Treatment T_7 which received 25% of the nutrients based on KAU POP incorporated in fertilizer manure block and 50 % of the recommended nutrients as topdressing had recorded highest uptake values with respect to the nutrients N, P, and K. But with respect to nitrogen, treatment T_9 which received soil test based POP recommendation recorded higher nitrogen uptake and it was on par with the treatment T_7. Lowest uptake of primary nutrients was recorded in the absolute control treatment (T_{11}).

4.3.2. Secondary nutrients

The uptake of secondary nutrients by okra as influenced by various treatments is given in the Table 4.22. The uptake of calcium was found to be significantly higher in the treatment T_9 and on par with treatment T_8which received nutrients based on general POP recommendation. Highest magnesium uptake was recorded by the treatment with fertilizer manure block (100g) incorporated with 25% of the nutrients based on KAU POP and 50 % of the recommended nutrients as topdressing (T_7) followed by the treatments T_8 and T_9. With respect to sulphur highest uptake was recorded by the treatment T_9 (Soil test based recommendation). Lowest uptake of secondary nutrients was recorded by the control (T_{10}) and absolute control (T_{11}) treatments.

4.3.3. Micro nutrients

The uptake of micronutrients by the test crop okra as influenced by various treatments is presented in the Table 4.23. Treatment T_7 recorded significantly higher uptake for Zn and Copper, while significantly higher boron uptake was recorded in the treatment T_9. Lowest uptakes of all the micronutrients were recorded in the absolute control treatment.

Table 4.21. Effect of different treatments of nutrient management options on uptake of primary nutrients by okra plants in pot culture experiment

Treatments	Uptake of primary nutrients (mg/ plant dry matter in g)		
	N	P	K
T_1 (100% POP 100 g block)	852.2^{e}	383.0^{e}	1860^{d}
T_2 (50% POP 100g block)	819.6^{e}	342.9^{f}	1520^{e}
T_3 (25% POP 100g block)	796.9^{e}	219.4^{h}	1376^{ef}
T_4 (100% POP 25g @ 4 N.os)	1475^{c}	439.5^{d}	2229^{c}
T_5 (50% POP 25g @ 4 N.os)	988.0^{d}	293.6^{g}	1242^{fg}
T_6 (25% POP 25g @ 4 N.os)	666.0^{f}	221.3^{h}	1169^{g}
T_7 (T3+ 50% POP topdressing)	1832^{a}	598.1^{a}	3430^{a}
T_8 (General POP recommendation)	1738^{b}	515.2^{c}	2966^{b}
T_9 (Soil test based POP recommendation)	1844^{a}	562.2^{b}	3087^{b}
T_{10} (control)	494.3^{g}	128.8^{i}	641.6^{h}
T_{11} (Absolute control)	239.8^{h}	47.39^{j}	424.0^{i}
CD(0.05)	**85.20**	**29.71**	**151.8**

4. 22. Effect of different treatments of nutrient management options on uptake of secondary nutrients by okra plants in pot culture experiment

Treatments	Uptake of secondary nutrients (mg /plant dry matter in g)		
	Ca	Mg	S
T_1 (100% POP 100 g block)	1582[cd]	315.3[d]	461.7[d]
T_2 (50% POP 100g block)	1677[bcd]	250.8[e]	390.2[e]
T_3 (25% POP 100g block)	1179[ef]	236.7f	285.9[f]
T_4 (100% POP 25g @ 4 N.os)	1801[bc]	419.8[c]	476.7[d]
T_5 (50% POP 25g @ 4 N.os)	1428[de]	255.5[e]	370.1[e]
T_6 (25% POP 25g @ 4 N.os)	1038[f]	217.1[g]	281.7[f]
T_7 (T3+ 50% POP topdressing)	2026[b]	617.3[a]	843.8[b]
T_8 (General POP recommendation)	2752[a]	599.8[b]	794.9[c]
T_9 (Soil test based POP recommendation)	2771[a]	597.3[b]	987.7[a]
T_{10} (control)	1019[f]	139.5[h]	168.4[g]
T_{11} (Absolute control)	588.6[g]	82.12[i]	84.26[h]
CD(0.05)	**357.2**	**13.24**	**29.58**

Table 4.23. Effect of different treatments of nutrient management options on uptake of micro nutrients by okra plants in pot culture experiment

Treatments	Uptake of micro nutrients (mg /plant dry matter in g)		
	Zn	Cu	B
T_1 (100% POP 100 g block)	6.629[e]	0.804[d]	0.48[d]
T_2 (50% POP 100g block)	6.523[e]	0.772[d]	0.419[e]
T_3 (25% POP 100g block)	5.271[f]	0.609[e]	0.404[e]
T_4 (100% POP 25g @ 4 N.os)	8.864[c]	1.087[c]	0.720[c]
T_5 (50% POP 25g @ 4 N.os)	4.597[g]	0.602[e]	0.294[f]
T_6 (25% POP 25g @ 4 N.os)	4.109[g]	0.45[f]	0.233[g]
T_7 (T3+ 50% POP topdressing)	10.49[a]	1.696[a]	0.847[b]
T_8 (General POP recommendation)	9.293[b]	1.638[a]	0.866[b]
T_9 (Soil test based POP recommendation)	9.526[b]	1.425[b]	0.939[a]
T_{10} (control)	3.052[h]	0.208[g]	0.127[h]
T_{11} (Absolute control)	1.907[i]	0.096[h]	0.031[i]
CD(0.05)	**0.519**	**0.097**	**0.048**

4.4. Effect of different treatments of nutrient management options on soil properties after harvest

4.4.1. Effect of different treatments of nutrient management options on electrochemical properties and organic carbon content in soil

The pH, EC and organic carbon content of soil after harvest of the crop are depicted in the Table 4.24.The treatments did not show any significant difference in soil pH as well as electrical conductivity of soil after harvest of the crop. The organic carbon content of the soil after harvest varied from 0.506 to 0.735 %. Significantly higher organic carbon was recorded by the treatments which included fertilizer-manure blocks. Lower organic carbon was recorded by the absolute control treatment where no farmyard manure or fertilizer was applied.

4.4.2. Effect of different treatments of nutrient management options on available primary nutrients in soil after harvest

The effect of treatments on available nitrogen, phosphorus and potassium status of soil after harvest of the crop is presented in the Table 4.25. Available nitrogen content of the soil after harvest of the crop exhibited significant difference between the treatments and it varied from 196.8 to 271.8 kg ha^{-1}. Treatments T_3,T_5,T_6 and T_7 were on par with T_8 with respect to available nitrogen content. The available phosphorus status of the soil exhibited significant difference between treatments and ranged from 20.81 kg ha^{-1}(T_{11}) to 61.68 kg ha^{-1}(T_1). Highest available phosphorus content was exhibited by the treatment T_1 were 100 % of the recommended nutrients were applied in the form of 100 g fertilizer-manure block placed below the planting depth. Least content of available phosphorus was recorded in the absolute control (T_{11}). Significant difference was noticed between treatments in available potassium content of soil after harvest and ranged from 132.1 (T_{11}) to 395.64 kg ha^{-1} (T_4). Available potassium content of treatment T_4 was found to be in on par with treatment T_2 (386.6kg ha^{-1}). Treatments T_2,T_3,$T_5$and T_6 were found to be on par with each other with respect to available potassium content of post harvest soil.

Table 4. 24. Effect of different treatments of nutrient management options on electrochemical properties and organic carbon content in soil after harvest of okra plants in pot culture experiment

Treatments	pH	EC ($dS\ m^{-1}$)	Organic carbon (%)
T_1(100% POP,100g block)	5.556	0.013	0.735^{a}
T_2(50% POP,100g block)	5.686	0.016	0.713^{a}
T_3(25% POP,100g block)	5.616	0.006	0.686^{ab}
T_4(100% POP, 25g block @ 4 No.s per plant)	5.533	0.013	0.716^{a}
T_5(50% POP, 25g block @ 4 No.s per plant)	5.533	0.012	0.706^{a}
T_6(25% POP, 25g block @ 4 No.s per plant)	5.573	0.010	0.713^{a}
T_7(T3+ 50% POP as topdressing 1 MAP)	5.473	0.013	0.706^{a}
T_8(General POP recommendation)	5.613	0.013	0.606^{b}
T_9(Soil test based POP recommendation)	5.240	0.012	0.610^{b}
T_{10}(Control)	5.733	0.010	0.610^{b}
T_{11}(Absolute control)	5.400	0.036	0.506^{c}
CD (0.05)	**NS**	**NS**	**0.091**

Table 4.25. Effect of different treatments of nutrient management options on available primary nutrients in soil after harvest of okra plants in pot culture experiment

Treatments	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})
T_1 (100% POP 100 g block)	271.8^{a}	61.68^{abc}	386.6^{a}
T_2 (50% POP 100g block)	255.1^{ab}	58.51^{bcd}	357.4^{b}
T_3 (25% POP 100g block)	232.1^{c}	51.23^{bcd}	339.7^{b}
T_4 (100% POP 25g @ 4 N.os)	271.8^{a}	63.37^{abc}	395.6^{a}
T_5 (50% POP 25g @ 4 N.os)	263.4^{a}	58.89^{bcd}	353.6^{b}
T_6 (25% POP 25g @ 4 N.os)	261.4^{a}	56.00^{cd}	347.5^{b}
T_7 (T3+ 50% POP topdressing)	271.8^{a}	57.59^{bcd}	246.6^{c}
T_8 (General POP recommendation)	223.0^{c}	50.96^{de}	266.3^{c}
T_9 (Soil test based POP recommendation)	225.0^{c}	41.68^{de}	255.8^{c}
T_{10} (control)	208.0^{cd}	32.33^{e}	201.0^{d}
T_{11} (Absolute control)	196.8^{d}	20.81^{f}	132.1^{e}
CD(0.05)	**20.01**	**11.00**	**24.08**

4.4.3. Effect of different treatments of nutrient management options on available secondary nutrients in soil after harvest

The effect of treatments on exchangeable calcium, exchangeable magnesium and available sulphur content of the soil after harvest is given in the Table 4.26. The exchangeable calcium content showed significant difference among treatments and it ranged from 632.7 (T_{11}) to 842.8 mg kg^{-1} (T_5). The exchangeable magnesium content in post harvest soil showed significant difference between treatments. The highest exchangeable magnesium content was noticed in T_7 (424.96 mg kg^{-1}) and least in T_{11}(149.9 mg kg^{-1}). The available sulphur content of the soil after harvest was also significantly influenced by the various treatments and ranged from 4.50 (T_{11})to 18.01 mg kg^{-1}(T_7). Treatments T_4 and T_8 were found to be in on par with T_7.

4.4.4. Effect of different treatments of nutrient management options on available micronutrients in soil after harvest

The data on available micro nutrient status of the soil after harvest of the crop is presented in the Table. 4.27. The available zinc content of the soil showed significant difference among treatments and it ranged from 2.67 (T_{11}) to 5.34 mg kg^{-1} (T_4). Treatments T_1,T_8 and T_{10} were found on par with T_4. The available copper content of the soil after harvest of the crop exhibited significant difference among treatments and the highest available copper content were recorded in T_9 (4.52mg kg^{-1}) and lowest (1.05 mg kg^{-1}) in T_{11}. Available boron content of the soil showed significant difference between the treatments and ranged from 0.213 (T_{11}) to 0.610 mg kg^{-1} (T_7).

Table 4.26. Effect of different treatments of nutrient management options on available secondary nutrients in soil after harvest of okra plants in pot culture experiment

Treatments	Av. Ca (mg kg^{-1})	Av. Mg (mg kg^{-1})	Av. S (mg kg^{-1})
T_1 (100% POP,100g block)	790.5^{c}	418.0^{a}	11.35^{cd}
T_2 (50% POP,100g block)	784.1^{c}	371.6^{ab}	15.81^{b}
T_3 (25% POP,100g block)	797.2^{bc}	360.6^{b}	10.44^{d}
T_4 (100% POP, 25g block @ 4 No.s per plant)	813.4^{abc}	348.8^{bc}	16.78^{ab}
T_5 (50% POP, 25g block @ 4 No.s per plant)	842.8^{a}	380.6^{ab}	12.33^{c}
T_6 (25% POP, 25g block @ 4 No.s per plant)	833.2^{ab}	361.7^{b}	8.716^{e}
T_7 (T3+ 50% POP as topdressing 1 MAP)	798.1^{bc}	424.9^{a}	18.01^{a}
T_8 (General POP recommendation)	792.9^{c}	392.9^{ab}	16.53^{ab}
T_9 (Soil test based POP recommendation)	786.0^{c}	350.2^{bc}	16.12^{b}
T_{10} (Control)	705.6^{d}	301.3^{c}	11.62^{cd}
T_{11} (Absolute control)	632.7^{e}	149.9^{d}	4.500^{d}
CD (0.05)	**36.79**	**55.39**	**1.581**

Table 4.27. Effect of different treatments of nutrient management options on available micronutrients in soil after harvest of okra plants in pot culture experiment

Treatments	Av. Zn (mg kg^{-1})	Av. Cu (mg kg^{-1})	Av. B (mg kg^{-1})
T_1 (100% POP,100g block)	5.27^{a}	2.44^{cd}	0.516^{b}
T_2 (50% POP,100g block)	4.49^{b}	2.60^{c}	0.500^{b}
T_3 (25% POP,100g block)	4.64^{b}	1.26^{g}	0.470^{bc}
T_4 (100% POP, 25g block @ 4 No.s per plant)	5.34^{a}	1.79^{f}	0.490^{b}
T_5 (50% POP, 25g block @ 4 No.s per plant)	4.52^{b}	1.92^{ef}	0.510^{b}
T_6 (25% POP, 25g block @ 4 No.s per plant)	4.65^{b}	1.88^{ef}	0.423^{c}
T_7 (T3+ 50% POP as topdressing 1 MAP)	4.57^{b}	2.98^{b}	0.610^{a}
T_8 (General POP recommendation)	5.18^{a}	2.64^{c}	0.470^{bc}
T_9 (Soil test based POP recommendation)	4.49^{b}	4.52^{a}	0.490^{b}
T_{10} (Control)	5.21^{a}	2.13^{de}	0.250^{d}
T_{11} (Absolute control)	2.67^{c}	1.05^{g}	0.213^{d}
CD (0.05)	**0.265**	**0.318**	**0.061**

4.5. Effect of different treatments of nutrient management options on Nutrient use efficiency (based on Agronomic efficiency)

The effect of fertilizer-manure blocks on nutrient use efficiency is presented in Table.4.28.The highest agronomic efficiency was recorded by the treatment T_7 (28.12) in which 25% of the recommended nutrients was applied as 100g fertilizer-manure block and 50% of the recommended nutrients as topdressing, this was followed by the treatments T_8 (26.42) which received nutrients as per general recommendation of KAU POP and T_9 (26.38) which received nutrients as per soil test based recommendation. When the nutrient contribution from organic manures is also considered, the efficiency in T_7 becomes 23.51. However, the nutrients are released from organic manures very slowly taking longer periods for complete release.

Table.4.28. Effect of different treatments of nutrient management options on Nutrient use efficiency (based on Agronomic efficiency)

Treatments	**Nutrient use efficiency (g/g) (Agronomic efficiency)**
T_1 (100% POP 100 g block)	12.59
T_2 (50% POP 100g block)	15.34
T_3 (25% POP 100g block)	9.815
T_4 (100% POP 25g @ 4 N.os)	19.55
T_5 (50% POP 25g @ 4 N.os)	12.17
T_6 (25% POP 25g @ 4 N.os)	9.525
T_7 (T_3+ 50% POP topdressing)	28.12
T_8 (General POP recommendation)	26.42
T_9 (Soil test based POP recommendation)	26.38

4.6. Effect of different treatments of nutrient management options on B:C ratio (based on per plant yield in pot)

Treatments T_7, T_8 and T_9 has B:C ratio more than one. Treatment T_7 had a B:C ratio of 1.26 and the treatment offer nutrient savings to a greater extent.

