ORGANIC MANURE SEED PELLETING FOR ENHANCING SOIL HEALTH AND PRODUCTIVITY OF RICE

by

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(2017-11-046)

THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM - 695 522

KERALA, INDIA

2019

DECLARATION

I, hereby declare that this thesis entitled **"ORGANIC MANURE SEED PELLETING FOR ENHANCING SOIL HEALTH AND PRODUCTIVITY OF RICE"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title, of any other University or Society.

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ACKNOWLEDGEMENT

First of all, I bow my head before the Almighty for making me confident and optimistic throughout my journey and enabled me to complete the thesis work successfully on time.

With immense pleasure, I wish to express my sincere gratitude and indebtedness to Dr. Biju Joseph, Assistant Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, and the Chairperson of my Advisory Committee for his valuable suggestions, diligent assistance and co-operation throughout the investigation.

I am indebted to Dr. K. Ushakumari, Professor and Head, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani and member of Advisory Committee, for her valuable advice and whole hearted approach for the successful completion of the thesis.

I am extremely thankful to Dr. P. Babu Mathew, Professor, Department of Agronomy, College of Agriculture, Vellayani, and a member of Advisory Committee for the support, constant criticism and valuable suggestions rendered during research work.

I express my gratitude to Dr. R. Gladis, Assistant Professor, Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani and a member of Advisory Committee for her encouragement throughout the period of my research work.

I extend my gratefulness to my teachers in the Department of Soil Science and Agricultural Chemistry, Dr. Usha Mathew, Dr. K. C. Manorama Thampatti, Dr. Rani B., Dr. B. Aparna, Dr. Naveen Leno and Dr. Meera A. V. for their teaching and guidance which enabled me to complete my course work. I owe my deepest gratitude to Visveswaran Sir and Gowri Priya mam for their valuable advices.

I express my immense gratitude to Dr. Sam T. Kurumthottickal, Dr. P. B. Usha and Dr. Sudharmaidevi C. R. Rtd. Professors and Head, Department of Soil Science and

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Agricultural Chemistry, College of Agriculture, Vellayani for their valuable advice during my course of study.

I place on record sincere gratitude to Dr. Sajitha Rani T, Professor, Instructional Farm, Vellayani, for her timely help and whole hearted approach right from the beginning of the thesis work.

I duly acknowledge the encouragement, help, love and moral support by my dear class mates Kavya, P R, Rehana, Vava, Aswathy, Navi, Ramesha, Chethan and Adithya.

With immense pleasure, I would like to express my sincere gratitude and love to my dearest seniors Pinky mol, Nibin chettan, Lakshmi chechi and Amala chechi for the splendid and stimulating guidance, kind treatment, abundant encouragement, moral support, constant inspiration, extreme patience and valuable suggestions, which rendered me to accomplish the research work completely.

I wish to express my heartful thanks to my dear seniors Nihala itha, Kari chechi, Mitra chechi, Dhanamol, Manasakka, Geethu chechi, Pooja chechi, Daly chechi, Shamsitha, Sreekuttan, Elizabeth chechi, Ishratha, Sheeba chechi, Gritta chechi, Rekha chechi, Shreya chechi, Greeshma chechi, Chinju chechi, Dhanesh eattan, Anjana chechi, Anumon, Nivya chechi, Anju chechi, Nitish eattan, Nyshanth eattan and Arunjith eattan for their affection, kind help and big hearted support offered during my thesis work.

Words are scarce to express my deep sense of gratitude to Biju chettan, Aneesh eattan, Anil eattan, Vijayakumar chettan, Sreekumar chettan, Sowmya chechi, Asha chechi and Shiny chechi. for their timely help and support during the lab work.

I am greatly thankful to Anoop eattan, Abhilash eattan, Rejash eattan and Sandeep eattan for their assistance in the conduct of experiment.

It would be unfair if I do not convey my special, deep felt affection and gratitude to all my friends of Horticos family, especially Aagneya boys and girls. A very special thanks to Chriz, Dundu, M R, Jyothi and Kinni for being the best batchmates, for their love, support and affection.

My loving gratitude to Amal, Anand, Alan, Melvin, Sooraj, Manikantan, Mappan, Govind, Sayu, Anju, Susan, Reni, Anki, S, Ponni, Golmei, LGA, Shilpa, Binsitha, Neetumol, Nasreena and all other friends of PG 17 batch for their help and care and for the happiest moments we cherished together. I also extend my heartfelt thanks to dear juniors.

I am thankful to Kerala Agricultural University for the technical and financial assistance for carrying out my study and research work. I would like to express my thanks to Librarian and library staffs of COA, Vellayani, for their support and assistance during the study period.

It would be impossible to list out all those who have helped me in one way or another in successful completion of this work. I once again express my heartful thanks to all those who helped me in completing this venture in time.

Mere words cannot express my profound indebtedness to my beloved father Rajendrakmar M. C., mother Ajithakumari A. and Kannan chettan for their unconditional love, sacrifices, prayers and support bestowed on me during my hard periods.

Anagha R.

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LIST OF ABBREVIATIONS

%	-	Per cent
^{0}C	-	Degree Celsius
B	-	Boron
BGA	-	Blue Green Algae
C	-	Carbon
Ca	-	Calcium
CEC	-	Cation Exchange Capacity
CD	-	Critical Difference
Cm	-	centimetre
cm^2	-	square centimetre
Cu	-	Copper
DAP	-	Diammonium phosphate
DAS	-	Days After Sowing
dS m^{-1}	-	deci Siemens per meter
EC	-	Electrical Conductivity
et al.	-	and other co workers
Fe	-	Iron
Fig.	-	Figure
FYM	-	Farmyard Manure
G	-	gram
g kg^{-1}	-	gram per kilogram
g $plant^{-1}$	-	gram per plant
g pot^{-1}	-	gram per pot
GRD	-	General Recommended Dose

K	-	Potassium
Kg	-	kilogram
kg ha^{-1}	-	kilogram per hectare
LAI	-	Leaf Area Index
Mg	-	Magnesium
Mg	-	milligram
Mg ha^{-1}	-	Megagram per hectare
mg kg^{-1}	-	milligram per kilogram
Mg m^{-3}	-	Megagram per cubic metre
Ml	-	millilitre
ml kg^{-1}	-	millilitre per kilogram
Mn	-	Manganese
MSL	-	Mean sea level
N	-	Nitrogen
No.	-	Number
NS	-	Non-significant
P	-	Phosphorus
pH	-	Negative logarithm of hydrogen ions
Ppm	-	parts per million
RDF	-	Recommended Dose of Fertilizers
S	-	Sulphur
SEm (±)	-	Standard error
Si	-	Silicon
sp.	-	species
T	-	tonnes

t ha^{-1}	-	tonnes per hectare
VAM	-	Vesicular Arbuscular Mycorrhizae
viz.	-	namely
WHC	-	Water holding capacity
Zn	-	Zinc

INTRODUCTION

1.INTRODUCTION

Rice (*Oryza sativa* L.), the staple food crop of the world, serves half of the population wholly or partially (FAO, 2009). China has the largest share in world rice production with an annual production of 208.10 million metric tons followed by India with 169.50 million metric tons. In Kerala, the area under rice cultivation is 1.98 lakh hectares with a total production of 5.77 lakh tonnes and a productivity of 2.92 tonnes per hectare (GoK, 2018).

There is a drastic decrease in area under rice cultivation, particularly, wet land, mainly due to high cost of cultivation, more resource requirement, utilization of land for construction work and preference towards cash crops. Generally, rice cultivation utilizes about 60 per cent of total available irrigation water and the exploitation of water can be checked by growing rice with less water. Upland rice cultivation is gaining recognition among farmers as the requirement of water and labour is less. There lies the importance of aerobic rice, which is grown similar to upland crop. Here, the soil is unpuddled, non-flooded or saturated and requires only 30-50 per cent less water than flooded lowland rice (Bouman *et al.*, 2005). Nowadays, aerobic rice cultivation is gaining popularity among farmers.

Farmers generally practice conventional rice cultivation methods such as transplanting, broadcasting and dibbling. Though these methods are widely acceptable among farmers, they often have some limitations. The rutted germination in broadcasting leads to overcrowding and the arbitrary transplanting method make it arduous to maintain optimum plant density. Direct seeding leads to a substantial loss of seeds, non-uniform germination and thereby yield reduction. The above limitations can be overcome by seed treatment methods such as pelleting.

Seed pelleting is a technique of seed encapsulation with inert materials to change their size and shape (Jyoti and Bhandari, 2016). It involves the sticking of target materials on to the surface of seeds. Pelleting increases the weight, size and shape of seed thereby reducing seed rate and improves germination. Pelleted seeds make planting of small seeds much easier by altering their shape, size and density thus expediating the evasion of seed herding (Komala *et al.*, 2018).

Seed pelleting can be effectively used in semi wet soil conditions and transplanting can be replaced with dropping which is labour saving without compromising on productivity. Seed pelleting aid in rigorous application of nutrients and accelerate germination and seedling emergence (Bharathi *et al.,* 2003) which is beneficial over conventional dibbling method.

Seed pelleting increases seedling quality and reduces transplanting cost (Govinden and Levantard, 2008). It stimulates the micro environment of seed by providing growth promoting substances and preclude the loss of materials as in broadcasting. Seed pelleting increases tillering with more shoot and root biomass, makes the plant tolerant to abiotic stress and improves yield.

Soil application of fertilizers is very easy but involves high application cost. Nutrient unavailability by fixation or loss through leaching leads to accumulation of nutrients insitu or elsewhere at toxic level resulting in environmental pollution. Ecologically sound management practices have to be adopted to surmount this and one such approach is organic farming. Application of organic manures for increasing soil fertility has gained importance in recent years (Meena *et al.,* 2013). Organic farming efficiently addresses soil management by increasing the soil nutrition and plant growth (Reganold *et al.*, 1993).

The call out on organic farming explains the requisite of user friendly and ecofriendly technique for seed management practices. Farmers use several organic sources with varying levels of nutrients. For standardizing their recommendation, it is necessary to evaluate different sources of organic manures. A number of practices are adopted by farmers themselves to achieve successful crop production in organic agriculture. One such practice is seed pelleting using organic manures.

Organic manure seed pelleting method is gaining popularity among farmers. Numerous studies have been done on seed pelleting in various crops, but there are only a few works on seed pelleting of rice using organic manures. Hence, there is an urgent need to scientifically validate this method.

With this background, a study entitled "Organic manure seed pelleting for enhancing soil health and productivity of rice" was undertaken with the following objectives:

- To develop seed pellets of rice using organic manures and microbial inoculants
- To study the effect of seed pelleting on soil properties, seedling vigour, growth and yield of rice variety Uma

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

A study entitled 'Organic manure seed pelleting for enhancing soil health and productivity of rice' was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani from October 2018 to February 2019. The objective of the study was to develop seed pellets of rice using organic manures and microbial inoculants and to study its effect on soil properties, seedling vigour, growth and yield of rice. This chapter deals with a concise review of related literature on the study.

2.1 RICE

Rice, under the family poaceae, is a short duration crop that grows in semiaquatic situation. Rice crop grows well in regions having adequate moisture and optimum temperature. It can be grown in low land and upland conditions. Biotic and abiotic factors such as light, temperature, rainfall, soil as well as nutrients affect the overall growth and development of rice (FAO, 2009).

Nowadays the limited area under rice cultivation due to lack of land, non-availability of water and exploitation of wetlands for other uses has compelled shifting from wetland rice to upland rice. Aerobic rice cultivation is also gaining popularity for increasing the productivity.

2.2 SEED PELLETING

Seed pelleting, the practice of seed encapsulation with inert materials to change their size and shape, involves the sticking of target materials on to the surface of seeds. Pelleting increases the weight, size and shape of seed and in this manner, reduces the seed rate and improves germination (Geetha and Balamurugan, 2011). Seed pelleting helps in modifying seed shape, surface properties, density and size facilitating seed singulation which avoids seed crowding (Komala *et al.*, 2018).

Pelleted seeds make planting of small seeds easier to a great extent. In seed pelleting, seeds are encircled with small amount of immobile material fairly large to develop a globular unit to aid precision planting. The inert materials establish natural water holding media and thus nutrients are made available to young seedlings (Krishnasamy, 2003). According to Vanangamudi *et al.* (2003), seed pelleting facilitates exact application of nutrients reducing their wastage.

Govinden and Levantard (2008) suggested that seed pelleting improves the structure of seed. It strengthens seed quality by advancing seedling value thereby diminishing the transplanting cost.

Pelleting advances the chances of successful germination and establishment of seedling under wide range of field conditions (Bharathi *et al.,* 2003). Seed pelleting assists in providing required materials for better and uniform emergence of crops. Nutrient pelleting supplements the rhizosphere region with macro and micronutrients that stimulate the vegetative growth of seedling besides the improvement in microbial activity (Suma, 2005).

Ponnuswamy and Vijayalakshmi (2011) inferred that seed when treated with inorganic nutrients, plant growth regulators, plant protectants and bio-inoculants increased the yield attributes of crops.

2.2.1 Seed pelleting on germination per cent and seedling vigour

Kuppuswamy *et al.* (1992) reported that green gram seeds pelleted with 50 per cent biodigested slurry recorded highest seed germination (98.4 %) due to availability of nitrogen.

Jeyabal and Kuppuswamy (1999) found that seedling length of rice seeds coated using biodigested slurry, zinc sulphate, *Azospiriullum*, Phosphobacteria and phytohormone improved when compared with control.

Arati (2000) observed that pelleting of chickpea seeds with pongamia leaf powder at 5g kg^{-1} registered higher germination, root length, shoot length and vigour index compared to control and this might be due to phytostimulatory effect of pongamia leaf powder.

Begam (2001) stated that black gram seeds when pelleted with DAP (120 g kg^{-1} seed), *Trichoderma viridae* (4g kg^{-1} seed) and *Rhizobium sp.* considerably increased the germination per cent and seedling length. When pulse seeds were treated with 3 g kg^{-1} thiram, thiram + carbendazim at 1:1 (3 g kg^{-1}) and 6 g kg^{-1} *Trichoderma viridae,* germination per cent and seedling vigour were enhanced (Krishna *et al*., 2003).

Treatment of cowpea seeds with neem leaf powder (5 g kg^{-1}) resulted in higher germination and vigour index over control due to the antistressor and insecticidal properties of neem leaves (Maraddi, 2002).

Nelsonnavamaniraj *et al*. (2002) found that tamarind seeds pelleted with fly ash enhanced the germination per cent (85 %), root length (18.12 cm), shoot length (10.56 cm) as well as dry weight of root and shoot due to the presence of nutrients in fly ash.

Kavitha *et al.* (2009) opined that pelleting of chilli seeds with botanicals at 100 g kg^{-1} and storage under cold condition resulted in maximum viability and vigour as botanicals contain growth promoting substances.

The research on mustard seed pelleting with botanicals (*Pungam, Prosopis, Arappu* and *Vasambu*), biofertilizers (*Azospirillum*, Phosphobacteria and *Rhizobium*), charcoal and wood ash shown that germination per cent, shoot and root length as well as vigour index of seeds pelleted with *Azospirillum* increased and this might be attributed to the production of cytokinin which influence cell division (Geetha and Balamurugan, 2011).

According to Suma *et al*. (2014) sesame seeds recorded higher germination per cent and higher seedling vigour when pelleted with *Azospirillum*.

According to Ananthi *et al.* (2015) red gram seeds hardened with 100 ppm $ZnSO_4$, polymer coating using imidacloprid 1ml kg^{-1}, bavistin 2g kg^{-1} and biofertilizers such as *Rhizobium* and *Pseudomonas fluorescence* (both 10 g kg^{-1}) recorded higher germination per cent.

Okra and chilli seeds pelleted with 300 g kg^{-1} *Annona squamosa* and *Albizzia amara* recorded higher germination, shoot length, root length and seedling vigour over control and this might be due to the presence of phenols in leaves of *Annona squamosa* and *Albizzia amara* (Kumar and Muthukrishnan, 2015).

Kiran *et al.* (2016) observed higher germination, seedling length and vigour index in sunflower seeds pelleted with 2 per cent $ZnSO_4$.

Seedling studies of onion seeds pelleted with cow dung, vermicompost and clay powders using polyvinyl alcohol and methyl cellulose as adhesives showed that germination per cent and vigour index of pelleted seeds were similar to non-pelleted seeds (Yogeesha *et al.*, 2017).

Narayanan *et al.* (2017) reported that pelleting of black gram seeds with combination of $MgSO_4$, polykote, carbendazim, dimethoate, *Pseudomonas fluorescence*, *Rhizobium*, Azophos and DAP registered highest germination per cent, root length, shoot length and vigour index and this could be due to fortification of seeds with combined seed treatments.

2.2.2 Seed pelleting on growth parameters

Pelleting using combination of vermicompost, micronutrient mixture biofertilizers and DAP and resulted in higher plant height and number of leaves in onion (Ahamedraza, 1997).

According to Begam (2001) tallest plant and maximum dry matter production were obtained for black gram seeds pelleted with DAP (120 g kg^{-1} seed) along with *Rhizobium sp.* and *Trichoderma viridae* (4 g kg^{-1} seed).

Susan *et al.* (2005) observed that leaf area, chlorophyll content, plant height and dry matter content of maize were elevated when seeds were pelleted with DAP (30 g), carbendazim (2 g), polykote (3 g), imidacloprid (1 ml) and micronutrient mixture (19.7 g).

Prakash *et al.* (2012) reported that pelleting of black gram seeds with fly ash (200 g kg^{-1}) recorded tallest plant, maximum number of branches $plant^{-1}$ and other growth parameters and this could be due to different nutrients present in fly ash.