Discussion

5. DISCUSSION

High yielding varieties are highly responsive to applied nutrients and loading of large quantities of chemical fertilizers in the cropped field is becoming a common practice. But soil with poor nutrient holding capacity can't retain the applied nutrients in the root zone for a longer period of time and also due to the influence of edaphic, climatic and genetic factors, the applied fertilizers get lost from the target of application. This will ultimately results in great economic loss and cause many environmental and health hazards. To overcome this problem fertilizer-manure blocks (compacted organic matrix based slow release fertilizer) were developed at Department of Soil Science and Agricultural Chemistry, Regional Agricultural Research Station, Pattambi and its effects on nutrient release characteristics and growth and yield of okra were studied. The study includes two experiments, laboratory incubation experiment and pot culture experiment. A slow release fertilizer will release nutrients slowly and often synchronized with the physiological need of the crop thus reducing nutrient loss and associated environment related problems. The results of the experiment presented in the chapter 4 are discussed here with supporting literature wherever possible.

5.1. Incubation experiment

5.1.1. Effect of treatments on available nitrogen content in soil

Available nitrogen content of the soil during the incubation period showed significant difference among all the treatments (T_1 to T_6). The release kinetics of nitrogen during the incubation period is shown in the figure 5.1. Application of 100 % recommended fertilizers alone (T_6), had released 74% of applied nitrogen within 6 days of incubation. While the percentage release of applied nitrogen from various fertilizer-manure blocks (T_1 to T_5), varied from 22 to 35% within 6 days of incubation. As a whole, all fertilizer-manure blocks showed a slow release pattern with respect to available nitrogen in soil as compared to sole fertilizers. This may be due to the binding of available nitrogen forms with the different component materials in the fertilizer manure block. When compared among the fertilizer-manure blocks, the proportion-1(treatment-T_1) exhibited slow release behavior to a greater extent than other proportions (T_2-T_5). The absolute release of nitrogen in different sampling intervals during the incubation period is presented in the Table 5.2. The peak and average release of nitrogen in soil as influenced by various treatments is shown in the Figure 5.2. The highest peak release of nitrogen was noticed in the treatment T_6 (sole fertilizer placement) compared to fertilizer-manure blocks. This indicated that the fertilizer manure blocks may release nitrogen even after 60 days of incubation. The average release of nitrogen from the fertilizer manure blocks was lower than that in sole fertilizer placement treatment and this may be due to more distribution of released of nitrogen from fertilizer-manure blocks. Sharma and Singh (2011) reported that organic matrix based slow release fertilizer released ammonium up to 50 days in wet soil under laboratory conditions and showed maximum retention of nutrients probably due to its immobilization in organic matrix. As in the present study, ammonium was available for longer duration in synchronization with the nitrogen demand of the brassica plants due to the slow release property of organic matrix based slow release fertilizer granules. They used clay soil and neem leaf powder as the component material for developing organic-matrix based slow release fertilizer. Neem cake possess nitrification inhibition properties and thus slows down the process of nitrogen release from urea (Sharma and Prasad, 1995). Likewise in this experiment clay powder (zeolite) and neem cake was used for developing the fertilizer-manure blocks. In the present context, also average distribution of nitrogen was observed in case of fertilizer-manure blocks made in proportion-1. According to Jakkula and Wani, (2018) zeolite can be used as an soil amendment for improving the nutrient and water retention and hence application of zeolites will reduce the ammoniacal nitrogen volatilization and nitrate leaching loss and hence it is used as a suitable carrier material for developing slow/controlled release fertilizers.

Table 5.1. Absolute release of available nitrogen (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	1-3	3-6	6-10	10-20	20-40	40-60
T_1	119.5	162.4	57.87	22.40	336.0	321.1	222.1
T_2	220.3	138.1	100.8	37.33	294.9	227.7	138.1
T_3	235.2	175.5	97.07	61.60	479.7	14.93	126.9
T_4	274.4	168.0	52.27	29.87	434.9	194.1	56.00
T_5	268.8	160.5	181.1	-1.867	444.3	169.9	-31.73
T_6	653.3	33.60	744.8	205.3	-67.2	-444.3	-235.2

5.1.2. Effect of treatments on available phosphorus content in soil

The available phosphorus content of the soil showed significant difference among the treatments (different fertilizer-manure blocks/fertilizers). The release kinetics of phosphorus is presented in the Fig 5.3. The average and peak release of phosphorus is shown in the Fig 5.4.The absolute release of phosphorus was presented in the Table 5.2. During initial stages of incubation the fertilizer-manure blocks exhibited slow release with respect to available phosphorus content in soil. Compared to the fertilizer-manure blocks the sole fertilizer placement treatment showed highest available phosphorus content during the initial stages of incubation (up to 20 days). After 20 days of incubation there was an increase in the phosphorus from fertilizer-manure blocks T_1 and T_2,while the treatments T_4 and T_5 showed high available phosphorus content after 40 days of incubation. However an even release of P during the period of incubation with positive release in synchronization with the critical needs of the crop is observed only in proportion-1 (Table 5.2). In the proportion-2, the interval of 40-60 days, the release is negative.

Fig 5.1. Effect of different fertilizer manure blocks/fertilizers on available nitrogen content of soil during incubation

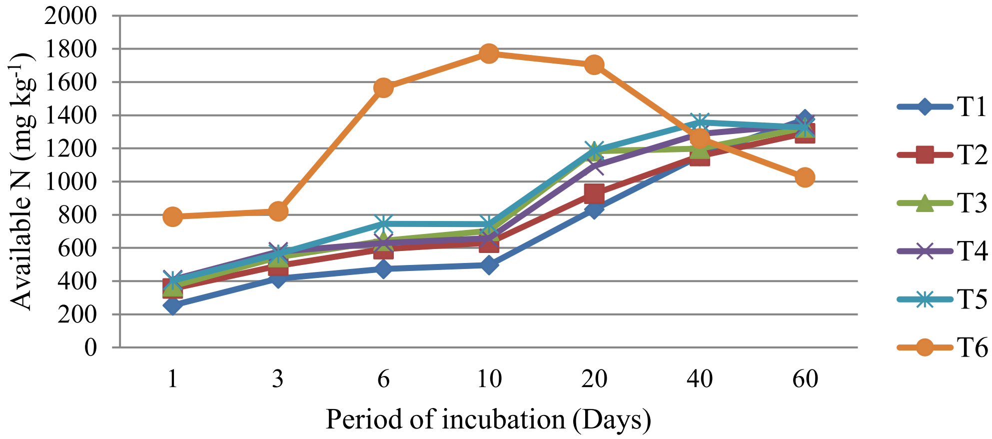


Fig 5.2. Peak and average release of nitrogen from fertilizer-manure blocks/fertilizers during incubation

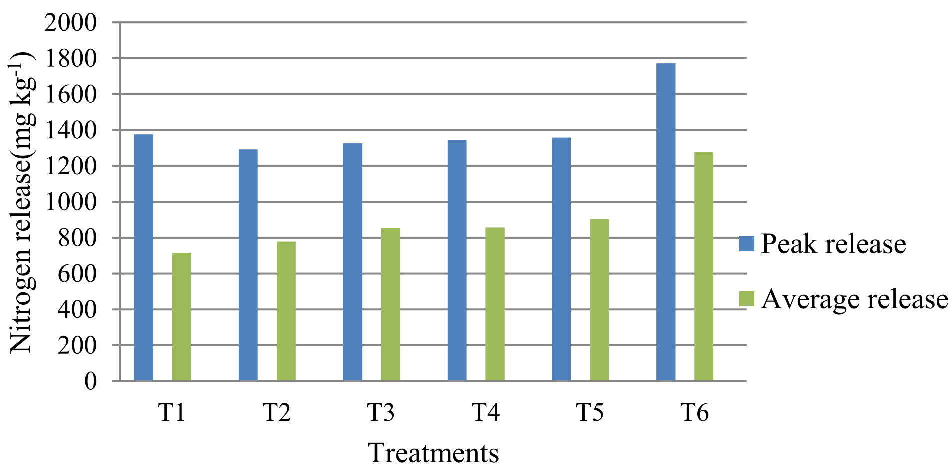


Table 5.2. Absolute release of available phosphorus (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	1-3	3-6	6-10	10-20	20-40	40-60
T_1	0.0855	1.648	-0.514	0.197	0.53	2.734	0.798
T_2	0.6385	1.152	-0.571	0.273	1.042	1.632	-1.729
T_3	0.8235	0.967	-0.771	0.839	0.132	-0.257	-0.324
T_4	0.8975	0.893	0.000	-0.079	0.526	-0.828	6.149
T_5	1.0875	0.389	0.065	-0.065	0.632	-0.130	5.588
T_6	2.8265	0.257	-0.248	-0.398	0.222	1.442	-1.284

Fig 5.3. Effect of different fertilizer manure blocks/fertilizers on available phosphorus content of soil during incubation

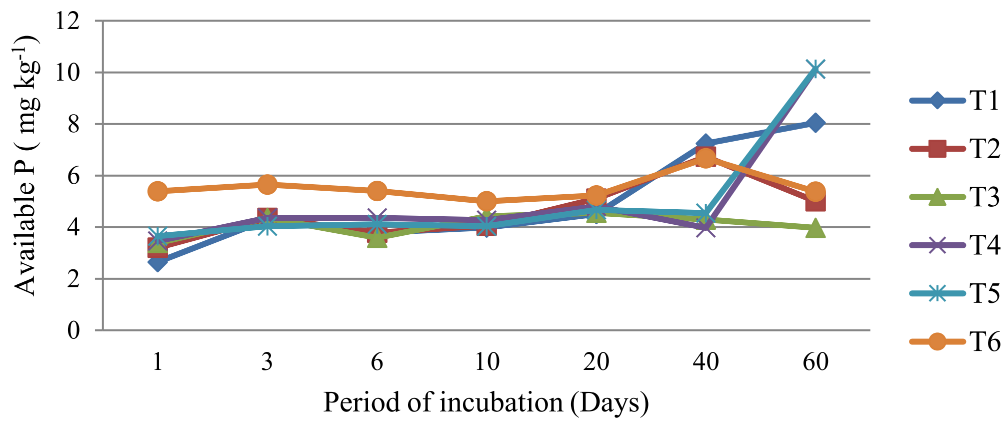
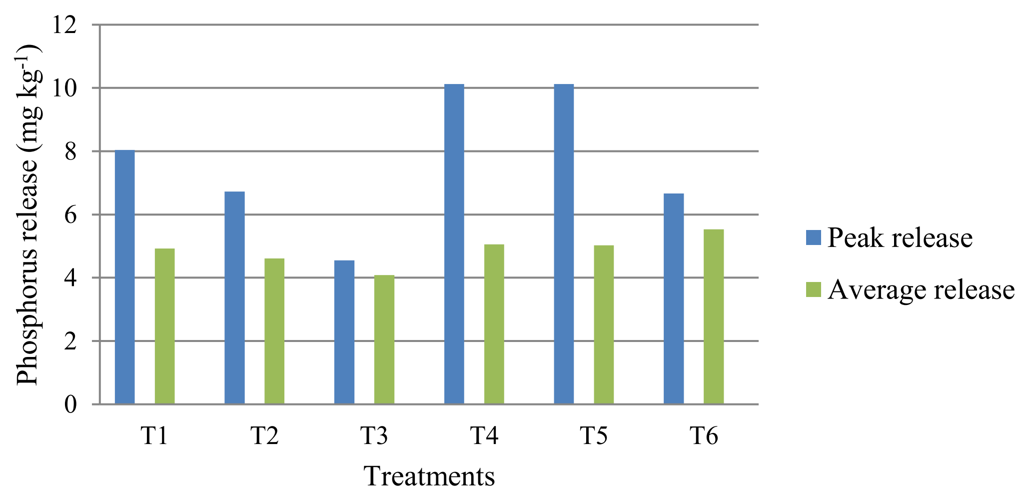


Fig 5.4. Peak and average release of phosphorus from from fertilizer-manure blocks/ fertilizers during incubation



5.1.3. Effect of treatments on available potassium content in soil

Available potassium content of the soil incubated with different fertilizer-manure blocks/fertilizers is presented in the Fig.5.5. During the initial stages of incubation (first 10 days), faster release of potassium was noticed under the sole fertilizer placement (treatment-T_6) compared to fertilizer-manure blocks (T_1-T_5). Fertilizer when placed alone (T_6) released almost 95 % of applied potassium within 3 days of incubation. The fertilizer-manure blocks slowly released the potassium ranging from 47.5 to 60.4 %. Thus compared to sole fertilizer application slow release of potassium was noticed from all fertilizer manure blocks. This slow release behavior of potassium from the fertilizer manure blocks may be due to the binding of potassium ions to cation exchange sites of different organic materials used for formulating the fertilizer manure blocks. The release pattern of potassium from different treatments during each sampling is presented in the Table 5.3. When compared among different fertilizer manure blocks, more sustained slow release behavior synchronized with the plant demand at various stages was exhibited by the treatment T_1(proportion-1). Average and peak release of potassium was presented in Fig 5.6. Which depicted the peak release of potassium of 1176.9 mg kg^{-1}, under sole fertilizer-placement while in treatments T_1, T_2, T_3,T_4 and T_5 the peak release recorded were 1162.4, 1165.3, 1176.5, 1275.7 and 1145.4 mg kg^{-1}respectively. The average release of potassium by T_6 was 1057.5 mg kg^{-1}, while in the treatments T_1 to $T_{5,}$ average release ranged from 847.48 to 1057.5 mg kg^{-1}. The average release of potassium from the fertilizer manure blocks was lower than that from sole fertilizers due to even distribution of nutrient release over the period of incubation by fertilizer-manure blocks. The lower average release and higher peak release by T_1 indicate its superiority in releasing the potassium evenly, which is synchronized with the growth periods of the crop. The absolute release of potassium in different sampling intervals during the incubation period is presented in the Table.5.3. and released proportion-1 77.19. 55.61, 34.03 mg kg^{-1} during 10-20, 20-40, and 40-60 days of incubation. This even release was not observed in other fertilizer-manure blocks.

A study conducted by Bley *et al*. (2017) found that, the conventional KCl released approximately 72% of the K within 24 hours, 85% within two days and 90 % within five days of incubation as compared to that of polymer coated KCl (slow release fertilizer). These findings confirmed the immediate release by the conventional fertilizers. The release of K from slow release fertilizer was approximately 20% after 28 days, 30% after 72 days and 40 % at five months of incubation. Thus the polymer coated product was recommended for transplanted seedlings of perennial crops. Owing to the observed release of nutrients from fertilizer-manure blocks in 60 days, the fertilizer-manure blocks can be recommended to supply the nutrients during the growth period of okra.

The results of many research indicated the role of the organic components used in formulating various fertilizer manure blocks on increasing the CEC, which helps in the retention and slow release of potassium (Schnitzer and Khan, 1972).