Abusuwar and Eldin (2013) revealed that alfalfa seeds pelleted with FYM found to be superior in plant density, number of leaves and productivity compared with seeds pelleted with clay and control. Abusuwar and Daur (2015) reported that alfalfa seeds pelleted with cow manure and poultry manure along with *Rhizobium* enhanced forage production. Presence of nutrients in these manures could have supported enhanced growth.

Prakash *et al.* (2014a) concluded that treatment of aerobic rice seeds with 250 g kg^{-1} fly ash resulted in enhanced plant growth characteristics such as plant height, leaf area and root weight. Prakash *et al.* (2014b) reported that there was enhancement in growth and photosynthetic rate for sesame seeds pelleted with fly ash at 250 g kg^{-1} with rice gruel.

Kiran *et al.* (2016) reported that sunflower seeds when pelleted with 2 per cent $ZnSO_4$ exhibited significant increase in plant height at 30, 60 and 90 DAS. This might be due to the role of $ZnSO_4$ in improving N and P uptake by plants.

Narayanan *et al.* (2017) reported that pelleting of black gram seeds with combination of $MgSO_4$, polykote, carbendazim, dimethoate, *Pseudomonas fluorescence*, *Rhizobium*, Azophos and DAP reported maximum values for growth parameters such as plant height, number of branches $plant^{-1}$ and dry matter production. Fortification of seeds would have led to an increase in root volume which might have increased the availability of water and nutrients.

2.2.3 Seed pelleting on yield and yield attributes

Jeyabal *et al.* (1992) observed that in soyabean, seeds coated with biodigested slurry 50 per cent, superphosphate 2 per cent, Bradyrhizobium 2 per cent and Phosphobacteria 2 per cent improved grain yield due to the enhanced availability of N and P.

Soyabean seeds pelleted with biogas slurry at 500 g kg^{-1} improved seed yield and quality (Narasimhaprasad, 1994).

Ahamedraza (1997) found that bulb yield of onion pelleted with vermicompost, biofertilizers, DAP and micronutrient mixture increased.

Meera (1998) concluded that high yield was obtained in cowpea seeds treated with vermicompost when used as a bioinoculant due to increased availability of N and P.

According to Ahmed (1999) pelleting using biodigestable slurry + biofertilizers + carbendazim resulted in higher yield of black gram.

Umrani *et al.* (2003) observed that green gram pelleted with DAP + $ZnSO_4$ + prosopis leaf extract recorded higher field emergence as compared to control.

Soyabean seeds pelleted with botanicals as filler materials along with fungicide exhibited maximum yield (Supreetha, 2004).

Saha *et al.* (2007) reported that panicle $hill^{-1}$, filled grains $panicle^{-1}$ and grain yield of rice recorded highest values when applied with 75 per cent RDF and pelleted form of organic manure (0.4 t ha^{-1} biomax). This might be attributed to the slow release of nutrients leading to higher availability.

According to Masuthi *et al.* (2009) pelleting with arappu leaf powder increased number of pods $plant^{-1}$ while maximum pod girth was obtained when pelleted with $ZnSO_4$ and arappu leaf powder.

Geetha and Balamurugan (2011) reported that mustard seed pelleting with *Azospirillum* enhanced field emergence.

Geetha and Bhaskaran (2013) concluded that pelleting ragi seeds with DAP at 30 g kg^{-1}, micro nutrient at 20 g kg^{-1} and arappu leaf powder at 300 g kg^{-1} enhanced field emergence, productive tiller, fingers ear $head^{-1}$ and seed yield.

Aerobic rice seeds treated with 250 g kg^{-1} fly ash recorded highest yield parameters such as number of productive tillers $plant^{-1}$, number of grains $panicle^{-1}$, 1000 grain weight and grain yield over other treatments and control (Prakash *et al.*, 2014a). Prakash *et al.* (2014b) obtained high yield in sesame when pelleted with fly ash at 250 g kg^{-1} with rice gruel. This might be due to the activation of enzymes of seed by the addition of fly ash.

According to Kiran *et al.* (2016), sunflower seeds when pelleted with 2 per cent zinc sulphate showed an enhancement in yield parameters like head diameter, number of filled seeds, seed recovery and seed yield $plant^{-1}$.

Sujatha and Ambika (2016) reported that black gram seeds pelleting with polymer layer (3 ml kg^{-1}), carbendazim (2 g kg^{-1}), imidachloprid (2 g kg^{-1}), *Trichoderma viridae* (4 g kg^{-1}) and *Azospirillum lipoferum* (40 g kg^{-1}) enhanced seed yield and harvest index.

Yogeesha *et al.* (2017) revealed that onion seeds pelleted with vermicompost, cow dung and clay powders with methyl cellulose and polyvinyl alcohol as adhesives gave better bulb yield (31.81 t ha^{-1}) than non-pelleted (27.85 t ha^{-1}).

2.3 CHARACTERIZATION OF ORGANIC MANURES

2.3.1 Nutritional properties of organic manures

The easily available organic source FYM provides the major and micronutrients. It contains 0.5 per cent N, 0.2 per cent P_2O_5 and 0.5 per cent K_2O and favours the plant growth and development (Khan *et al.*, 2010).

Vermicompost can be used as soil conditioners as well as media for plant growth as they exhibit porosity, aeration, WHC, proper drainage and microbial activity (Arancon *et al.*, 2008). Vermicompost contain N, P, K, Ca and Mg in plant available form. It acts as chelating agent and provides micronutrients and has 1.5 - 2.2 per cent N, 1.8 - 2.2 per cent P and 1 -1.5 per cent K (Moghadam and Shoor, 2013).

Biogas slurry has 93 per cent water, 7 per cent dry matter, 4.5 per cent organic matter and 2.5 per cent inorganic matter. Alam (2006) reported that bioslurry provide macro and micro nutrients. Khan *et al.* (2014) characterized bioslurry and reported that pH was 7.9, total N, P and K were 2.1 per cent, 1.1 per cent, and 0.98 per cent respectively and micronutrients like Fe, Cu, Mn, and Zn were 0.34 ppm, 0.004 ppm, 0.088 ppm and 0.023 ppm respectively. Compared to FYM, bioslurry is likely to have more nutrients which is plant available. NPK content of bioslurry is 1.5 per cent, 1.1 per cent and 1 per cent respectively (Kumar *et al.*, 2015).

Fly ash has minimal bulk density, hydraulic conductivity and specific gravity. It is a source of macro and micro nutrients such as P, K, Ca, Mg, S and several micronutrients. It also contains toxic and trace elements (Basu *et al.*, 2009). Patel *et al.* (2018) described that fly ash, fine powder which is coloured grey usually, consists of considerable amount of SiO_2, Al_2O_3 and CaO.

2.3.2 Enzymatic activity of organic manures

Enzymes play an important role in decomposition of organic matter, formation of humus and nutrient cycling and occur as intracellular or extracellular (Sinsabaugh *et al*., 1991).

According to Carpenter-Boggs *et al.* (2000) microbial biomass, respiration and dehydrogenase activity increased with addition of compost. Tate (2000) reported that organic manures supply C as well as energy for multiplication of microbes thereby enhancing enzymatic activities. Kanchikerimath and Singh (2001) found that application of manure increases the organic matter content increasing enzymatic activity. According to Mandal *et al.* (2007) improvement in organic matter content and microbial biomass carbon due to addition of manures and nutrients resulted in higher enzymatic activity. Zhen *et al*. (2014) observed that there was considerable increase in the quantity of microorganisms and microbial biomass due to application of organic manure thereby supporting soil respiration and enzyme activities. Enzymatic activity is a sign of microbial dynamics and is higher in organic manure (Subramanian *et al.,* 2016).

Díaz-Marcote and Polo (1995) revealed that urease activity enhanced with the addition of compost. Chang *et al.* (2007) reported that presence of organic matter and microbial population increased urease activity.

According to Martens *et al*. (1992) acid phosphatase activity was sustained with organic manure application. Dodor and Tabatabai (2003) found that higher organic C content promoted phosphatase activity.

Masciandaro *et al.* (1994) opined that dehydrogenase activity indicate overall microbial load and application of compost significantly influenced dehydrogenase activity.

2.3.3 Organic acid content of organic manures

Humic substances are classified as humic and non-humic substances. The characteristic feature of humic substance is their capability to react with metal ions, oxides, hydroxides, mineral and organic compounds. Humic acids have high molecular weight, black to brown in colour, soluble at high pH and insoluble in acidic condition. Humic acids are the major extractable component of humic substances. Low molecular weight portion of humic substance, known as fulvic acid, is obtained after separation of humic acid by acidification, which are soluble in water at alkaline and acidic pH. The colour of fulvic acids vary from light yellow to brown in colour (Stevenson, 1994).

Humic substances have the ability to promote germination as well as root, leaf and shoot growth of crop (Arancon *et al.*, 2006). According to Muscolo *et al.* (2007) humic substance control various mechanisms involved in plant growth and nutrient uptake.