Table 5.3. Absolute release of available potassium (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	**1-3**	**3-6**	**6-10**	**10-20**	**20-40**	**40-60**
T_1	226.0	209.2	110.4	327.8	77.19	55.61	34.03
T_2	301.9	231.1	103.3	325.8	34.44	24.07	22.41
T_3	328.5	241.1	100.4	330.7	25.31	17.01	11.20
T_4	374.5	303.0	81.75	347.3	21.58	17.01	8.300
T_5	357.5	228.7	74.70	311.7	22.41	16.60	11.62
T_6	927.7	64.74	10.79	51.46	-110.4	-128.9	-6.850

Fig 5.5. Effect of different fertilizer manure blocks/fertilizers on available potassium content in soil during incubation

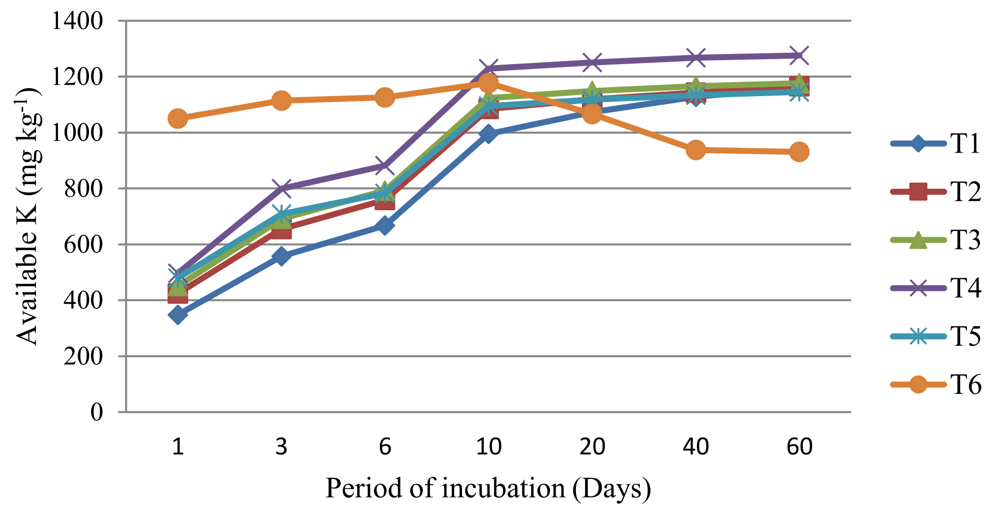
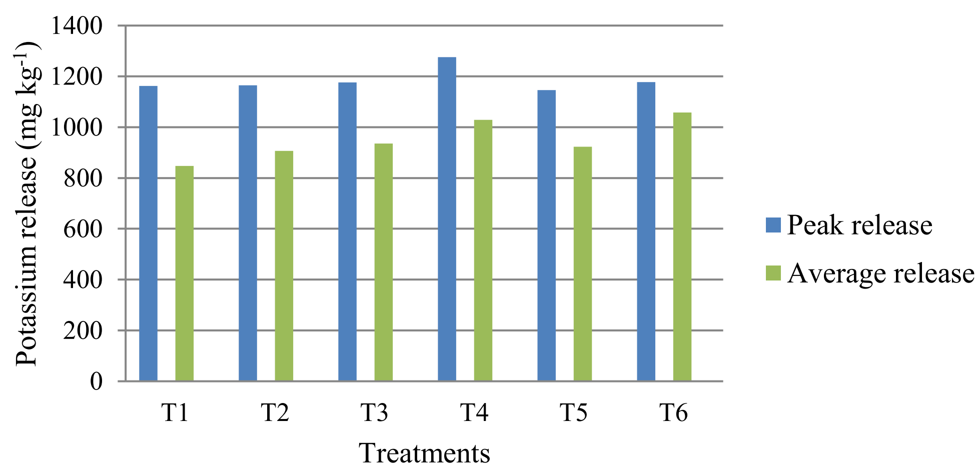


Fig 5.6. Peak and average release of potassium from fertilizer-manure blocks/fertilizers during incubation



5.1.4. Effect of treatments on exchangeable calcium content (mg kg^{-1}) in soil during incubation

Exchangeable calcium content of the soil at various incubation period by the fertilizer manure blocks showed significant difference between the treatments. The release kinetics of calcium is presented in Fig 5.7. Higher exchangeable calcium content was recorded in treatment T_6 than other fertilizer manure blocks (treatments T_1 to T_5) during all stages of incubation. The average and peak release of calcium from all the the treatments including fertilizer manure blocks were presented in the Fig 5.8. The highest average and peak release of calcium was obtained from the sole fertilizer placement treatment (T_6) compared to fertilizer-manure blocks. The absolute release of calcium from different treatments at different periods of incubation is given in the Table 5.4. Fertilizer-manure block prepared with proportion T_5 showed significantly highest mean exchangeable calcium, because zeolite powder is one of the component material used for formulating fertilizer-manure blocks in T_5 had more negative sites in the crystal structure of zeolites which is balanced by counter ions usually alkali and alkaline earth metals such as Na^+, K^+, and Ca^{2+} (Moshoeshoe *et al*., 2017) as well as zeolite has ability to retain nutrients and water and hence it prevent leaching loss of nutrients (Jakula and Wani, 2018).

Many research findings indicated the role of the organic components used in formulating various fertilizer manure blocks on increasing the CEC, which helped in the retention and slow release of potassium (Schnitzer and Khan, 1972).

Table 5.4. Absolute release of exchangeable Calcium (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	1-3	3-6	6-10	10-20	20-40	40-60
T_1	90.10	50.90	-10.30	-45.80	143.3	-31.00	68.80
T_2	81.70	35.00	-4.000	-45.50	-35.00	177.5	26.90
T_3	239.8	-123.1	13.40	-41.70	-6.4.00	170.9	-52.70
T_4	315.7	-45.00	-168.0	-5.400	-9.8.00	171.9	-21.60
T_5	282.6	-43.40	-107.5	57.70	-80.50	91.30	87.50
T_6	703.5	-123.0	-130.1	-39.70	44.30	515.2	-178.5

5.1.5. Effect of treatments on exchangeable magnesium content (mg kg^{-1}) in soil during incubation

Exchangeable magnesium content of the soil at various incubation period showed significant difference between the treatments (different fertilizer-manure blocks/ fertilizers). The release pattern of magnesium is presented in the Fig.5.9. During the initial stages of incubation, the exchangeable magnesium content in soil was highest in treatment T_6 (fertilizer alone) and lower in all fertilizer-manure blocks. As the days of incubation progressed, the fertilizer-manure blocks showed an increasing trend with respect to release of magnesium in soil. The exchangeable magnesium content of soil in treatments with fertilizer-manure blocks (T_1 to T_5) exceeded the fertilizer alone (T_6) after 20 days of incubation. The average and peak release of magnesium is presented in the Fig 5.10. The low average and high peak release of magnesium was noticed in all the fertilizer-manure blocks(T_1 to T_5) and it indicated the superiority of fertilizer manure blocks with respect to slow release of magnesium. The absolute release of magnesium from different treatments at various incubation periods are presented in the Table 5.5.

The absolute release is negative in some incubation periods in case of proportion-1. But the exchangeable magnesium content in the soil was maintained at a level fairly higher than critical limit throughout the entire period of incubation. The decrease in exchangeable magnesium level is not considered as a criteria for selection of the best proportions.

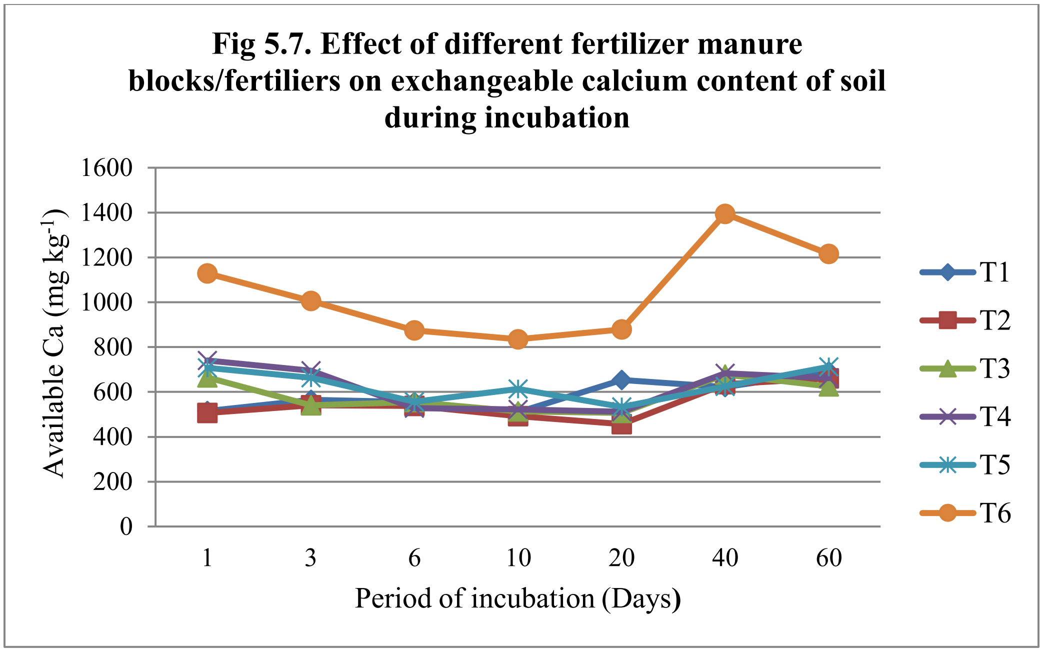


Fig 5.7. Effect of different fertilizer manure blocks/fertiliers on exchangeable calcium content of soil during incubation
Available Ca (mg kg-1)
1600
1400
1200
1000
800
600
400
200
0
1
3
6
10
20
40
60
Period of incubation (Days)
T1
T2
T3
T4
T5
T6

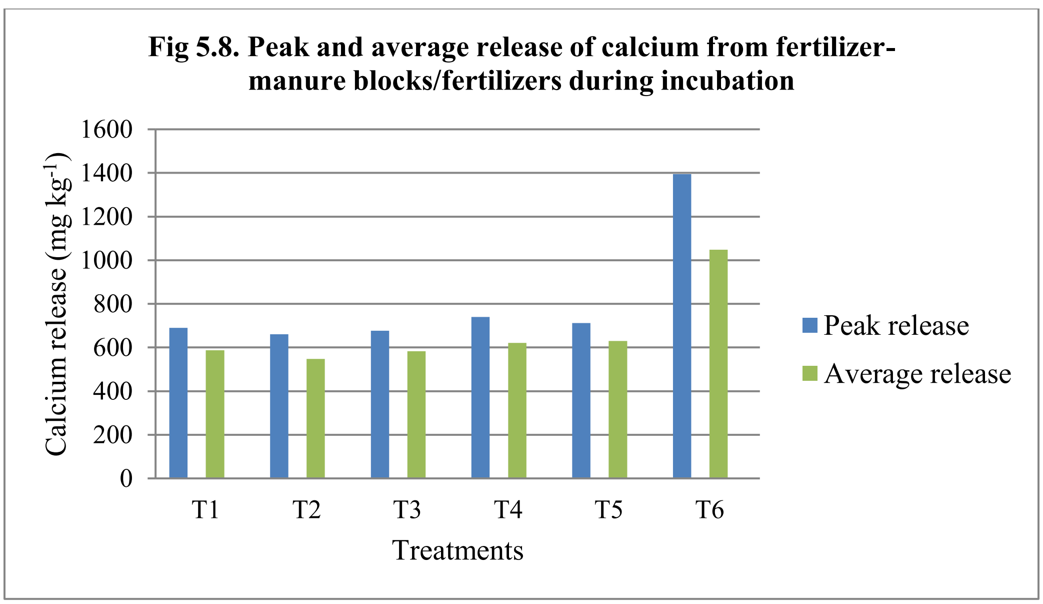


Fig 5.8. Peak and average release of calcium from fertilizer-manure blocks/fertilizers during incubation
Calcium release (mg kg-1)
1600
1400
1200
1000
800
600
400
200
0
T1
T2
T3
T4
T5
T6
Treatments
Peak release
Average release

Fig 5.9. Effect of different fertilizer-manure block/fertiliers on exchangeable magnesium content of soil during incubation

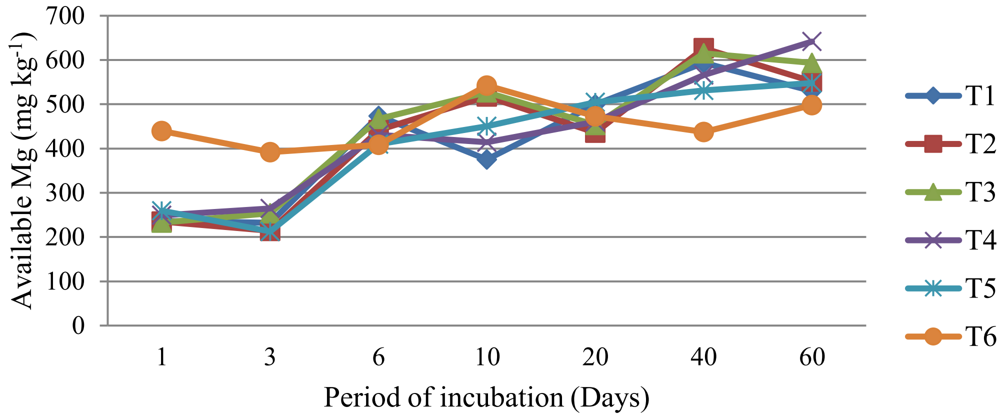


Fig 5.10. Peak and average release of magnesium from fertilizer-manure blocks/fertilizers during incubation

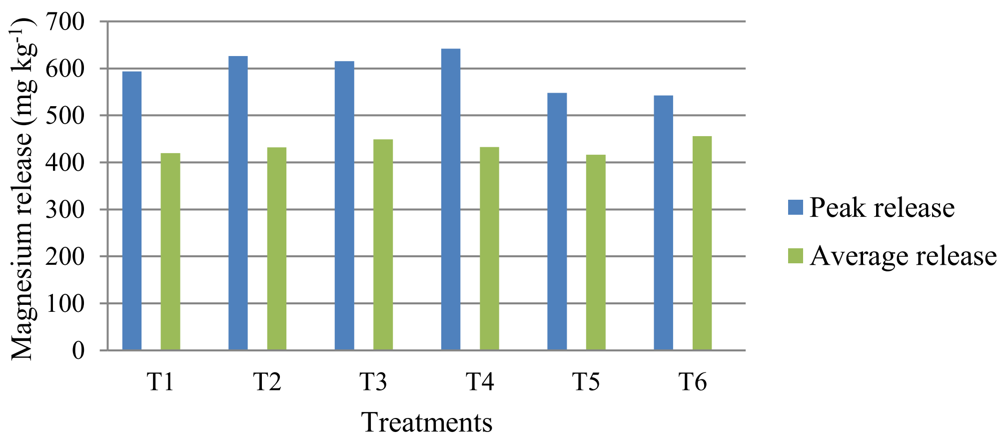


Table 5.5. Absolute release of exchangeable magnesium (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	1-3	3-6	6-10	10-20	20-40	40-60
T_1	87.70	-4.000	241.1	-98.10	124.0	94.30	-63.50
T_2	86.20	-20.60	227.6	76.20	-82.30	190.8	-75.20
T_3	84.20	21.10	213.2	60.30	-74.10	161.9	-21.80
T_4	100.5	15.70	166.2	-17.00	46.90	105.0	75.80
T_5	111.0	-46.90	197.6	40.00	54.10	26.70	17.00
T_6	290.7	-47.40	16.60	134.0	-69.70	-35.60	60.90

5.1.6. Effect treatments on available sulphur content (mg kg^{-1}) of soil during incubation

Available sulphur content of the soil by different fertilizer-manure blocks/fertilizers during various incubation period significantly differed between treatments. The peak and average release of sulphur is shown in Fig 5.12.The absolute release of sulphur during the incubation period is presented in the Table 5.1.6. The release pattern of sulphur is presented in the Fig 5.11. During all stages of incubation, the highest sulphur release was exhibited by the sole fertilizer placement treatment. Thus it indicates the ability of fertilizer-manure blocks for slow release of sulphur into soil. When compared among various fertilizer-manure blocks, the proportion-1(T_1) showed sustained slow release with respect to release of sulphur to the soil.