Yang *et al.* (2004) observed that application of organic substances increased the amount of humic substances and the content of humic acid was greater than that of fulvic acid (Watanabe *et al.*, 2007). Gathala *et al.* (2007) found that there was an increase in content of humic acid and fulvic acid when organic amendments were added.

Bioslurry when digested comprise organic form of nitrogen and substances having low molecular weight such as humic acid and vitamins (Liu *et al.*, 2008).

Zhang and Dousen (2002) observed that addition of vermicompost increased humic substances due to supplementary decomposition releasing humic fractions. Pramanik *et al.* (2007) revealed that humic acid obtained from vermicompost resulted in development of maize roots. Application of different vermicomposts significantly enhanced the humic substances in soil (Lakshmi *et al.*, 2013). Adak *et al.* (2014) suggested that humic substances in vermicompost perform the role of buffering agent for soil pH.

2.4 EFFECT OF ORGANIC MANURES ON GROWTH AND YIELD

2.4.1 Effect of FYM on growth and yield

Significant increase was recorded in yield and yield characters of rice when treated with 10 t ha^{-1} FYM (Verma *et al.*, 2001). Sharma and Sharma (2002) inferred that application of FYM at 10 t ha^{-1} increased the grain yield of rice-wheat system.

Satyanarayana *et al.* (2002) reported that combined application of FYM in rice with 120: 60: 45 kg N: P_2O_5: K_2O ha^{-1} resulted in more tillers, grains $panicle^{-1}$, 1000 grain weight and better yield. A study by Sharma (2013) pointed that application of 50 per cent N through FYM improved the growth and yield characters of rice in rice-wheat cropping system.

In rice, plant height (92.81 cm), dry matter (106.89 g $hill^{-1}$) and number of productive tillers $hill^{-1}$ (27.51) increased significantly when applied with 20 t ha^{-1} FYM (Shekara *et al.*, 2011).

Priyanka *et al.* (2013) observed that field trial carried out in rice produced significant increase in number of tillers $hill^{-1}$ and dry matter accumulation when applied with 20 t ha^{-1} FYM over control.

Singh *et al.* (2013) revealed that integrated use of FYM at 5 t ha^{-1} with BGA in rice recorded a greater number of tillers m^{-2}, filled grains $panicle^{-1}$, 1000 grain weight and grain yield as compared to control.

Grain yield of rice was increased by the application of 15 t ha^{-1} FYM when integrated with 120 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1}. LAI, number of filled spikelets per panicle, N and P uptake and grain protein content were also enhanced (Tadesse *et al.,* 2013). Panigrahi *et al.* (2015) revealed that FYM when applied at 15 t ha^{-1} when applied resulted in significant increase in plant height, tillering, dry matter accumulation, LAI and grain yield of rice than RDF.

According to Imade *et al.* (2017), significant increase was observed in growth characters of rice such as plant height, total number of tillers hill^{-1}, leaf area index, dry matter accumulation hill^{-1}, yield and quality parameters when applied with RDF along with FYM at 10 t ha^{-1} as compared to control.

Apon *et al.* (2018) observed that 100 per cent RDF + 5 t ha^{-1} FYM improved the number of panicles m^{-2}, length of panicle, test weight, grain yield and straw yield of rice.

2.4.2 Effect of vermicompost on growth and yield

Murali and Setty (2000) reported that there was considerable increase in growth parameters and yield of rice when 5 t ha^{-1} vermicompost was applied. Guerrero *et al.* (2008) pointed out that integrated application of vermicompost at 5-10 t ha^{-1} along with 50 per cent RDF resulted in improved yield of rice.

Sujathamma *et al.* (2000) concluded that in rice, grain (3546 kg ha^{-1}) and straw (5435 kg ha^{-1}) yield was found to be superior when 50 per cent N through vermicompost was given along with 50 per cent N through chemical fertilizers.

According to Prakash and Bhadoria (2003) application of vermicompost resulted in higher grain yield of rice which might be due to presence of humic substances, hormones enhancing growth and nutrient released during mineralization.

A study by Tharmaraj *et al.* (2011) described that rice treated with vermicompost and vermiwash resulted in highest leaf and root length, number of leaves and height when compared with control.

Plant height (74.3 cm), tiller number (16.5), productive tillers (11.3), filled grains per panicle and yield of rice was found to be superiorly higher when treated with vermicompost at 2.5 t ha^{-1} (Thirunavukkarasu and Vinoth, 2013).

Significant increase in growth characters, yield attributes as well as grain and straw yield was recorded in rice when treated with vermicompost (Manivannan and Sriramachandrasekharan, 2016).

2.4.3 Effect of bioslurry on growth and yield

Gnanamani and Bai (1992) reported that grain yield of rice flourished by 23 per cent when bioslurry was applied with synthetic fertilizers containing N, P and K. Field trial conducted by Dhobighat and Painyapani (2006) indicated that the use of bioslurry increased the yields of rice and maize by 34 per cent and yields of wheat by 25 per cent.

Field experiment by Garg *et al.* (2005) found that root length, LAI and yield of wheat (6.21 Mg ha^{-1}) was found to be superior when 15 Mg ha^{-1} bioslurry was applied.

A trial carried out in maize to study the effect of cattle slurry revealed that plant height, number of leaves, leaf area and yield increased when bioslurry was applied at 12 t ha^{-1} (Rahman *et al.*, 2008).

Field trial conducted on the effect of biogas slurry on fodder maize revealed that application of 70 kg biogas slurry ha^{-1} improved the plant height, leaf number, dry matter, yield as well as nutrient content in maize (Islam *et al.,* 2010).

Plant height, tillers per plant, 1000 grain weight and yield were found to be superior in a field experiment conducted in rice when treated with cow dung slurry at 5 t ha^{-1} (Shaheb *et al.,* 2017).

Hossain *et al.* (2018) reported that tillers per hill, grains per panicle and grain yield increased when bioslurry was applied at 5t ha^{-1} along with inorganic fertilizer.

2.4.4 Effect of charcoal on growth and yield

Koyama *et al.* (2016) found that there was a significant increase in number of grains and grain yield of rice when 40 g rice husk charcoal was applied.

Mensah and Ekeke (2016) revealed that charcoal at 5 per cent by weight of soil treatment increased plant height, number of leaves, leaf area, stem girth and chlorophyll content of maize over other treatments and control.

The results of a pot culture experiment to evaluate the growth parameters and yield of rice revealed that length of panicle, number of tillers, number of panicles, 1000 grain weight and grain yield were more when treated with 2 per cent rice husk charcoal (Mishra *et al.*, 2017).

Results obtained from a field experiment to assess the impact of charcoal on wheat showed that number of tillers, productive tillers, number of grain spike and 1000 grain weight were more when charcoal and compost were applied at 5 + 5 Mg ha^{-1} (Imran *et al.*, 2017).

2.4.5 Effect of fly ash on growth and yield

Fly ash when applied at 20 per cent and 40 per cent resulted in a significant increase in plant growth characters and yield (Singh and Siddiqui, 2003).

Findings of a field experiment to evaluate the impact of fly ash on rice indicated that application of fly ash at 90 Mg ha^{-1} recorded in superior growth characters and maximum yield (Lee *et al.*, 2006).

Application of 20 t ha^{-1} coal burnt fly ash resulted in maximum germination, growth parameters as well as yield in wheat and sorghum along with 120 kg ha^{-1} N and 40 kg ha^{-1} N respectively (Aggarwal *et al.*, 2009).

According to Das *et al.* (2013) soil application of fly ash at 5 and 15 t ha^{-1} resulted in an increase in yield when applied along with 50 per cent RDF and FYM at 5 t ha^{-1}. Patel *et al.* (2018) revealed that application of 60 t fly ash ha^{-1} along with

5 t FYM ha^{-1} and 75 per cent GRD resulted in maximum tillers $hill^{-1}$, grain $panicle^{-1}$ and grain yield over control.

Field experiment conducted to study the impact of fly ash on performance of rice revealed that there was an increase in yield when treated with 60 t fly ash ha^{-1} along with 75 per cent GRD and 5 t FYM ha^{-1} (Lal *et al.*, 2014).

A field trial carried out to find the effect of fly ash on maize showed that plant growth characters such as height (195.2 cm), number of leaves $plant^{-1}$ (13.30), dry matter (283.89 g $plant^{-1}$), yield attributes and yield enhanced when treated with fly ash at 15 t ha^{-1} along with municipal compost at 15 t ha^{-1} and RDF (Rao *et al.*, 2017).

2.4.6 Effect of biofertilizers on growth and yield

Barley seeds inoculated with *Azospirillum brasilience* along with P fertilization increased dry matter production of root and shoot (Negi *et al.*, 1991).

Inoculation of maize seeds with *Bacillus polymyxa,* phosphate solubilising biofertilizer registered enhanced biomass production (Racheward *et al.,* 1991).

Arangarasan *et al.* (1998) found that there was significant increase in plant height of rice when treated with *Azospirillum* and phosphate-solubilizing microorganisms.