Fig 5.11. Effect of different fertilizer-manure blocks/fertilizers on available sulphur content of soil during incubation

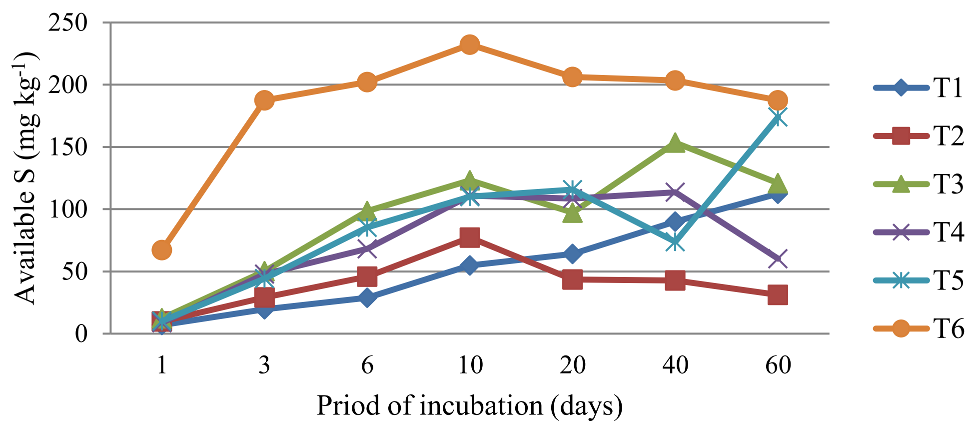


Fig 5. 12. Peak and average release of sulphur from fertilizer-manure blocks/fertilizers during incubation

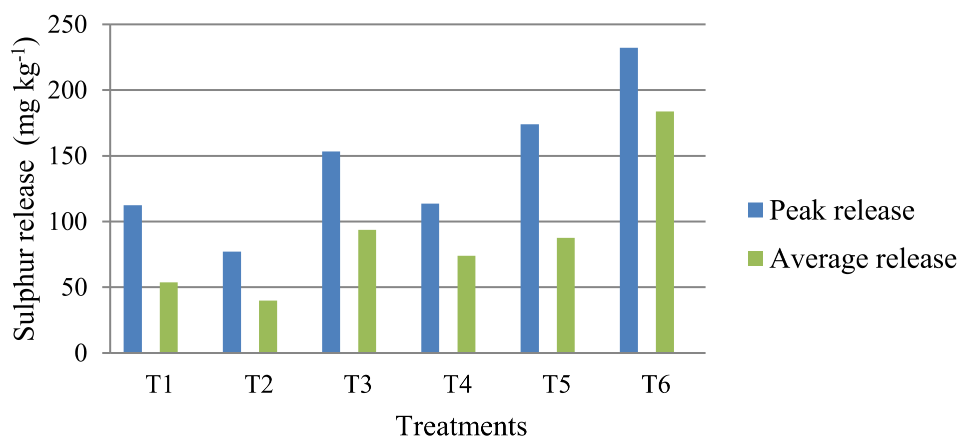


Table 5.6. Absolute release of available sulphur (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	1-3	3-6	6-10	10-20	20-40	40-60
T_1	3.748	12.55	9.250	26.16	9.036	26.20	22.31
T_2	6.595	19.33	16.71	31.34	-33.65	-0.877	-11.41
T_3	9.103	37.95	48.18	24.81	-25.99	56.17	-32.66
T_4	5.500	39.17	20.37	42.68	-2.447	5.108	-53.44
T_5	6.910	34.26	40.94	24.67	5.863	-42.10	100.3
T_6	63.85	120.3	14.86	30.00	-26.06	-2.660	-16.14

5.1.7. Effect of treatments on available zinc (mg kg^{-1}) content in soil during incubation

Available zinc content of the soil incubated at various period showed significant difference between all the treatments (different fertilizer-manure blocks/fertilizers). The absolute release of copper from different treatments at various incubation period is presented in the Table 5.7. The release pattern of zinc is presented in the Fig 5.13. During all stages of incubation, the highest available zinc release was noticed from fertilizers (T_6) applied soil. The slow release of zinc from fertilizer-manure blocks may be due to the binding of zinc ions with the organic materials present in the fertilizer-manure blocks. The average and peak release of zinc during the incubation period is shown in the Fig 5.14. The highest average and peak release of zinc was exhibited by the fertilizer alone treatment than the soil treated with fertilizer-manure blocks (T_1 to T_5). The absolute release of zinc from different treatments shown in Table 5.1.7. revealed that the absolute release was negative in some periods in case of proportion-1(T_1). But the available zinc content in soil maintained at a level fairly higher than the critical limit throughout the

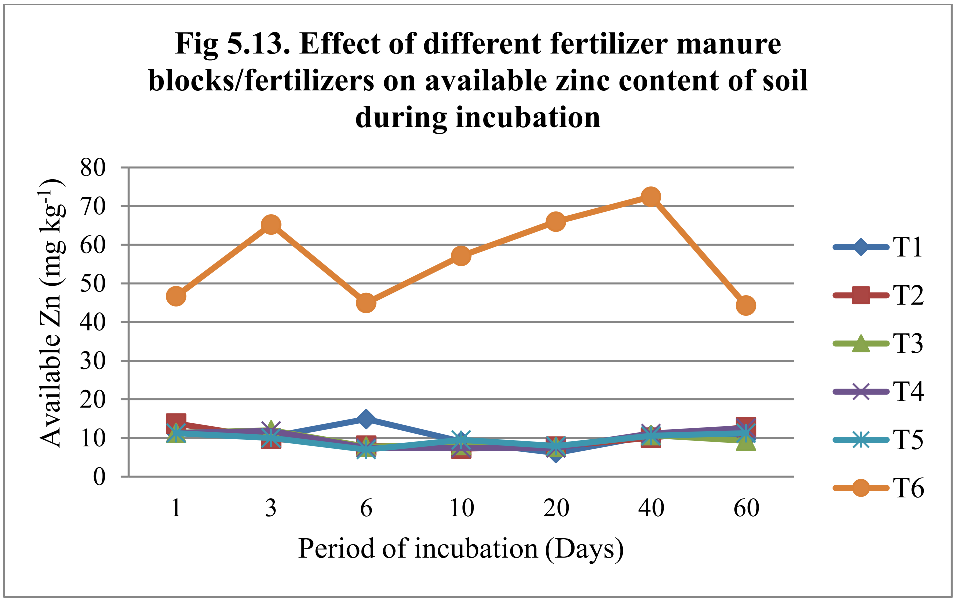


Fig 5.13. Effect of different fertilizer manure blocks/fertilizers on available zinc content of soil during incubation
Available Zn (mg kg-1)
80
70
60
50
40
30
20
10
0
1
3
6
10
20
40
60
Period of incubation (Days)
T1
T2
T3
T4
T5
T6

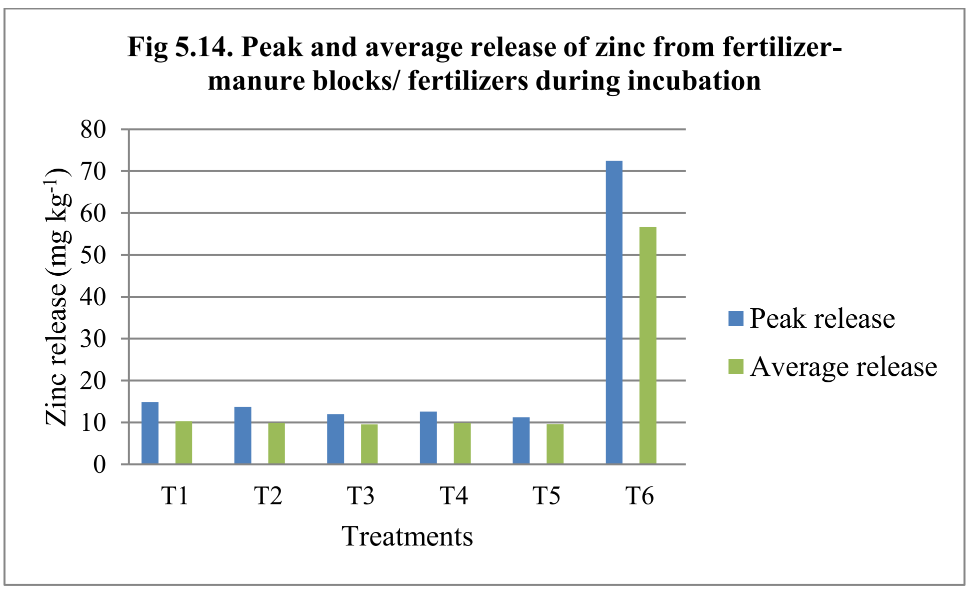


Fig 5.14. Peak and average release of zinc from fertilizer-manure blocks/ fertilizers during incubation
Zinc release (mg kg-1)
80
70
60
50
40
30
20
10
0
T1
T2
T3
T4
T5
T6
Treatments
Peak release
Average release

entire period of incubation and the decrease in available zinc level was not considered as a criteria for selection of the best proportion.

Table 5.7. Absolute release of available zinc (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	**1-3**	**3-6**	**6-10**	**10-20**	**20-40**	**40-60**
T_1	8.100	-1.000	4.550	-5.800	-2.950	4.550	-1.067
T_2	10.50	-3.950	-1.800	-0.750	0.516	2.304	2.730
T_3	8.050	0.700	-4.234	0.400	-0.400	2.954	-1.420
T_4	8.080	0.520	-4.384	-0.016	0.016	3.734	1.400
T_5	7.980	-1.230	-3.000	2.500	-1.534	2.634	0.650
T_6	43.40	18.58	-20.26	12.13	8.850	6.500	-28.20

5.18. Effect of treatments on available copper content (mg kg^{-1}) in soil during incubation

Available copper content of soil during incubation period showed significant difference between the treatments (various fertilizer-manure blocks/fertilizers). The absolute release of copper by various treatments at different incubation period is presented in the Table 5.8. The release pattern of copper was presented in the Fig 5.15. The highest available copper release was exhibited by the fertilizers alone (treatment- T_6) during all stages of incubation. The slow release of copper from fertilizer-manure blocks may be due to the binding of copper ions with the organic materials present in the fertilizer-manure block. The average and peak release of copper irrespective of the incubation period by various treatments is presented in the Fig 5.16. and it depicts the higher average and peak release of copper by the sole fertilizer placement treatment compared to all the fertilizer-manure blocks (treatments T_1 to T_5). The absolute release was negative in some periods in case of proportion-1. But the available copper content in soil is maintained at a level fairly higher than the critical limit throughout the entire period of incubation, the decrease in available copper level is not considered as a criteria for selection of the best proportion.

Table 5.8. Absolute release of available copper (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	**1-3**	**3-6**	**6-10**	**10-20**	**20-40**	**40-60**
T_1	4.740	-0.550	-1.857	0.140	-0.517	0.324	-0.427
T_2	5.093	-0.560	-2.017	0.147	-0.837	0.450	-0.163
T_3	4.446	-0.093	-1.293	-0.347	-0.797	0.524	-0.457
T_4	4.396	0.240	-1.616	-0.350	-0.680	0.136	-0.113
T_5	4.470	-0.087	-1.130	0.1230	-1.163	0.130	-0.403
T_6	9.980	0.920	-0.590	-1.010	-0.580	1.040	-1.354

Fig 5.15. Effect of fertilizer -manure blocks/fertilizers on available copper content of soil during incubation

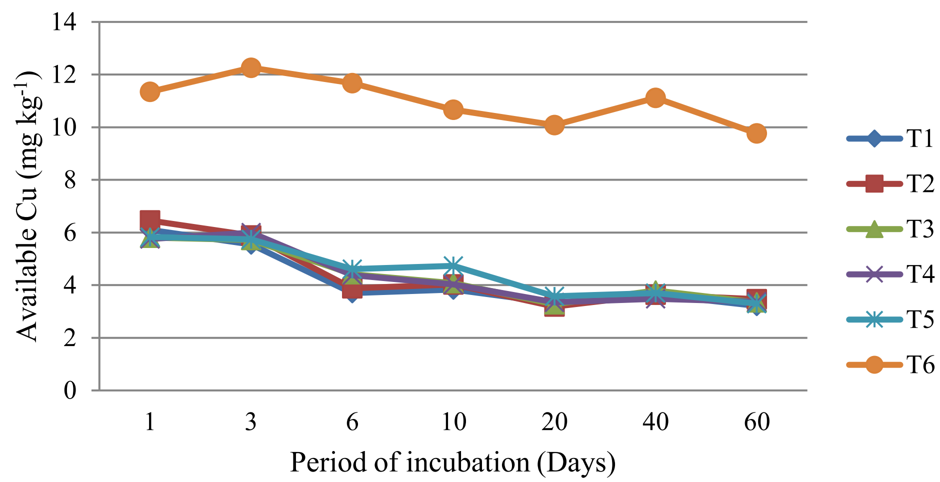
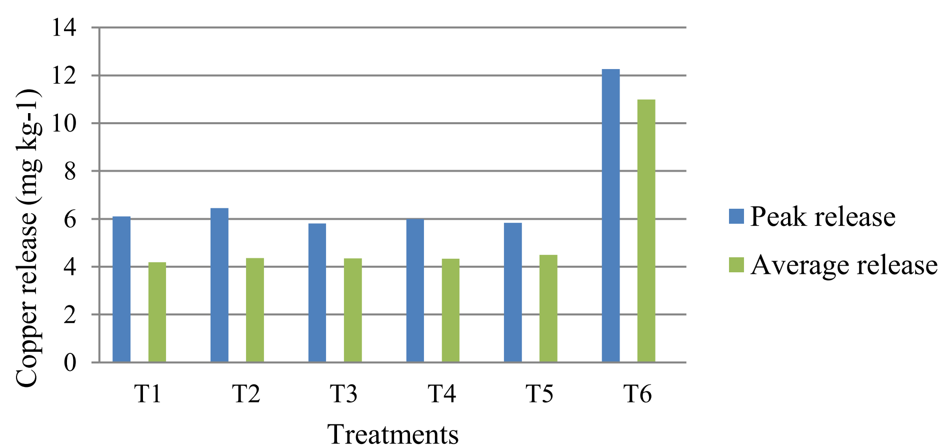


Fig 5.16. Peak and average release of copper from fertilizer-manure blocks/fertilizers during incubation



5.19. Effect of treatments on available boron content (mg kg^{-1}) in soil during incubation

Available boron content of the soil during different incubation period fertilizer-manure blocks/fertilizers was significantly differed between treatments. The absolute release of boron by fertilizer manure blocks during various incubation period are presented in the Table 5.9 and the release pattern of boron is presented in the Fig 5.17. During the initial stages of incubation(first 10 days), high boron release was exhibited by the sole fertilizers alone (T_6) compared to fertilizer-manure blocks (T_1 to T_5). The fertilizer incorporation (T_6) released almost 68% of the applied boron within 10 days of incubation. But in the case of fertilizer-manure blocks, the percentage of release ranged from 17 to 23 % within 10 days of incubation. After 10 days of incubation, an increasing trend was observed in all the fertilizer manure blocks with respect to release of boron. The average and peak release of boron presented in the Fig 5.18. showed the low average and highe peak release of boron by all the fertilizer-manure blocks (T_1 to T_5) and it indicated the superiority of fertilizer manure blocks with respect to slow release of boron.

Table 5.9. Absolute release of available boron (mg kg^{-1}) from fertilizer-manure blocks during the period of incubation

Treatments	Intervals of incubation (days)						
	0-1	**1-3**	**3-6**	**6-10**	**10-20**	**20-40**	**40-60**
T_1	1.860	0.390	0.170	0.213	1.620	6.933	1.094
T_2	1.940	0.360	0.266	0.267	1.207	6.400	1.100
T_3	1.853	0.513	0.520	0.414	3.520	4.240	0.460
T_4	1.820	0.813	0.733	0.254	5.120	1.486	1.107
T_5	2.133	0.453	0.660	0.447	4.847	0.000	1.800
T_6	9.433	0.987	0.886	1.014	0.243	-0.097	3.120

Fig 5.17. Effect of different fertilizer-manure blocks/fertilizers on available boron content of the soil during incubation

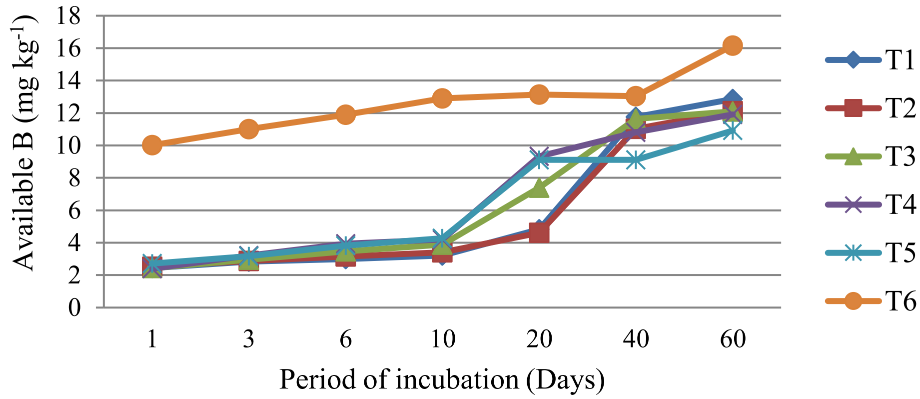
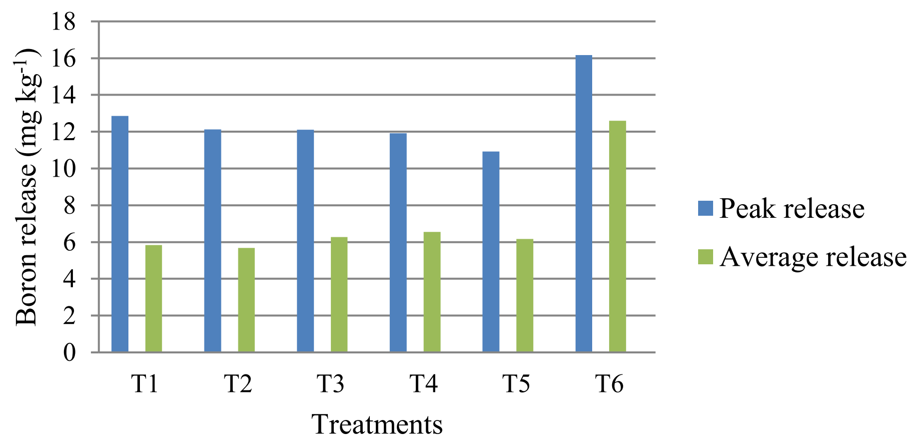


Fig 5. 18. Peak and average release of boron from fertilizer-manure blocks/fertilizers during incubation



Thus, the more controlled and sustained release of N, K, secondary and micronutrients nature by the fertilizer manure block of proportion-1 (Coirpith- 35%, Cowdung- 25%, Vermicompost-13%, Ground nut cake- 10%, Neem cake 10% , Zeolite- 2%, Humic acid- 5%) was the criteria for selection and the selected proportion was used in the pot culture study to identify the best package of its application. Fertilizer-manure block made with proportion-1 (T_1) had released 65 per cent of added N, 54 per cent Ca, 47 per cent S during 60 days of incubation, while almost 100 percent of applied K and Mg was released within 60 days. Since almost 100 percent of the potassium is released within 60 days topdressing with potassium can be recommended, for better fruit development. Phosphorus has been released very slowly throughout the entire period of incubation. The phosphatic fertilizer used in the fertilizer-manure block was rock phosphate (Rajphos) which itself got a slow releasing property. In the case of micro nutrients Zn and Cu were released by about 12 per cent and 32 per cent respectively, whereas almost 100 percent of the boron was released with in 60 days of incubation. According to Bley *et al*. (2017) slow release fertilizers (polymer coated product) were recommended in case of transplantable seedlings of perennial crops. Owing to the observed slow release of nutrients from fertilizer-manure blocks in 60 days, the fertilizer-manure blocks can be recommended to supply the nutrients during the entire growth period of okra.

The results of the incubation experiment can be summarized as:

1) The results of the incubation study indicated the superiority of fertilizer-manure blocks with respect to slow release of nutrients.
2) Though the peak release was high for different fertilizer-manure blocks the average release was lower in case of proportion 1 which indicated even distribution of the nutrients throughout the incubation experiment.
3) When compared among various fertilizer-manure blocks, treatment T_1 (proportion-1 with Coirpith- 35%, Cowdung- 25%, Vermicompost-13%,

Groundnutcake- 10%, Neem cake 10%, Zeolite- 2%, Humic acid- 5%) was identified as superior due to:

- Low average release of nutrients which indicated even distribution
- Reduced rate of release of different nutrients
- The release of nutrients in concurrence with the different growth stages of the crop
- Low cost of production (Rs. 1.57)

5.2. Pot culture experiment

As per the results of the laboratory incubation study proportion-1 was selected as the combination of organic materials/fillers for developing slow release fertilizer-manure block. The pot culture experiment was conducted in grow bags with the objective to find out the effect of fertilizer-manure blocks on growth and yield and uptake of nutrients in okra.

5.2. 1. Effect of different treatments of nutrient management options biometric parameters

The effect of fertilizer-manure blocks in different size and fertilizer dosages on different biometric parameters of Okra are graphically represented (Fig. 19, 20, 21). Pant height, number of leaves per plant, and number of branches per plant showed significant difference between treatments. The results revealed that biometric parameters were higher under the treatment T_7 where 25 % of the recommended nutrients applied in the form of 100g fertilizer manure block as basal and 50% of the recommended nutrients as top dressing at 1 month after planting.

The comparison of size and placement of the different fertilizer-manure blocks revealed the superiority of the 100 g block placed below the planting depth over 4 numbers of 25g blocks placed around the plant just below the surface. This may be due to the fact that leaching of nutrients from the 25 g blocks placed just below the surface occurred before the complete establishment of the root system. However the root system might have entered directly in to the 100g blocks resulting in effective utilization of the nutrients entrapped inside the fertilizer-manure blocks. This is very clearly visible in the Plate.9.

5.2.2. Effect of different treatments of nutrient management options on yield and yield characteristics of okra

The Fruit yield, fruit number, fruit length, fruit girth and number of seeds per fruit of the okra as influenced by the fertilizer manure block with 100, 50 and 25 % POP recommended fertilizer are presented graphically (Fig. 22, 23, 24, 25, 26, 27, 28). Highest fruit number was recorded by the treatment T_7 where in 25 % of the recommended nutrients based on KAU POP given as fertilizer-manure block and 50% as top dressing. However it was on par with the treatments T_8(Nutrients as per KAU POP recommendation) and T_9(Nutrients as per soil test based recommendation), which showed savings of 25 % fertilizers on using fertilizer-manure blocks. This is attributed to reduced loss of nutrients from the fertilizer-manure block owing to its slow release of nature and improved fertilizer use efficiency (FUE) to a greater extent. Kiran *et al.* (2010) also suggested such improvement of FUE on use of slow release fertilizer technology.

More over the slow release nature of the fertilizer-manure block as evidenced from incubation experiment supplied nutrients in accordance with the crop growth stages due to reduced leaching and increased plant uptake. Akter *et al.*(2017) reported that the combined use of fertilizers and organic manures had improved crop growth and yield in tomato. Similar results of use of fertilizers and organic manures were reported by in *Brassica juncea.* Singh *et al.* (2013) recorded the parity of yield between full recommended dose of urea and diammonium phosphate (DAP) and organic matrix entrapped urea and DAP containing ¼ th of the recommended dose.

The yield attributes such as number of fruits per plant, fruit length and girth showed the similar trend as that of the fruit yield. Treatments T_4, T_9 and T_7 were having highest number of seeds per fruit. This can be attributed to the graded supply of all nutrients for seed filling and yield.

The use of organic components along with fertilizers slowed down the release of nutrients which resulted in the reduction of 25 % fertilizer recommendation compared to 100 % POP. Puri (1999) reported the effect of neem on inhibition of nitrification enzyme and release of nutrients. Neem cake is a component in fertilizer-manure block of the present study, which might have played a main role in releasing nutrients slowly.

Significantly early flowering was observed in the treatment T_8 which received nutrients as per KAU POP recommendation. This is in line with the reported work of Shukla *et al*. (2018) who found that, the occurrence of days to flowering in okra is directly related to the fertility status of the soil. The control and absolute control treatments T_{10} and T_{11} had taken more days to flowering (34.83 and 36.33 days) and this might be due to in adequate nutrient supply in these treatments.

Fig 5.19. Effect of different treatments of nutrient management options on plant height (cm) of okra in grow bags

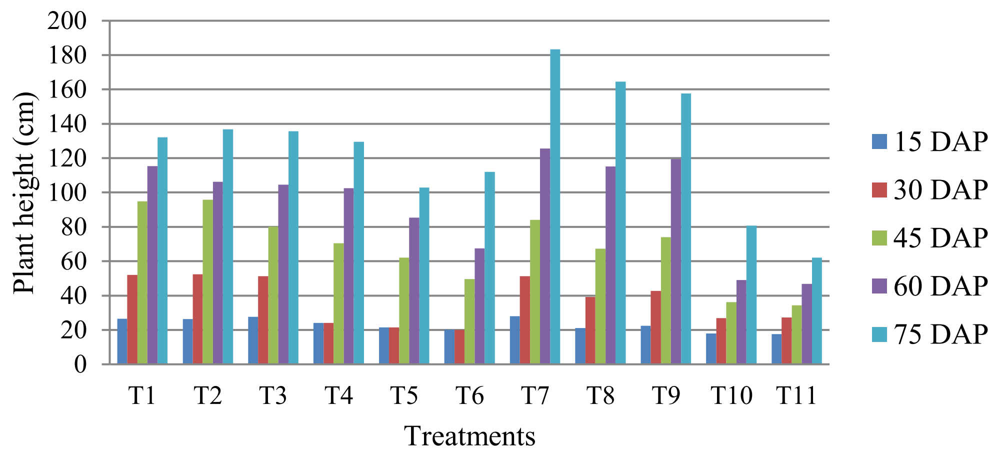
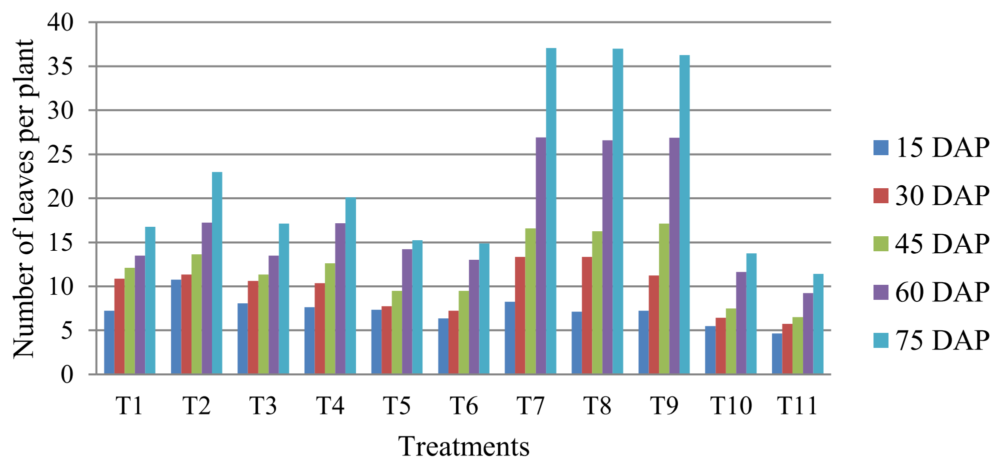


Fig 5.20. Effect of different treatments of nutrient management options on number of leaves per plant of okra in grow bags



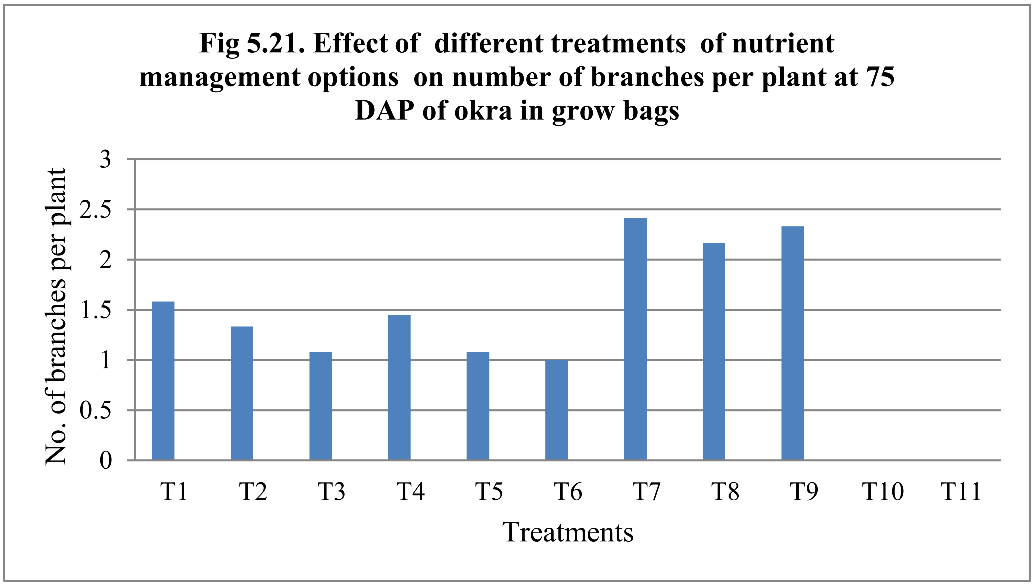


Fig 5.21. Effect of different treatments of nutrient management options on number of branches per plant at 75 DAP of okra in grow bags
No. of branches per plant
3
2.5
2
1.5
1
0.5
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
Treatments

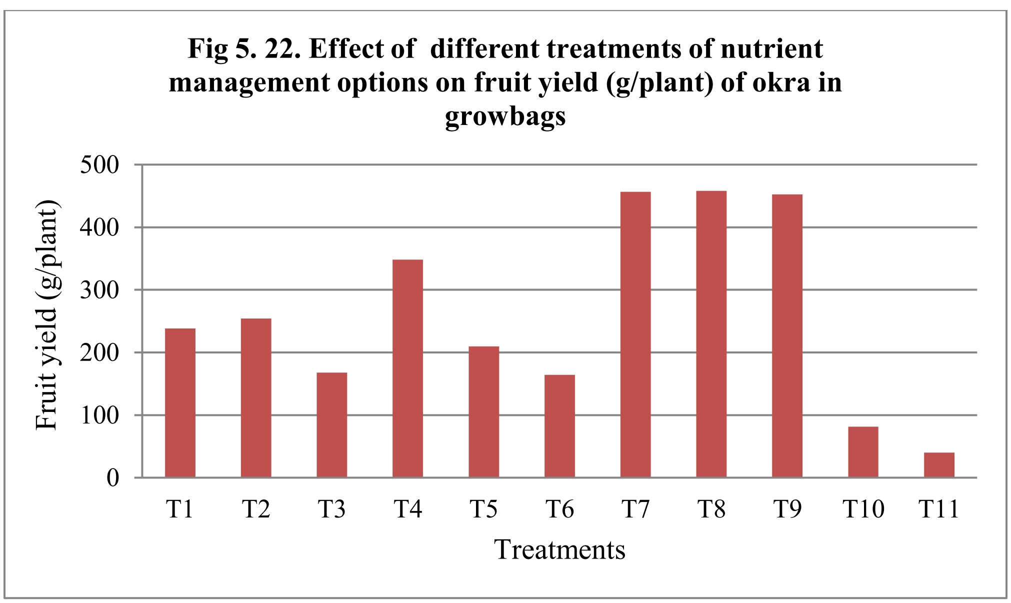


Fig 5. 22. Effect of different treatments of nutrient management options on fruit yield (g/plant) of okra in growbags
Fruit yield (g/plant)
500
400
300
200
100
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
Treatments

Fig 5.23. Effect of different treatments of nutrient management options on number of fruits per plant of okra in grow bags

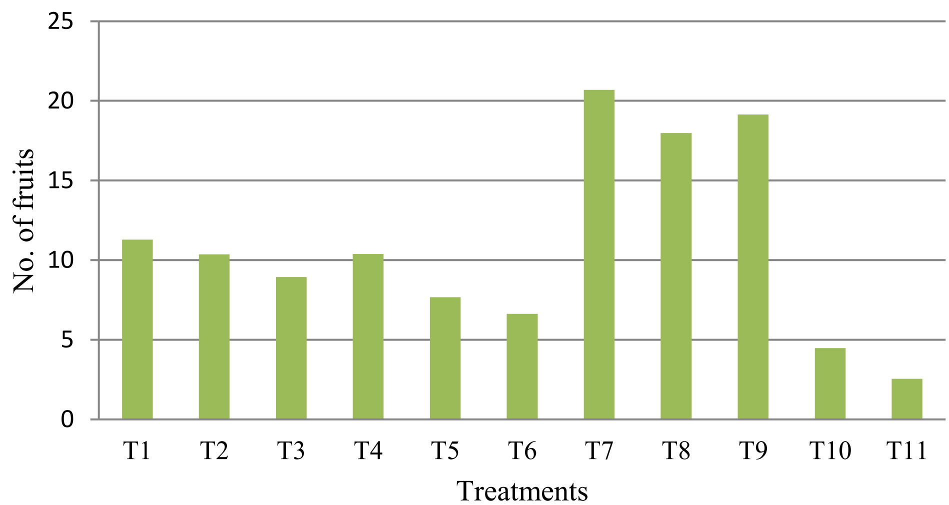


Fig 5.24.Effect of different treatments of nutrient management options on length of fruits(cm) of okra in grow bags