Rice seeds treated with *Azospirillum sp.* considerably increased the germination per cent, growth and shoot biomass (Isawa *et al.*, 2010). Bao *et al.* (2013) reported an enhancement in number of tillers and length of shoot in rice when treated with *Azospirillum sp.*

Rice seeds inoculated with *Azospirillum sp.* recorded highest germination per cent, growth characteristics such as biomass, length of root and shoot. *Azospirillum* treated plants exhibited highest content of chlorophyll, carotenoid and increased rate of photosynthesis (Kannan and Ponmurugan, 2010). Hossain (2015) reported that inoculation of *Azospirillum sp.* in rice resulted in maximum germination per cent, significant increase in growth components such as height, leaf per plant, length and breadth of leaves as well as fresh and dry weight per plant.

Field trial carried out to evaluate the effect of Phosphobacteria when inoculated in wheat showed that the germination per cent, tiller number, number of spikes, 1000 grain weight and grain yield increased significantly (Malik *et al.,* 2012).

In rice, seeds treated with *Azospirillum* + Phosphobacteria + VAM at 600 g ha^{-1} recorded improved plant height, leaf length, leaf breadth, days to first flowering, days to 50 per cent flowering, panicle length, number of tillers $plant^{-1}$, number of productive tillers $plant^{-1}$ and 100 seed weight compared to control (Anand and Kamaraj, 2017).

Results of a field experiment to evaluate the effect of phosphobacteria on performance of wheat showed that there was significant increase in plant height, number of spikes $plant^{-1}$, spike length, no. of grains $spike^{-1}$, grain yield and straw yield (MeCarty *et al.*, 2017).

2.5 EFFECT OF ORGANIC MANURES ON SOIL PROPERTIES

Continuous application of inorganic fertilizers lessens the soil physical, chemical and biological properties as well as fertility status of soil. Use of manure reinstate the destroyed soil by supplying organic matter, nutrients and by lowering the pH (Zingore *et al.*, 2007).

The combined application of organic wastes, biofertilizer and chemical fertilizers improve crop yield, soil pH, organic carbon and available nutrients (Rautaray *et al.,* 2003; Ahmad *et al.*, 2014).

15 t FYM ha^{-1} when applied along with 100 kg P_2O_5 ha^{-1} enhanced the available nitrogen and phosphorus of soil. There was also increase in water holding capacity and reduction in bulk density of soil (Tadesse *et al.*, 2013).

Ojha *et al.* (2014) reported that 21 t FYM ha^{-1} was superior in improving the soil fertility. The physical as well as chemical properties were also enhanced. Findings of a field experiment in wheat revealed that application of FYM at 10 t ha^{-1} elevated the available N, P and K over the control (Parewa *et al.*, 2014). Available N, P and K increased when FYM was applied at 10 t ha^{-1} along with 100 per cent RDF (Meena *et al.*, 2018).

Azarmi *et al.* (2008) conducted a field experiment and reported that vermicompost when applied at 15 t ha^{-1} enriched the nutrient status (N, P, K, Ca, Zn and Mn) of soil including the organic carbon and EC. Physical properties were also enhanced. Manivannan *et al.* (2009) revealed that combined use of vermicompost along with chemical fertilizers or alone enriched the soil fertility thereby improving the physical, chemical and biological properties of soil. Vermicompost and chemical fertilizer when applied together significantly increased the available N, P and K status of soil (Mahmud *et al.*, 2016). Addition of vermicompost at 10 per cent to soil increased the nutrient content, organic carbon, organic matter, CEC as well as WHC. Xu and Mou (2016) concluded that soil fertility is improved when vermicompost is applied as an amendment.

Kumar *et al.* (2015) reported that addition of bioslurry improved the soil properties as well as reduced the overuse of fertilizers. Research on the impact of application of bioslurry with inorganic fertilizers revealed that there was a positive influence on the organic carbon content, CEC and nutrient status of soil (Debebe and Itana, 2016). Islam *et al.* (2016) carried out a field experiment and results showed that 20 t bioslurry when applied with inorganic fertilizers improved soil parameters such as soil moisture, organic matter, available N, P, K and S. Jared *et al.* (2016) observed that bioslurry could rejuvenate soil due to high levels of nutrients present in it. Bioslurry 5t ha^{-1} enhanced the soil properties and health when applied with NPKSZn (Shaheb *et al.*, 2017).

Zhang *et al.* (2004) inferred that fly ash could be used as an amending agent of soil influencing the growth of crop as well as environment. Das *et al.* (2013)

reported that soil pH enhanced from 5.38 to 6.01 by fly ash addition. Pani *et al.* (2015) concluded that 25 per cent fly ash addition improved the physical and chemical properties of soil and thereby improved the growth of sunflower. Available nutrients as well as pH were found to increase when fly ash was applied to soil. Available P and K content enhanced but there was no significant increase in N content (Baskar *et al.*, 2017). Combined application of fly ash with other organic manures significantly influenced the soil properties thereby improving the growth of plants (Rao *et al.*, 2017).

2.6 EFFECT OF ORGANIC MANURES ON UPTAKE OF NUTRIENTS

The uptake of N, P and K in grain and straw in rice was enhanced by the application of FYM (Modak and Chavan, 2000). Field experiment by Sharma and Sharma (2002) revealed that application of FYM at 10 t ha^{-1} improved the N uptake by 38 to 45 kg ha^{-1}, P uptake by 7 to 10 kg ha^{-1}, K uptake by 25 to 42 kg ha^{-1}. Field trial in rice revealed that there was an increase in uptake of nutrients such as nitrogen, phosphorus, potassium, sulphur and zinc in grain and straw when FYM was applied in combination with different levels of fertilizers (Parihar *et al.*, 2015).

Das *et al.* (2013) obtained maximum uptake of N, P, K and micronutrients (Fe, Mn, Cu and Zn) in grain and straw of rice with RDF 100 per cent and 50 per cent RDF + FYM 5 t ha^{-1}. Warjri *et al.* (2017) concluded that uptake of Zn and S in rice was highest when treated with combination of FYM along with N, P, K fertilizers, 40 kg ha^{-1} S and 5 kg ha^{-1} Zn than control.

Application of vermicompost at 2.5 t ha^{-1} resulted in highest N, P and K uptake by grain and straw of rice (Thirunavukkarasu and Vinoth, 2013). Results of field experiment by Kumar *et al.* (2014) revealed that NPK uptake in rice was superior for treatment receiving 5 t ha^{-1} vermicompost along with 125 per cent RDF.

Ansari *et al.* (2008) opined that uptake of micronutrients by rice increased due to application of vermicompost as it influenced the activity of beneficial microbes. Prasad *et al.* (2010) reported that addition of vermicompost improved the micronutrient uptake by rice.

Organic manures and bioslurry are used as they release nutrients slowly thereby increasing uptake in mustard (Zamil *et al.*, 2004). Adeleye *et al.* (2010) inferred that N, P, K and S uptake by yam increased due to application of bioslurry and organic manure. Field experiment by Basak *et al.* (2016) revealed that total uptake of N, P and S by rice was higher when treated with 3 t ha^{-1} PM slurry in combination with 75 per cent RFD. Uptake of K was maximum for the treatment receiving 75 per cent RFD + Compost (10 t ha^{-1}).

Selvakumari *et al.* (2000) reported that N, P and K uptake in rice was enhanced by the combined application of fly ash, fertilizers and bio fertilizers. Sharma *et al.* (2001) observed that uptake of Fe, Mn, Zn and Cu by rice and maize were significantly higher in plots applied with fly ash.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A study entitled 'Organic manure seed pelleting for enhancing soil health and productivity of rice' was carried out in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani from October 2018 to February 2019. The objectives of the study were:

- To develop seed pellets of rice using organic manures and microbial inoculants
- To study the effect of seed pelleting on soil properties, seedling vigour, growth and yield of rice variety Uma.

The investigation includes:

1. Preparation and characterization of organic manure seed pellets
2. Pot culture experiment to evaluate the organic manure seed pellets and the effect of seed pelleting on soil health and productivity of rice

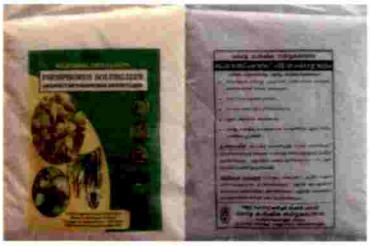
The materials and methods used for the study are described in this chapter.

3.1. PREPARATION AND CHARACTERIZATION OF ORGANIC MANURE SEED PELLETS

Pelleting materials as per combinations detailed below were selected and used for the study.

1. FYM + *Azospirillum* + Phosphobacteria (T_2)
2. Vermicompost + *Azospirillum* + Phosphobacteria (T_3)
3. Bioslurry flakes + *Azospirillum* + Phosphobacteria (T_4)
4. Charcoal powder + *Azospirillum* + Phosphobacteria (T_5)
5. Fly ash + *Azospirillum* + Phosphobacteria (T_6)
6. Pongamia leaf powder + *Azospirillum* + Phosphobacteria (T_7)
7. Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas (T_8: Farmer practice)

Plate 1 (a). Different components of pelleting materials



Phosphobacteria

Azospirillum

Pseudomonas

Fenugreek paste

Plate 1 (b). Different components of pelleting materials

3.1.1 Preparation of pelleting materials

Pelleting materials were prepared by using the ingredients as per the treatments. Carrier based inoculum of *Azospirillum* and Phosphobacteria were used at the rate of 5 g kg^{-1} and fenugreek paste was added at the rate of 25 g kg^{-1} as adhesive.