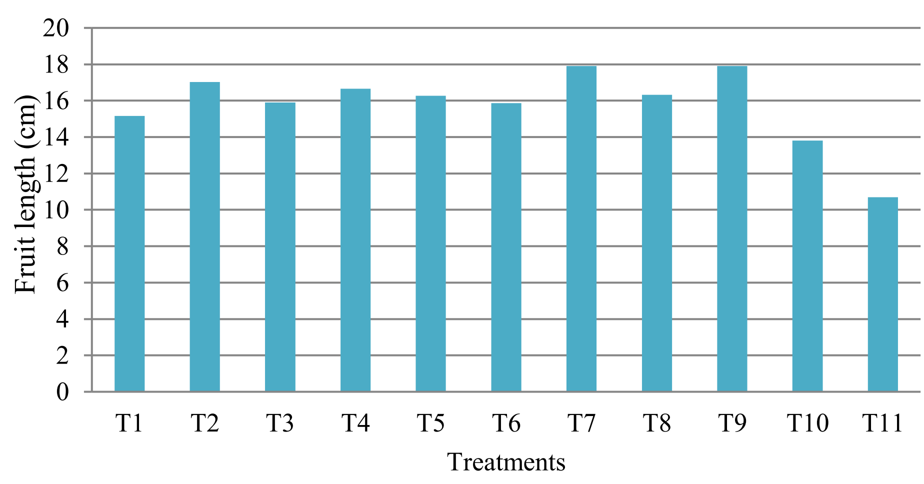


Fig 5. 25. Effect of different treatments of nutrient management options on fruit girth (cm) of okra in grow bags

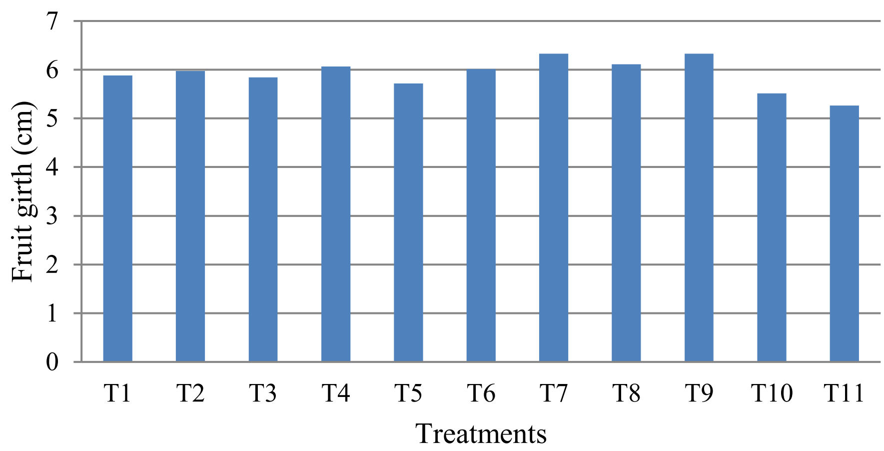
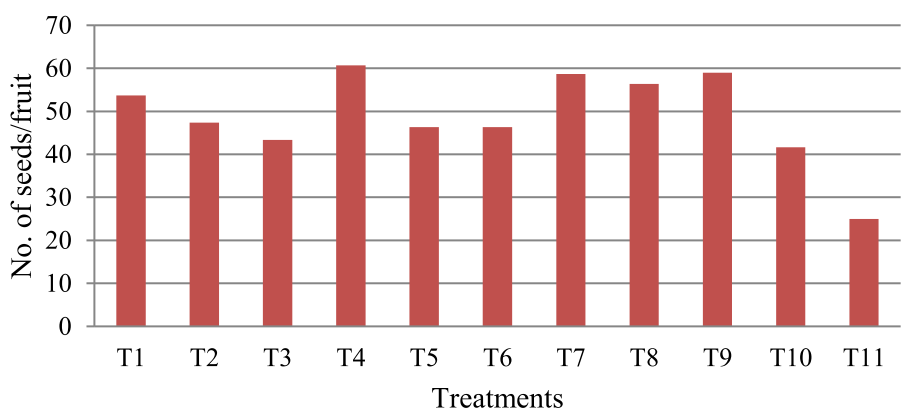


Fig 5.26. Effect of different treatments of nutrient management options on number of seeds per fruit of okra in growbags



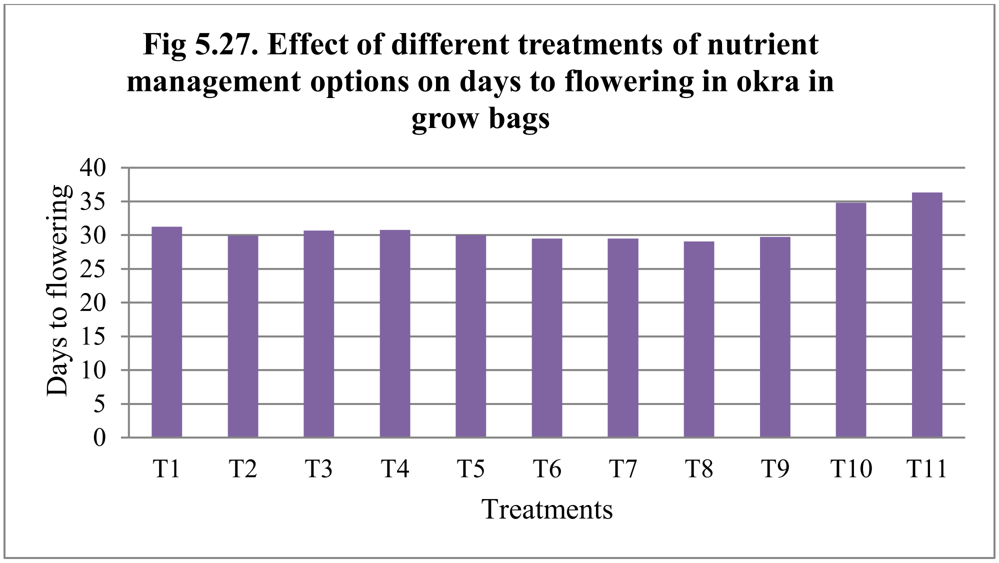


Fig 5.27. Effect of different treatments of nutrient management options on days to flowering in okra in grow bags
Days to flowering
40
35
30
25
20
15
10
5
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
Treatments

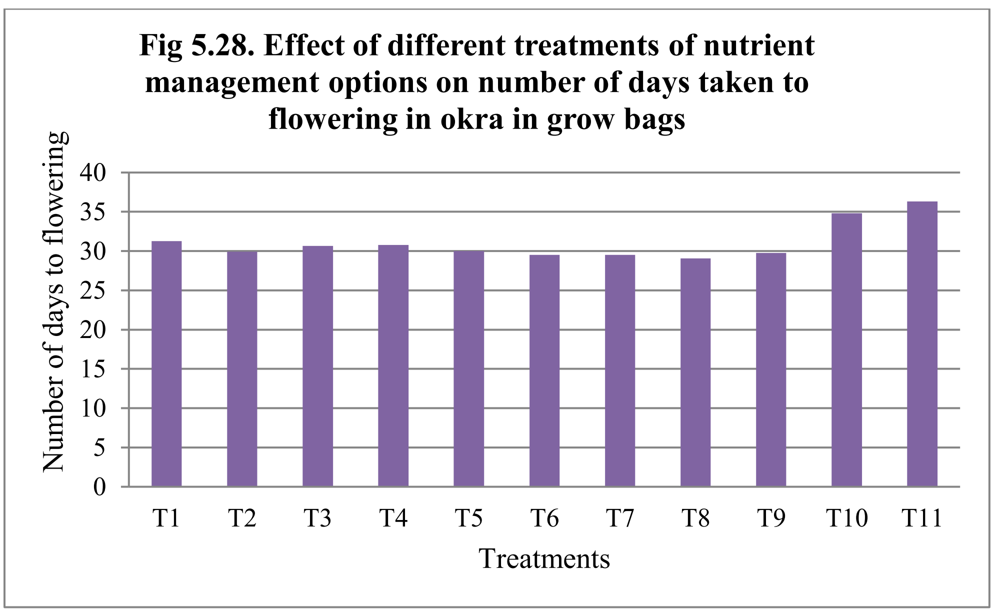


Fig 5.28. Effect of different treatments of nutrient management options on number of days taken to flowering in okra in grow bags
Number of days to flowering
40
35
30
25
20
15
10
5
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
Treatments

5.2.7. Effect of different treatments of nutrient management options on nutrient uptake by the crop after final harvest

5.2.7.1 Effect of different treatments of nutrient management options on uptake of primary nutrients

Application of fertilizer-manure block showed significant influence on the nutrient uptake. The graphs representing uptake of primary, secondary and micro nutrients are presented in the Fig. 5.29 to 5.31. The highest nitrogen uptake recorded in the treatment T_9 (1844 mg g of plant dry matter$^{-1)}$) and it was on par with that in treatment T_7 (1832 mg g of plant dry matter^{-1}) followed by the treatment T_8 (1738 mg g of plant dry matter^{-1}). The higher nitrogen uptake in the treatments T_7, T_8, and T_9 can be attributed to the long term availability of nitrogen owing to the split application of nitrogen. The highest phosphorus and potassium uptake was exhibited by the treatment T_7 where 25 % of the recommended nutrients was applied in the form of 100 g fertilizer-manure block and 50 % of the recommended nutrients in the form of sole fertilizers as top dressing. This may be attributed due to the highest biomass yield in the treatment T_7 and split application of the 50% of fertilizer dosage 1 month after planting. In general treatments with KAU POP recommendation and soil test based recommendation (T_8 and T_9), had no topdressing of P and K. But in T_7, 50 % recommended dose of nitrogen, phosphorus and potassium was applied as topdressing.

Sourabh and Akhilesh (2016) reported that, split application of nutrients resulted on more nutrient content than single application. Likewise fertilizer-manure disc offer uniform and even release of nutrients in coalescence with the growth stages of crop. Sharma and Singh (2011), recorded higher nutrient levels in organic matrix based slow release fertilizer treated plant leaves. It was due to reduced nitrobacter activity in soil.

5.2.7.2. Effect of different treatments of nutrient management options on uptake of secondary nutrients

The graphs representing uptake of secondary nutrients(Ca, Mg, S) showed that the highest calcium uptake was recorded by the treatment T_8 and it was on par with the treatment T_9, whereas highest magnesium and sulphur uptake was recorded in the treatments T_7 and T_9 respectively. Lower Ca, Mg and S uptake was recorded by the absolute control in which no nutrient sources were added. The lower calcium in T_7 can be attributed to Ca-K interaction and lower magnesium in T_8 can be attributed to Ca-Mg interaction in experimental soil. The pattern of S uptake corroborated the trend in biomass yield.

5.2.7.3. Effect of different treatments of nutrient management options on uptake of micronutrients

The graphs representing uptake of micronutrients (Fig.5.31) showed that the highest zinc and copper uptake was recorded in the treatment T_7 (25 % of recommended nutrients applied in the form of fertilizer-manure block and 50 % of nutrients as top dressing. The uptake of copper by the treatment T_8 was on par with that of T_7. Highest boron uptake was recorded by the treatment T_9 which received nutrients as per soil test based recommendation. Lower micronutrients uptake was recorded in the absolute control. The Zn-P interaction and interaction between different cations can be the reason for the observed trends in micronutrient uptake. The superiority of the treatment T_9 with respect to B uptake corroborate the trend in biomass yield.

Fig 5.29. Effect of different treatments of nutrient management options on uptake of primary nutrients by okra plant

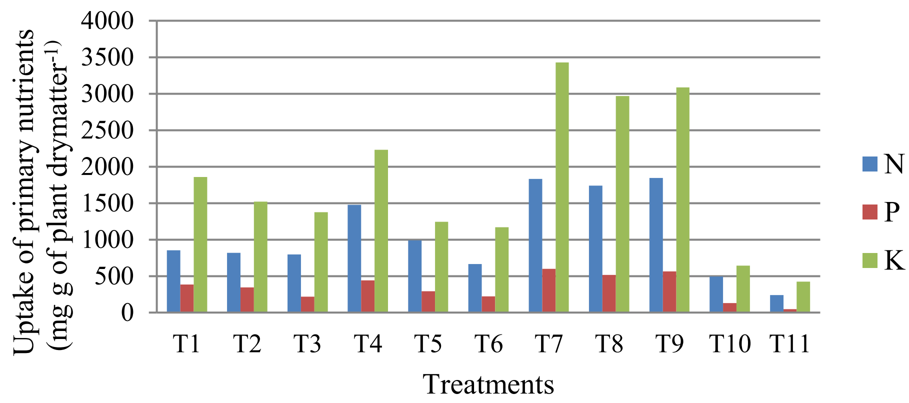


Fig 5.30. Effect of different treatments of nutrient management options on uptake of secondary nutrients by okra plant

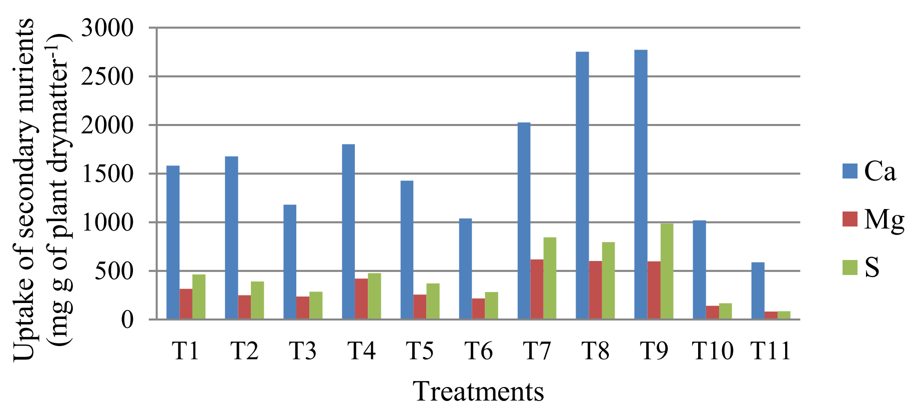
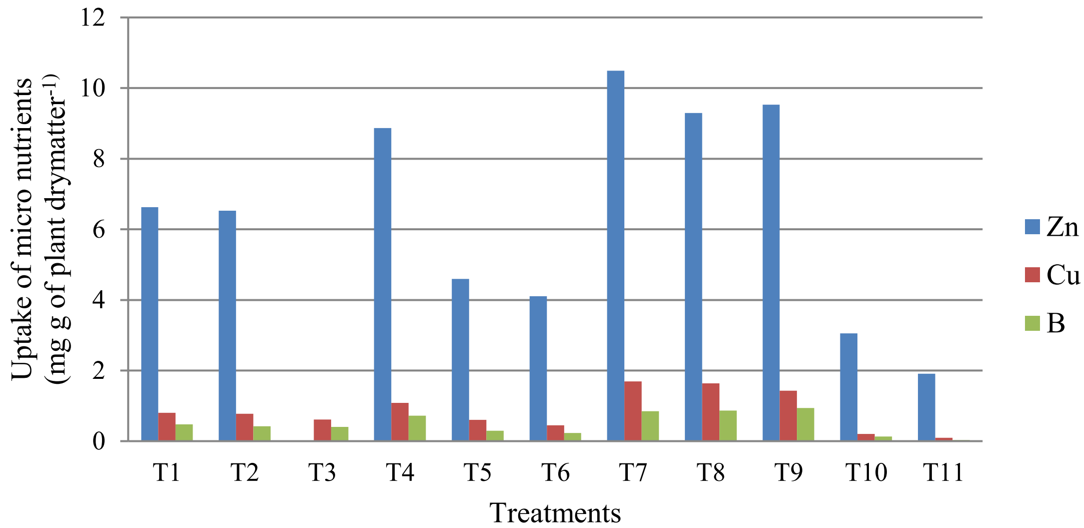


Fig 5.31. Effect of different treatments of nutrient management options on uptake of micro nutrients by okra plant



5.2.3. Effect of different treatments of nutrient management options on soil properties after harvest

The treatments did not show any significant difference on pH as well as electrical conductivity of soil collected after harvest of the crop. However the soil organic carbon significantly influenced by the treatments it and ranged from 0.506 to 0.735 %. Lower organic carbon was reported in the absolute control followed by control (T_{10}), T_9 and T_8. However the organic carbon was higher in soil where fertilizer-manure blocks were used in grow bags. This may be due to the un decomposed carbon present in the organic manures in fertilizer-manure blocks left in soil after harvest of the crop.

The average organic carbon content of organic manures vary between 11.5 to 15.1 % (Kumar *et al*., 2012). Saha *et al*. (2010) reported that soil organic carbon increased significantly in the farmyard manure (FYM) treated plot of *Mangifera indicia.*

5.2.4. Effect of different treatments of nutrient management options on primary nutrients in soil analyzed after harvest of the crop

The use of fertilizer-manure blocks had significant effect on available status of primary nutrients in soil. The highest available N, P, K status were observed for the treatment with fertilizer-manure blocks. This indicate long term sustainability of the fertilizer-manure blocks or rather the ability of the disc to retain the incorporated N, P, K for a prolonged period of time. However in case of P and K, the lower values of available nutrients indicated higher crop removal. Singh *et al.* (2013) reported an increase in available N,P,K and organic carbon status of soil where urea was used as entrapped from in organic matrix. Zaman *et al.* (2015) reported that application of vermi compost significantly increased total nitrogen, available P and exchangeable K status of both acidic and non-calcareous soil grown with stevia.

5.2.5. Effect of different treatments of nutrient management options secondary nutrient status in soil analyzed after harvest of the crop

Application of fertilizer-manure blocks exhibited significant difference among treatments on secondary nutrients content of post harvest soil and given in the Fig 5.34. The available Mg content of soil after harvest varied from 149.9 to 424.96 mg kg^{-1} and sulphur from 4.50 to 18.01mg kg^{-1}.Though the exchangeable calcium was sufficient in all the treatments, the soil from control treatment was deficient in sulphur. Treatment T_7 recorded highest values with respect to magnesium and sulphur. Generally the organic components as well as the secondary fertilizers added to the matrix ensure retention of secondary nutrients to a greater extent in soil. Abdulla and Sukhraj (2010) reported the positive role of vermi compost on yield of okra through the supply of secondary and micronutrients. Zaman *et al.* (2015) reported that application of vermicompost significantly increased available Ca, Mg and S status of both acidic and non-calcareous soil grown with stevia.

5.2.6. Effect of different treatments of nutrient management options on available micronutrient status of soil after harvest of the crop

The analytical results of the post harvest soil revealed that the treatments differed significantly with respect to the available micronutrient status of the soil and is presented in Fig 5.35. Available zinc and copper was present in sufficient range in soil in all treatments even after harvest of the crop. However available boron was sufficient in Treatment T_1, T_2, T_5 and T_7 where fertilizer-manure blocks were used. Abdulla and Sukhraj (2010) reported the positive role of vermi compost on yield of okra through supply of secondary and micronutrients. Zaman *et al.* (2015) reported that application of vermi compost significantly increased available Zn and B status of both acidic and non-calcareous soil grown with stevia.

5.2.8. Effect of different treatments of nutrient management options on Nutrient use efficiency(based on Agronomic efficiency)

The fertilizer-manure blocks had huge impact on nutrient use efficiency calculated based on agronomic efficiency and graphically presented in Fig. 5.36. Highest nutrient use efficiency is recorded by the treatment T_7 (28.12) (which received 25% of the recommended dose of nutrients in the form of 100 g fertilizer-manure block and 50% of the recommended nutrients as top dressing) followed by the treatments T_8 (26.42) (which received nutrients as per general recommendation of KAU POP) and T_9 (26.38) (which received nutrients as per soil test based recommendation). While considering the nutrient contribution from the component materials used for developing the fertilizer-manure block, the NUE of the treatment T_7 becomes 23.51, but the availability of nutrients from these component material will be released very slowly on long term basis.

5.2.9. Effect of different treatments of nutrient management options on B:C ratio (based on per plant yield in pot)

Treatments T_7, T_8, and T_9 had more or less same B:C ratio. Treatment T_7had recorded B: C ratio of about 1.26. Since B:C ratio greater than one is economical, the treatments T_7, T_8, T_9 are economically feasible and treatment T_7 offer nutrient savings to a greater extent. However, the higher nutrient use efficiency and ease of application favour the technology of fertilizer-manure blocks in grow bag cultivation.

Fig 5.32. Effect of different treatments of nutrient management options on organic carbon content of soil after harvest

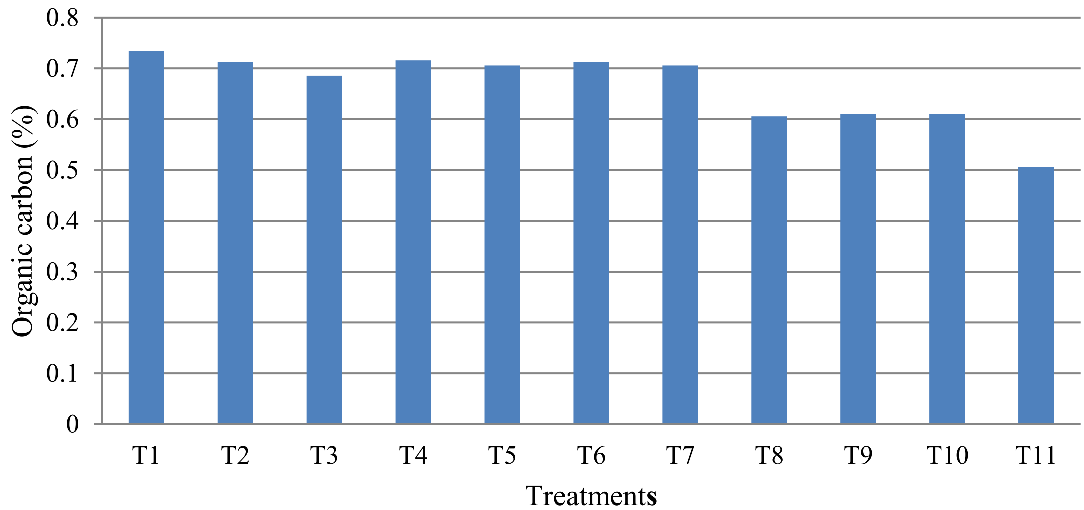
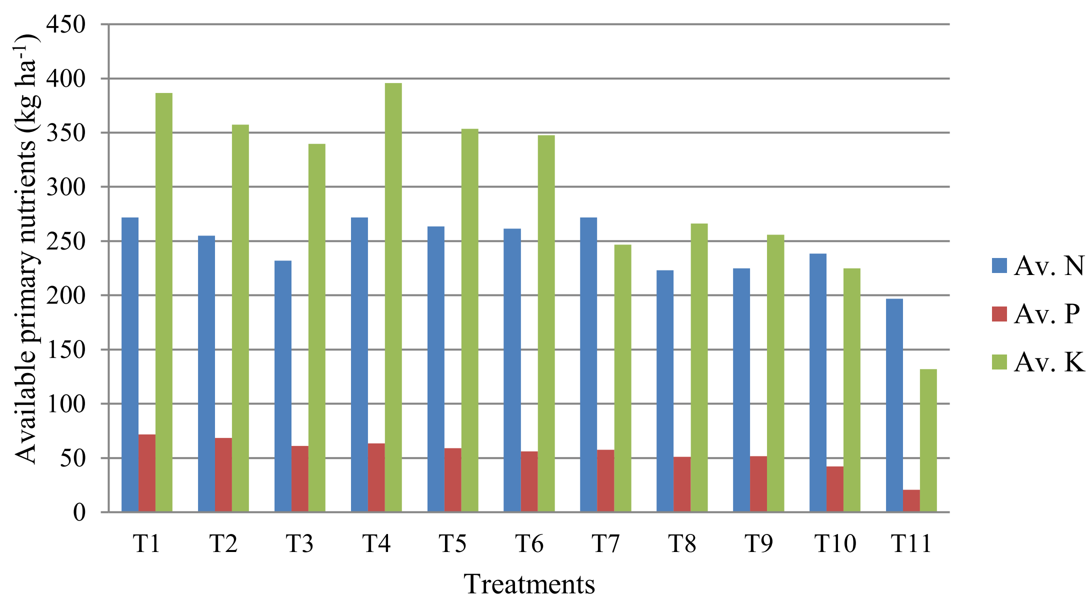


Fig 5.33. Effect of different treatments of nutrient management options on available primary nutrient content in soil after harvest



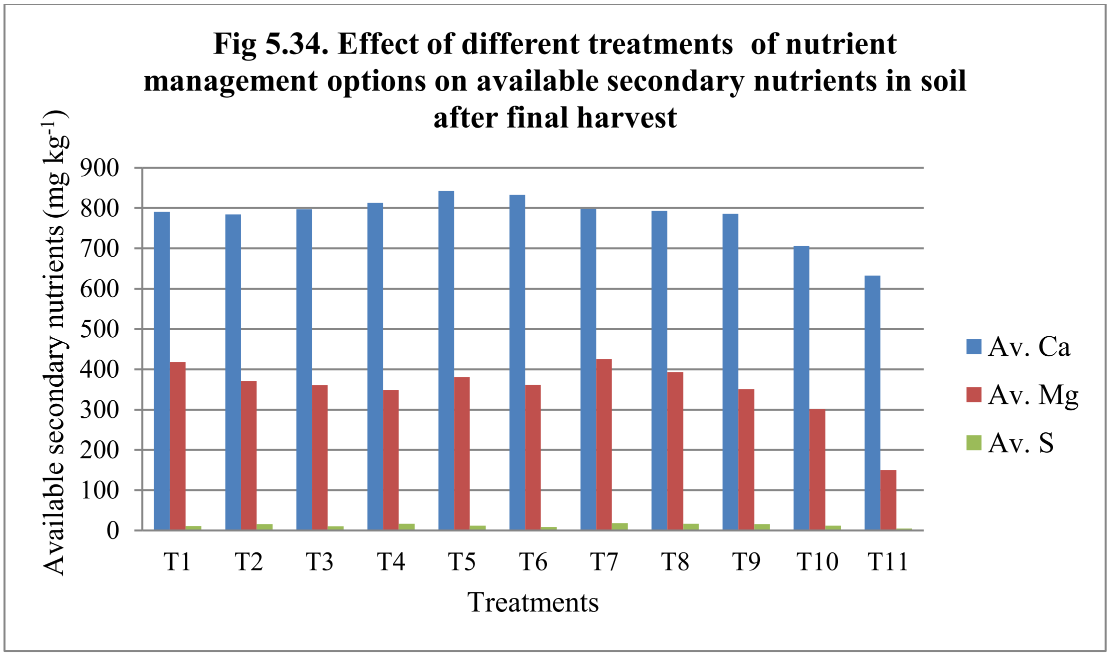


Fig 5.34. Effect of different treatments of nutrient management options on available secondary nutrients in soil after final harvest
Available secondary nutrients (mg kg-1)
900
800
700
600
500
400
300
200
100
0
T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11
Treatments
Av. Ca
Av. Mg
Av. S

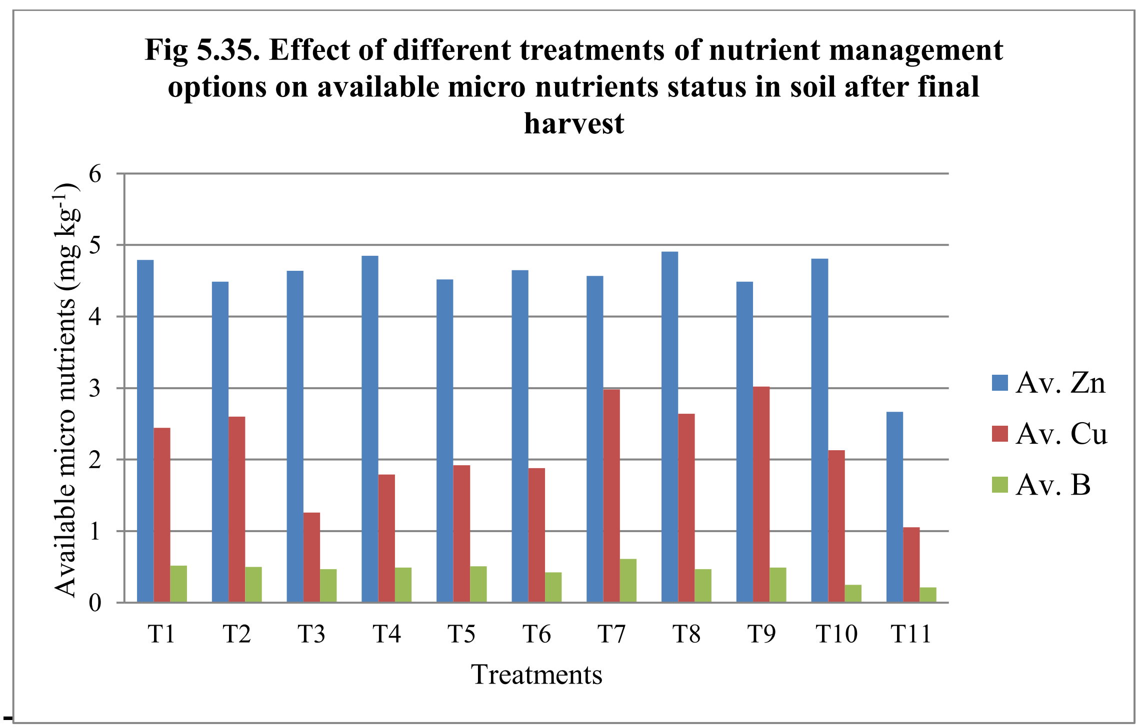
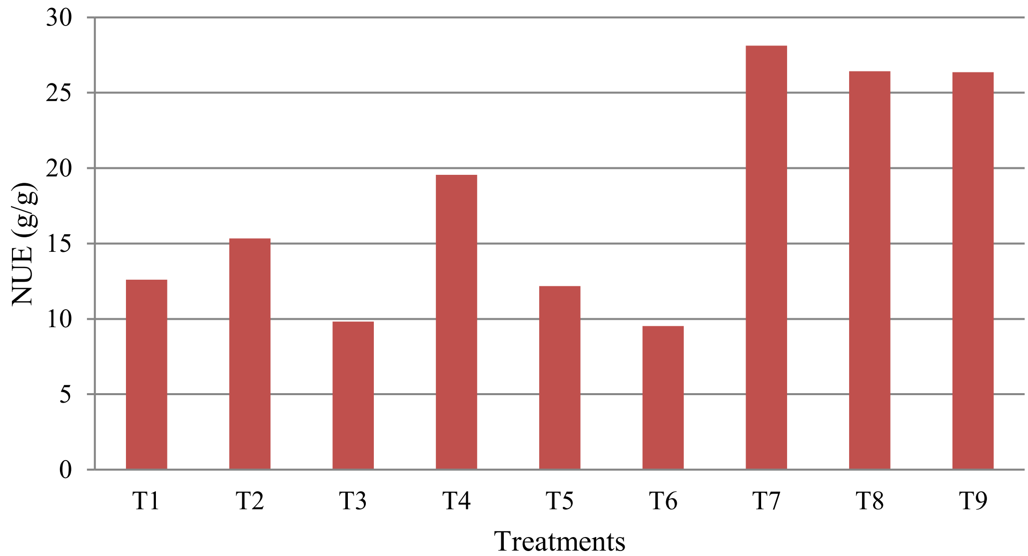


Fig 5.35. Effect of different treatments of nutrient management options on available micro nutrients status in soil after final harvest
Available micro nutrients (mg kg-1)
6
5
4
3
2
1
0
T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11
Treatments
Av. Zn
Av. Cu
Av. B

Fig 5.36. Effect of different treatments of nutrient management options on nutrient use efficiency by okra plant



Summary

6. SUMMARY

Experiment to evaluate the effect of fertilizer-manure block (organic matrix based slow release fertilizer) on growth and yield of okra was carried out at Regional Agricultural Research Station, Pattambi, Kerala Agricultural University. The objective of the experiment was to develop sustainable nutrient management strategy for okra through the use of slow release fertilizer-manure blocks. Fertilizer-manure block is a compacted organic matrix based fertilizer developed by mixing different organic/filler materials along with fertilizer nutrients. This study includes two experiments: laboratory incubation experiment and a pot culture experiment. The laboratory incubation study was conducted to select the best proportion (combination) of organic materials/fillers for developing slow release fertilizer. A slow release fertilizer will release nutrients slowly often synchronized with the physiological need of the crop and reduce nutrient loss and thus eliminate environment related problems.