3.1.2 Characterization of pelleting materials

The prepared pelleting materials were characterized for physical properties, chemical properties, enzymatic activities and organic acid content as per standard methods specified in Table 1.

3.1.2.1 Extraction of humic and fulvic acid

Humic and fulvic acid were separated by extraction with 0.5 N sodium hydroxide for 12 hours followed by acidification with concentrated HCl (Jackson, 1973).

3.1.3 Preparation of pellets

Pellets of size 25 cc were prepared using two seeds per pellet and allowed to germinate in portrays.

3.1.3.1 Analysis of pellets

After 15 days, seedlings were separated and pellets were analysed. Chemical properties, enzymes and organic acids were analysed as per standard methods detailed in Table 1.

3.1.4 Seedling studies

Studies to determine germination per cent, days to 50 % germination, mean root length, mean shoot length, seedling length and vigour indices were conducted 15 days after pelleting.

Table 1. Standard analytical methods for characterization of organic manure pelleting materials

Parameter	Method	Reference
Physical		
Bulk density	Tap volume	Saha *et al.* (2010)
Water holding capacity	Keen Racksowski box	Piper (1966)
Chemical		
pH (1:5)	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	FAI (2017)
EC (1:5)	Conductometry EC-TDS Analyzer (CM 183, Elico India)	FAI (2017)
Mineralisable N (N_{min})	Macrokjeldahl distillation and titrimetry after extraction with 2 M KCl	Hesse (1971)
P	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using spectrophotometer	Jackson (1973)
K	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using flame photometer	Jackson (1973)
Ca and Mg	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using versanate titration method	Hesse (1971)
S	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and turbidimetry	Massoumi and Cornfield (1963)
Fe, Mn, Zn, Cu	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using atomic absorption spectrometry	Jackson (1973)
B	Spectrophotometry - Azomethine-H method	Roig *et al.* (1988)
Enzyme assay		
Urease activity	Colorimetric determination of NH_4^+ released by p-dimethyl amino benzaldehyde	Porter (1965)
Acid phosphatase activity	Colorimetric estimation of p-nitro phenol released	Tabatabai and Bremner (1969)
Dehydrogenase activity	Colorimetric determination of 2,3,5-triphenyl formazan (TPF)	Casida *et al.* (1964)

3.1.4.1 Germination per cent

The pellets were allowed to germinate and the germination per cent was calculated and recorded.

3.1.4.2 Days to 50 % germination

Number of days taken for 50 % of the pellets to germinate were observed and recorded.

3.1.4.3 Mean root length

Two seedlings from each treatment unit was selected to determine root length. The root length was measured from the point of attachment of seed to the tip of the longest root and the average expressed in cm.

3.1.4.4 Mean shoot length

Seedlings used for measuring the root length were also used for measuring the shoot length. Length was measured from the collar region to the tip of the youngest leaf and the average was computed and expressed in cm.

3.1.4.5 Seedling length

The shoot and root length of each sampled seedlings from the treatment units were added and their mean expressed as seedling length in cm.

3.1.4.6 Seedling vigour indices

Seedling vigour indices were calculated using the formula put forward by Abdul-Baki and Anderson (1973).

Seedling vigour index-I= Germination (%) x Seedling length (cm)

Seedling vigour index-II=Germination (%) x Seedling dry weight (mg)

3.2 POT CULTURE EXPERIMENT

A pot culture experiment was conducted at Instructional farm, College of Agriculture, Vellayani, located at 8° 42' North latitude and 76° 98' East latitude at an altitude of 29 m above MSL, during October 2018 to February 2019, to study the effect of organic manure seed pelleting on growth, yield, nutrient uptake and quality of rice.

3.2.1 Experimental details

The experiment was laid out in Completely Randomized Design (CRD) replicated four times with the test crop of rice variety Uma. There were 8 treatments *viz.*

T_1 Control (Seeds alone without pelleting)

T_2 FYM + *Azospirillum* + Phosphobacteria

T_3 Vermicompost + *Azospirillum* + Phosphobacteria

T_4 Bioslurry flakes + *Azospirillum* + Phosphobacteria

T_5 Charcoal powder + *Azospirillum* + Phosphobacteria

T_6 Fly ash + *Azospirillum* + Phosphobacteria

T_7 Pongamia leaf powder + *Azospirillum* + Phosphobacteria

T_8 Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas

3.2.2 Weather parameters

The weather parameters for the standard weeks related to the experimental period were recorded. The mean temperature of the location ranged from 23.21°C to 32.24 °C and relative humidity from 74.00 to 86.16 per cent during the growth stages of rice. A total rainfall of 299.4 mm was received during the crop period. The weather data during crop period is illustrated in Fig. 1 and is presented in Appendix 1.

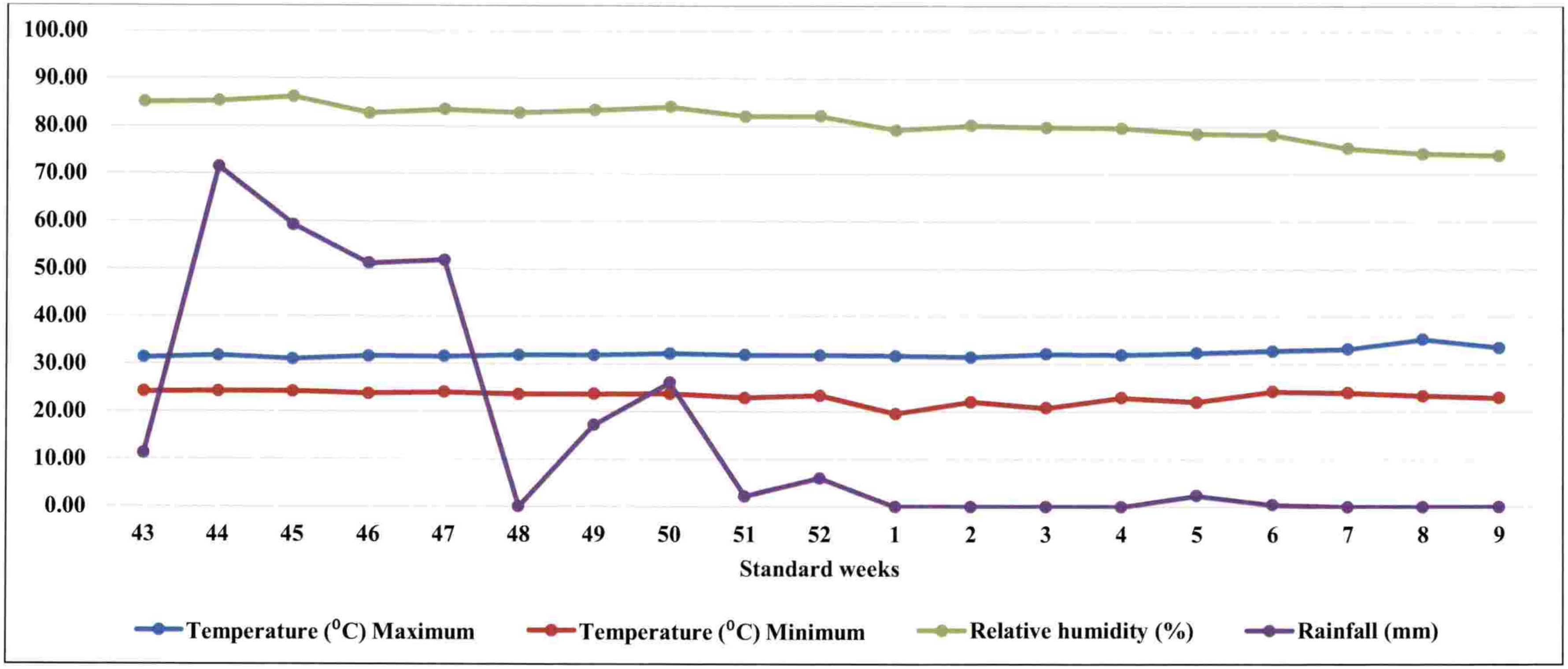


Fig. 1. Weather data during the cropping period: October, 2018- February, 2019

3.2.3 Soil parameters

The soil used for pot culture study was classified as loamy, kaolinitic, isohyperthermic, typic kandiustults of Vellayani series.

3.2.4 Planting

The pots required for the pot culture experiment were filled with the experimental soil. Lime and FYM were applied based on soil weight. Planting was done at the rate of one pellet per pot as per the treatments and maintained according to the layout given in the Fig. 2.

3.2.5 Fertilizer application

Fertilizers were applied as urea (46 % N), rajphos (20 % P_2O_5) and muriate of potash (60 % K_2O) at the rate of 60:30:30 kg ha^{-1} being the recommendation for medium duration variety of rice. Full dose of P, one-third N and half K were applied as basal. One-third N was applied at active tillering stage, one-third N and half K were applied at panicle initiation stage.

3.3 ROOT STUDIES

At active tillering stage, one plant each from each of the replication from all the treatments were carefully uprooted keeping all the roots intact. The roots were separated, washed and root studies undertaken.

3.3.1 Root length

The root length was measured from the collar region to the tip of the longest root using a centimetre scale and expressed in cm.

3.3.2 Root biomass

The weight of roots from the sampled plants were recorded and expressed in grams.

1 T_2R_1	**16** T_4R_2	**17** T_1R_1	**32** T_1R_4
2 T_5R_1	**15** T_2R_3	**18** T_8R_3	**31** T_3R_4
3 T_6R_1	**14** T_4R_1	**19** T_7R_2	**30** T_1R_3
4 T_5R_2	**13** T_8R_2	**20** T_8R_4	**29** T_4R_3
5 T_6R_2	**12** T_5R_3	**21** T_5R_4	**28** T_7R_4
6 T_8R_1	**11** T_2R2	**22** T_1R_1	**27** T_2R_1
7 T_3R_1	**10** T_7R_1	**23** T_7R_3	**26** T_4R_1
8 T_6R_3	**9** T_3R_1	**24** T_3R_2	**25** T_6R_1

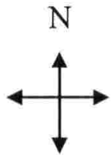


Fig. 2. Layout of pot culture experiment

Plate 2. Layout of pot culture experiment

Plate 3. General view of pot culture experiment

a) Active tillering stage

b) Panicle initiation stage

c) Harvest stage

Plate 4. Different growth stages of rice

3.4 SHOOT BIOMASS

The weight of shoots from the sampled plants were recorded and expressed in grams.

3.5 PLANT GROWTH CHARACTERS

3.5.1 Plant height

Plant height was measured from the base of the plant to the tip of the youngest leaf and expressed in cm. Plant height was noted at active tillering, panicle initiation and harvest stages.

3.5.2 Number of tillers

The number of tillers at active tillering, panicle initiation and harvest stages were counted and recorded.

3.5.3 Leaf Area Index (LAI)

Length and breadth of third leaf from top were measured at active tillering stage. Leaf area index per plant was calculated using the method suggested by Yoshida *et al.* (1976).

$$LAI = \frac{(L \times W) \times K \times \text{number of leaves}}{\text{Land area}}$$

Where, K- Constant factor (0.75)

L- Length of 3rd leaf (cm)

W- Width of 3rd leaf (cm)

3.5.4 Chlorophyll content

Chlorophyll content was estimated at active tillering stage following the procedure proposed by Yoshida *et al.* (1976) and expressed in per cent.

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

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

Total chlorophyll = $(20.2 \times A_{645} + 8.02 \times A_{663}) \times V/ (1000 \times W)$

A= Absorbance at specific wavelengths

V= Final volume of aliquot

W= fresh weight of the sample (g)

3.6 YIELD AND YIELD ATTRIBUTES

3.6.1 Productive tillers

The number of productive tillers per plant was recorded at harvest stage.

3.6.2 Length of panicle

Length of panicle was recorded at harvest stage using three tagged panicles per treatment unit and the mean was expressed in cm.

3.6.3 Number of spikelets per panicle

The panicles selected to study length of panicle was also used to determine the number of spikelets per panicle.

3.6.4 Filled grain per cent

Filled grains and chaff were counted separately from the selected panicles and the average was computed. Per cent filled grains was calculated using the equation given below.

$$\text{Filled grain per cent} = \frac{\text{Number of filled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

3.6.5 Thousand grain weight

One thousand filled grains were counted from each treatment unit and expressed in grams.

3.6.6 Period of retention of flag leaf

The period of retention of flag leaf of three randomly selected tiller from each treatment unit were noted and their average expressed as number of days.

3.6.7 Grain and straw yield

The crop was harvested separately from each pot. Grain and straw yield were recorded after drying in sunlight and expressed in g pot^{-1}.

3.6.8 Harvest Index (HI)

The harvest index was calculated using the formula proposed by Donald and Hamblin (1976) as detailed below.

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.7 CHEMICAL ANALYSIS

3.7.1 Collection and analysis of soil samples

A representative sample was collected from the soil used for the pot culture experiment and analysed for pH, EC, ammoniacal nitrogen, nitrate nitrogen, available P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B as per procedure detailed in Table 2.

Table 2. Analytical procedures for soil analysis

Parameter	Method	Reference
pH (1:2.5)	Potentiometry (Cyber Scan PC510, EuTech Instruments, Singapore)	FAI (2017)
EC (1:2.5)	Conductometry EC-TDS Analyzer (CM 183, Elico India)	FAI (2017)
Organic carbon	Walkley and Black rapid titration method	Walkley and Black (1934)
Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
Mineralisable N (N_{min})	Macrokjeldahl distillation and titrimetry after extraction with 2M KCl	Hesse (1971)
Available P	Bray No.1 extraction and estimation using spectrophotometer	Bray and Kurtz (1945)
Available K	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
Exchangeable Ca and Mg	Versanate titration method	Hesse (1971)
Available S	$CaCl_2$ extraction and estimation using spectrophotometer	Massoumi and Cornfield (1963)
Available Fe, Mn, Zn and Cu	0.1 N HCl extraction and estimation using atomic absorption spectrometry	Sims and Jhonson (1991)
Available B	Hot water extraction and spectrophotometry (Azomethine – H method)	Gupta (1967)

Soil samples were also collected from surface 15 cm from each treatment at harvest stage and analysed for pH, EC, ammoniacal nitrogen, nitrate nitrogen, available P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B following standard procedures shown in Table 2.

3.7.2 Collection and analysis of plant samples

Samples of shoot and grain were collected separately at harvest stage and analysed for content of nutrients as per procedure indicated in Table 3.

3.7.2.1 Nutrient uptake

The nutrient uptake was calculated from the nutrient content and dry weight of samples after oven drying at 70 °C.

$$\text{Nutrient uptake (g pot}^{-1}\text{)} = \text{Nutrient content x dry weight (g)}$$

3.7.2.2 Grain quality parameters

3.7.2.2.1 Starch

The starch content of rice grain was estimated by adopting cyanide method as suggested by Aminoff *et al.* (1970).

3.7.2.2.2 Amylose

Amylose content of rice grain was estimated using spectrophotometry using iodine reagent as suggested by Thayumanavam and Sadasivam (1984).

3.7.2.2.3 Amylopectin

Amylopectin content of rice grain was determined by subtracting the amylose content from starch content as proposed by Thayumanavam and Sadasivam (1984).

Table 3. Analytical procedures for plant sample analysis

Nutrient	Method	Reference
N	Microkjedahl digestion and distillation	Jackson (1973)
P	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using Vanado molybdate yellow colour method	Jackson (1973)
K	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using flame photometer	Jackson (1973)
Ca and Mg	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using Versanate titration method	Hesse (1971)
S	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and turbidimetry	Massoumi and Cornfield (1963)
Zn and Cu	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using AAS	Jackson (1973)
B	Spectrophotometry - Azomethine-H method	Roig *et al.* (1988)
Si	Blue silicomolybdous acid method	Ma *et al.* (2002)

3.8 STATISTICAL ANALYSIS

The data obtained were analysed statistically using analysis of variance according to the design, CRD and their significance was tested using F test (Snedecor and Cochran, 1975). If the effects were found significant, critical differences at 5 % probability level were used to compare the means of treatments calculated.

RESULTS

4. RESULTS

The results obtained from the study 'Organic manure seed pelleting for enhancing soil health and productivity of rice' are presented in this chapter.

4.1 CHARACTERIZATION OF PELLETING MATERIALS

The pelleting materials used in the study were characterized for physical, physico-chemical and chemical properties, enzymatic activity and organic acid content.

4.1.1 Physical properties

Physical properties of pelleting materials are presented in Table 4a. The bulk density and water holding capacity were significantly different in various combinations. Fly ash combined with *Azospirillum* and Phosphobacteria (T_6) had the highest bulk density of 1.07 Mg m^{-3} which was significantly higher than all other treatments. The lowest value was recorded by T_8 (0.24 Mg m^{-3}). The highest water holding capacity was recorded by T_7 (380.8 %) while T_6 (57.15 %) recorded the lowest value.

4.1.2 Physico-chemical properties

Table 4b depicts pH and EC of pelleting materials. The treatments had a significant influence on them. pH of pelleting materials ranged from 7.41 (T_3) to 8.03 (T_2). Highest EC was recorded by T_4 (3.502 dS m^{-1}) and T_6 recorded the lowest value (0.792 dS m^{-1}).