Initially many number of trials were undertaken for formulating fertilizer manure blocks with different proportions of the component materials. Five combinations of organic materials/fillers was selected based on the shape retention and consistency of the fertilizer-manure blocks. The component materials used for developing fertilizer-manure blocks includes coir pith, cow dung, vermicompost, neem cake, groundnut cake, humic acid and zeolite. Using these in five different proportions fertilizer-manure blocks of 100 g size were formulated along with calculated quantities of fertilizers. Laboratory incubation study was undertaken to identify the best proportion of component materials for developing slow release fertilizer manure block based on the nutrient release pattern with respect to available nutrients such as N, K, P, Ca, Mg, S, Zn, Cu and B. The experiment was laid out in a completely randomized design with 6 treatments and 3 replications. *viz.,* T_1 (Proportion-1- Coirpith- 35%, Cowdung- 25%, Vermicompost-13%, Groundnutcake- 10%, Neem cake 10%, Zeolite- 2%, Humic acid- 5%), T_2 (Proportion-2- Coirpith- 35%, Cowdung- 22.5%, Vermicompost-18% , Groundnutcake- 7.5%, Neem cake 7.5%, Zeolite- 2%, Humic acid- 7.5%), T_3 (Proportion-3- Coirpith- 35%, Cowdung-

20%, Vermicompost-18%, Groundnutcake- 7.5%, Neem cake 7.5%, Zeolite- 2%, Humic acid- 10%), T_4 (Proportion-4-Coirpith- 35%, Cowdung- 20%, Vermicompost- 12.5%, Groundnutcake- 7.5%, Neem cake 7.5%, Zeolite- 5%, Humic acid- 12.5%), T_5 (Proportion-Coirpith- 40%, Cowdung- 30%, Vermicompost- 20%, Groundnut cake- 5%, Neem cake 5%), T_6 (sole fertilizer placement- check). The proportion-1 (Coir pith- 35%, Cow dung- 25%, vermicompost-13%, groundnut cake - 10%, neem cake - 10%, zeolite - 2%, humic acid- 5%) was selected as the best proportion due to its slow nutrient release pattern, as well as nutrient release pattern in synchronization with the physiological need of the crop. Fertilizer-manure block made with proportion-1 (T_1) had released 65 per cent of added N, 54 per cent Ca, 47 per cent S during 60 days of incubation, while almost 100 percent of applied K and Mg was released within these days. In the case of micro nutrients Zn and Cu have shown release of about 12 % and 32 % respectively whereas almost 100 percent boron was released within 60 days of incubation.

Effect of treatments showed significant influence on the available N, P, K, Ca, Mg, S, Zn, Cu, B content of the soil during different periods of incubation. The results of the incubation study reveals that, during the initial stages (up to 20 days) of incubation, the pattern of release was slow with respect to available N and K. Gradually the nutrient release was increased and highest N and K content was recorded at the later stages of incubation. A sustained release of N and K was recorded for the treatment T_1(proportion-1). Though the content of phosphorus is low during the initial stages of incubation there was an irregular trend with respect to phosphorus release. Lowest exchangeable calcium content was recorded for the soil treated with fertilizer-manure block than that of the sole fertilizer placement treatment (T_6) during the entire period of incubation. Exchangeable Mg content of the soil treated with fertilizer-manure block (T_1-T_5) were lower during the initial stages of incubation compared to the sole fertilizer placement treatment (T_6). But from 20 days of incubation onwards, the exchangeable Mg content of the soil treated with fertilizer-manure block showed an increasing trend reaching a maximum level than that of the sole fertilizer placement treatment (T_6). Treatments also exhibited a slow release trend with respect to micronutrients. The available Zn, Cu, and B contents of soil treated with fertilizer-manure blocks were lower than that of the sole fertilizer placement treatment throughout the incubation period. However, available secondary and micronutrients in soil were maintained at levels fairly above the respective critical limits throughout the incubation period.

Among the five different proportions of fertilizer manure blocks, proportion-1was selected due to its slow release characteristics in coherence with crop growth stages besides retaining its shape Moreover, it has the second lowest cost of production. Though fertilizer-manure block made of proportion-5 has lowest cost of production, it could not be selected because of the un- sustained release of nutrients

Pot culture experiment was conducted to identify the best package of application of the fertilizer-manure block in okra variety Arka Anamika as test crop. The pot culture experiment was laid down in a completely randomized design with 11 treatments and 3 replications *viz*., T_1 (Blocks of size 100 g with nutrients as per 100 % POP @ 1 block per grow bag, placed below the level of planting), T_2 (Blocks of size 100 g with nutrients as per 50 % POP@ 1 block per grow bag, placed below the level of planting), T_3 (Blocks of size 100 g with nutrients as per 25 %POP @ 1 block per grow bag, placed below the level of planting), T_4 (Blocks of size 25 g with nutrients as per 100 % POP @ 4 block per grow bag, placed on 4 sides of the plant at soil surface),T_5 (Blocks of size 25 g with nutrients as per 50 % POP @ 4 block per grow bag, placed on 4 sides of the plant at soil surface), T_6 (Blocks of size 25 g with nutrients as per 25 % POP @ 4 block per grow bag, placed on 4 sides of the plant at soil surface),T_7(T_3 + 50 % POP recommendation as top dressing), T_8 (Nutrients as per POP of KAU), T_9(Nutrients as per soil test based recommendation), T_{10} (Control - Organic manure as per POP of KAU),T_{11} (Absolute control).

In pot culture experiment, fertilizer-manure blocks showed significant influence on the growth and yield in okra. Days to flowering, number of fruits per plant, fruit yield per plant, length of fruits, girth of fruits, and number of seeds per fruit were significantly influenced by the fertilizer manure blocks. Application of nutrients as per general POP recommendation(T_8) took less days to flowering and on par with the treatments T_2, T_3, T_5, T_6, T_7, and T_9. Control and absolute control treatments took long days to flowering. However application of 25 % of the recommended nutrients as 100g fertilizer manure block and 50% of the recommended nutrients was given as topdressing (T_7) had more number of fruits per plant(20.70), fruit yield per plant(457.9 g), fruit length(17.90 cm), fruit girth (6.326 cm) as well as number of seeds per fruit(58.67). The treatment T_8 and T_9(soil test based recommendation)were found to be on par with treatment T_7 with respect to fruit yield per plant.

Fertilizer manure block had significant influence on the biometric parameters of okra such as, plant height, number of leaves per plant and number of branches per plant. Plant height and number of leaves per plant were recorded at 15 days interval from planting to final harvest. Plant height and number of leaves were higher for the plants received treatment T_7while the number of branches were on par with T_8 and T_9

Application of fertilizer manure blocks had significant influence on the available nutrient status of the post harvest soil (N, K, P, Ca, Mg, S, Zn, Cu, B). Highest available nitrogen content was recorded by the treatment T_1, T_4 and T_7 and were on par with T_2, T_5 and T_6. Lowest phosphorus content was recorded by the absolute control. Highest available potassium content was observed in the treatment T_4 (395.64 kg ha^{-1}) and it was on par with T_1 (386.57 kg ha^{-1}). Highest exchangeable calcium content was recorded in the treatment T_5 whereas highest exchangeable magnesium content was recorded by the treatments T_7 (424.96 mg kg^{-1}) which was found to be on par with the treatment T_1(418.0). Highest sulphur content was recorded by the treatment T_7 (18.01 mg kg^{-1}). In the case of micro nutrients highest zinc, copper and boron content was recorded by the treatments T_1, T_9, and T_7 respectively.

Application of fertilizer-manure blocks showed significant influence on nutrient uptake by the crop. Highest nitrogen uptake was recorded by the application of soil test based recommendation (T_9) and lowest by the absolute control (T_{11}). Highest phosphorus and potassium uptake was recorded in T_7. The highest calcium uptake was observed in the treatment T_9 and it was on par with T_8 whereas highest magnesium uptake was recorded in the treatment T_7 and T_9. In the case of micronutrients, highest zinc and copper uptake was recorded in treatment T_7 which received 25% of the recommended nutrients as 100g fertilizer-manure block and 50 % of the nutrients as topdressing, whereas the highest boron content was recorded in the treatment T_9 (soil test based recommendation).

By using fertilizer-manure blocks nutrient use efficiency (Agronomic efficiency) was improved. The highest nutrient use efficiency was recorded by the treatment T_7 (28.12) which received 25 % of recommended nutrients as 100g fertilizer-manure block and 50 % of the nutrients as topdressing whereas treatments T_8 (General POP recommendation) and T_9 (Soil test based POP recommendation) have recorded nutrient use efficiency of about 26.42 and 26.38 respectively. Results of the economic analysis reveals that, highest B:C ratio was recorded by the treatment T_8 (1.41) followed by T_9 (1.40) and T_7 (1.26). Since B:C ratio greater than one is economical , the treatments T_7, T_8, and T_9 were considered as economically feasible.

Results of this study revealed that fertilizer-manure blocks are efficient and sustainable nutrient management technology in comparison with general POP recommendation. Twenty five per cent reduction in the recommended dose of nutrients was achieved by using fertilizer-manure blocks. Among various treatments, application of 25% of the recommended nutrients applied in the form 100g fertilizer-manure block and 50 % as topdressing 1 month after planting (T_7) was the best treatment which produced highest yield (457.9 g/plant), high nutrient use efficiency (28.12 g/g), with B:C ratio of 1.26 and saves 25% of the recommended nutrients(the component materials used for developing fertilizer-manure blocks also act as nutrient source). Thus, fertilizer-manure block is a slow release fertilizer capable of ensuring hiegher productivity, long term nutrient availability and reduced fertilizer load in the soil by improving nutrient use efficiency.

Future line of work

- Studies can be undertaken to standardize controlled release fertilizer-manure formulations in open field conditions and in various crops including long duration crops.

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Abstract

PILOT TESTING OF FERTILIZER-MANURE BLOCKS IN OKRA

(*Abelmoschus esculentus* L. Moench.)

By

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ABSTRACT OF THESIS

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ABSTRACT

The present study entitled "Pilot testing of fertilizer-manure blocks in Okra (*Abelmoschus esculentus* L. Moench.)" was undertaken at Regional Agricultural Research Station Pattambi. The objective was to develop fertilizer-manure blocks for okra (organic matrix based compacted slow release fertilizer). The study include two experiments, laboratory incubation study and a pot culture experiment. The laboratory incubation study was conducted to select the best proportion of organic materials for developing fertilizer-manure block based on the nutrient release pattern. Pot culture experiment was conducted to identify the best package of application of the fertilizer-manure block.

In the experiment-I fertilizer manure blocks were developed by mixing organic materials such as coir pith, cow dung, vermicompost, neem cake, ground nut cake, humic acid and zeolite powder in five different proportions along with per plant recommended dose of nutrients calculated based on KAU-POP recommendations. The five different proportions were as fixed based on the shape retention and consistency of the product. The fertilizer manure blocks in five different proportions (treatments T_1-T_5) and sole fertilizers (T_6) were incubated in soil up to 60 days. Destructive soil sampling was done and analyzed for available N, P, K, Ca, Mg, Zn, Cu, and B and nutrient release kinetics during the incubation period was studied.

The results of the incubation study revealed that, fertilizer-manure blocks made of all five proportions (treatments T_1-T_5) showed slow release pattern with respect to various nutrients as compared to sole fertilizer placement. Fertilizer-manure block made with proportion-1 (T_1) had released 65 per cent of applied N, 54 per cent Ca, 47 per cent S at 60 days of incubation, while almost 100 percent of applied K and Mg was released within these days. In the case of micro nutrients Zn and Cu had released 12 per cent and 32 per cent of their contents respectively, whereas almost 100 percent born was released within 60 days of incubation. When compared among the different fertilizer-manure blocks, treatment T_1 (proportion-1) exhibited slow release behavior to a greater extent and

synchronization with physiological need of the tested crop, low cost of production and hence, was selected for the conduct of the pot culture experiment.

In pot culture study fertilizer- manure blocks were prepared in two dimensions (100 g and 25 g) using three dosage of fertilizers (100 per cent POP, 50 per cent POP, and 25 per cent POP). Okra variety Arka Anamika was used as the test crop. The experiment consisted of 11 treatments with 3 replications such as T_1 : Blocks of size 100 g with nutrients as per 100per cent POP @ 1 block per grow bag, placed below the level of planting, T_2 : Blocks of size 100 g with nutrients as per 50per cent POP @ 1 block per grow bag, placed below the level of planting, T_3:Blocks of size 100 g with nutrients as per 25 per cent POP @ 1 block per grow bag, placed below the level of planting, T_4 : Blocks of size 25 g with nutrients as per 100 per cent POP @ 4 blocks per grow bag, placed on 4 sides of the plant at soil surface, T_5 : Blocks of size 25 g with nutrients as per 50 per cent POP @ 4 blocks per grow bag, placed on 4 sides of the plant at soil surface, T_6 : Blocks of size 25 g with nutrients as per 25 per cent POP @ 4 blocks per grow bag, placed on 4 sides of the plant at soil surface, T_7 : T_3 + 50 per cent POP recommendation as top dressing, T_8 : Nutrients as per general POP of KAU, T_9 : Nutrients as per soil test based POP recommendation, T_{10} : Control(Organic manure as per POP of KAU) and T_{11} : Absolute control.

Fertilizer-manure blocks showed significant effect on growth and yield of okra. Days to flowering, number of fruits per plant, fruit yield per plant, length of fruits, girth of fruits, and number of seeds per fruit were significantly influenced by the treatments. Treatment T_8 (nutrients as per general POP recommendation) had recorded lowest value for days to flowering which was found to be on par with the treatments T_2, T_3, T_5, T_6, T_7, and T_9. Treatment T_7 had recorded more number of fruits per plant (20.70), fruit yield per plant (457.9 g), fruit length (17.90 cm), fruit girth (6.326 cm) as well as number of seeds per fruit (58.67). Treatment T_8 and T_9 (soil test based recommendation) were found to be on par with treatment T_7 with respect to fruit yield per plant. Taller plant and more number of leaves were recorded for the treatment T_7 while the number of branches were on par with the treatments T_8 and T_9.

Application of fertilizer manure blocks had shown significant influence on the available nutrient status of the post harvest soil (N, K, P, Ca, Mg, S, Zn, Cu, B). Highest available nitrogen content was recorded in the treatment T_1, T_4 and T_7 which was found to be on par with the treatments T_2, T_5 and T_6. Lowest phosphorus content was recorded in the absolute control treatment. Highest available potassium content was recorded in the treatment T_4 (395.64 kg ha $^{-1}$) and it was on par with that in treatment T_1 (386.57 kg ha^{-1}). Highest available calcium content was recorded in the treatment T_5 whereas highest available magnesium content was recorded in the treatments T_7 (424.96 mg kg^{-1}) which was found to be on par with the treatment T_1(418.0). Highest sulphur content was recorded in the treatment T_7 (18.01 mg kg^{-1}). In the case of micro nutrients highest zinc, copper and boron content was recorded in the treatments T_8, T_9, and T_7 respectively.

Application of fertilizer-manure blocks showed significant influence on nutrient uptake by the crop. However, highest nitrogen uptake was recorded in the treatment T_9 and lowest in T_{11}. Highest phosphorus and potassium uptake was recorded in the treatment T_7.

The use of fertilizer-manure blocks made with Coirpith- 35%, Cowdung- 25%, Vermicompost-13%, Groundnut cake- 10%, Neem cake 10%, Zeolite- 2%, Humic acid- 5% in 100g size containing 25% of the recommended dose of nutrients placed 5cm below the level of planting and top dressing of 50% of KAU POP recommendation improved okra growth and yield in grow bags and saved 25% of the fertilizers in comparison with POP recommendation.