4.1.3 Nutritional properties

4.1.3.1 Primary nutrients

Analytical data on primary nutrient content of pelleting materials are presented in Table 5a. There was no significant difference among the treatments for ammoniacal and nitrate nitrogen. However, P and K content were significantly influenced by the treatments. The highest P content of 1.36 % was recorded by T_4 while T_7 registered the lowest value of 0.06 %. The highest K content was

Table 4a. Physical properties of pelleting materials

Treatment	BD (Mg m^{-3})	WHC (%)
T_2- FYM + *Azospirillum* + Phosphobacteria	0.39	259.3
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.86	129.1
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	0.57	160.8
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.59	120.1
T_6- Fly ash + *Azospirillum* + Phosphobacteria	1.07	57.15
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.32	380.8
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	0.24	273.7
SEm (±)	0.01	1.491
CD (0.05)	0.03	4.378

Table 4b. Physico-chemical properties of pelleting materials

Treatment	pH	EC (dS m^{-1})
T_2- FYM + *Azospirillum* + Phosphobacteria	8.03	2.154
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	7.41	3.123
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	7.51	3.502
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	7.46	1.187
T_6- Fly ash + *Azospirillum* + Phosphobacteria	7.52	0.792
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	7.86	2.232
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	7.61	1.183
SEm (±)	0.022	0.053
CD (0.05)	0.06	0.156

Table 5a. Ammoniacal nitrogen, nitrate nitrogen, phosphorus and potassium content of pelleting materials

Treatment	Ammoniacal N (%)	Nitrate N (%)	P (%)	K (%)
T_2- FYM + *Azospirillum* + Phosphobacteria	0.008	0.002	0.71	0.48
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.006	0.003	0.48	0.94
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	0.007	0.009	1.36	0.78
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.005	0.003	0.22	0.38
T_6- Fly ash + *Azospirillum* + Phosphobacteria	0.004	0.003	0.14	0.12
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.008	0.005	0.06	1.18
T_8- Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	0.005	0.003	0.51	0.69
SEm (±)			0.013	0.016
CD (0.05)	NS	NS	0.037	0.046

observed in T_7 (1.18 %) followed by the remaining treatments in the order $T_3 > T_4 > T_8 > T_2 > T_5 > T_6$.

4.1.3.2 Secondary nutrients

The results on secondary nutrient content of pelleting materials as influenced by various treatments are shown in Table 5b.

There was a significant influence of treatments on all the three secondary nutrients Ca, Mg and S. Data revealed that T_4 registered the highest content of Ca (3.46 %) which was on par with T_2 (3.42 %) and T_8 (3.42 %) whereas T_7 recorded the lowest value (2.20 %). The Mg content was also highest in T_4 (2.57 %) which was on par with T_2 (2.33 %). This was followed by T_3 (1.30 %) which was on par with T_5 (1.22 %) followed by T_8 (0.89 %), T_7 (0.62 %) and T_6 (0.58 %) which were on par. T_6 registered the lowest value. The highest S content was associated with T_4 (1.03 %) which was significantly higher than all other treatments. The lowest S content was observed in T_3 and T_6 (0.23 %).

4.1.3.3 Micronutrients

The micro nutrient content of pelleting materials are presented in Table 5c.

There was a significant difference between the treatments with respect to micronutrient content. T_6 recorded the highest value (1.62 %) for Fe and T_7, the lowest (0.04 %). Mn content ranged from 20.50 mg kg^{-1} (T_7) to 398.6 mg kg^{-1} (T_4). T_4 recorded the highest (128.6 mg kg^{-1}) value of Zn whereas T_7 recorded the lowest (26.60 mg kg^{-1}). Cu content of pelleting materials was highest in T_4 (57.00 mg kg^{-1}) followed by T_3- 25.20 mg kg^{-1} > T_6- 24.80 mg kg^{-1} > T_2- 20.00 mg kg^{-1} > T_8- 17.80 mg kg^{-1} > T_5- 13.00 mg kg^{-1} > T_7- 8.50 mg kg^{-1}. The highest B content was observed in T_3 (4.80 mg kg^{-1}) which was on par with T_6. This was followed by T_8 (3.94 mg kg^{-1}). The lowest B content was observed in T_5 (0.25 mg kg^{-1}) which was on par with T_4 (0.27 mg kg^{-1}).

Table 5b. Secondary nutrient content of pelleting materials

Treatment	Ca (%)	Mg (%)	S (%)
T_2-FYM + *Azospirillum* +Phosphobacteria	3.42	2.33	0.47
T_3-Vermicompost +*Azospirillum* + Phosphobacteria	3.14	1.30	0.23
T_4-Bioslurry flakes + *Azospirillum* + Phosphobacteria	3.46	2.57	1.03
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	3.12	1.22	0.24
T_6- Fly ash + *Azospirillum* + Phosphobacteria	2.26	0.58	0.23
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	2.20	0.62	0.35
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	3.42	0.89	0.32
SEm (±)	0.093	0.111	0.019
CD (0.05)	0.272	0.327	0.055

Table 5c. Micronutrient content of pelleting materials

Treatment	Fe (%)	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})
T_2-FYM + *Azospirillum* + Phosphobacteria	0.57	206.9	120.8	20.00	2.86
T_3-Vermicompost + *Azospirillum* +Phosphobacteria	0.50	305.1	107.6	25.20	4.80
T_4-Bioslurry flakes + *Azospirillum* + Phosphobacteria	0.30	398.6	128.6	57.00	0.27
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.34	69.20	33.80	13.00	0.25
T_6- Fly ash + *Azospirillum* + Phosphobacteria	1.62	208.4	44.20	24.80	4.62
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.04	20.50	26.60	8.50	1.74
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	0.10	272.5	79.10	17.80	3.94
SEm (±)	0.018	1.619	0.906	0.5	0.137
CD (0.05)	0.053	4.752	2.661	1.467	0.403

4.1.4 Enzymatic activity

The enzymatic activity of pelleting materials was estimated for various treatments and the results are summarized in Table 6. There was significant influence of treatments on enzymatic activity. Urease activity was found to be the highest in T_7 (51.65 ppm of urea g^{-1} soil h^{-1}) while T_6 recorded the lowest value (5.25 ppm of urea g^{-1} soil h^{-1}). Results pointed out that the highest acid phosphatase activity was recorded by T_7 (113.1 μg of p-nitrophenol g^{-1} soil h^{-1}) and the lowest value was recorded by T_6 (6.18 μg of p-nitrophenol g^{-1} soil h^{-1}). Results of dehydrogenase activity of pelleting materials showed that T_3 recorded the highest value of 312.0 μg of TPF g^{-1} soil 24 h^{-1} which was followed by T_2 (287.5 μg of TPF g^{-1} soil 24 h^{-1}). T_6 recorded the lowest value (1.68 μg of TPF g^{-1} soil 24 h^{-1}).

4.1.5 Organic acid content

The results with respect to the content of organic acids are shown in Table 7. There was a significant influence of treatments on the humic acid and fulvic acid content. The humic acid content was highest in T_3 (28.52 %) which was on par with T_4 (27.06 %) while the lowest was recorded by T_6 (1.45 %). The highest fulvic acid content was recorded by T_3 (23.76 %) which was on par with T_4 (22.81 %). T_6 recorded the lowest value (1.21 %).

4.2 ANALYSIS OF PELLETS AFTER 15 DAYS

Seedlings were separated after 15 days and pellets were analysed for physico-chemical and nutritional properties, enzymatic activity and organic acid content.

4.2.1 Physico-chemical properties

The data on pH and EC of various treatments are presented in Table 8. Data revealed that pH and EC were significantly different among the treatments. The highest pH was recorded by T_3 (8.07) while T_4 registered the lowest value

Table 6. Enzymatic activity of pelleting materials

Treatment	Urease (ppm of urea g^{-1} soil h^{-1})	Acid phosphatase (μg of p-nitrophenol g^{-1} soil h^{-1})	Dehydrogenase (μg of TPF g^{-1} soil 24 h^{-1})
T_2- FYM + *Azospirillum* + Phosphobacteria	7.46	109.5	287.5
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	9.67	97.95	312.0
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	19.74	82.26	277.4
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	20.62	11.96	7.92
T_6- Fly ash + *Azospirillum* + Phosphobacteria	5.25	6.18	1.68
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	51.65	113.1	202.5
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	7.87	112.2	277.0
SEm (±)	0.327	0.232	0.44
CD (0.05)	0.96	0.682	1.293

Table 7. Organic acid content of pelleting materials

Treatment	Humic acid (%)	Fulvic acid (%)
T_2- FYM + *Azospirillum* + Phosphobacteria	23.34	20.34
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	28.52	23.76
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	27.06	22.81
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	20.14	15.93
T_6- Fly ash + *Azospirillum* + Phosphobacteria	1.45	1.21
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	21.32	18.34
T_8- Bioslurry + Plant extracts +*Azospirillum* + Pseudomonas	22.19	19.13
SEm (±)	0.79	0.70
CD (0.05)	2.33	2.05

Table 8. Physico-chemical properties of pellets after15 days

Treatment	pH	EC (dS m^{-1})
T_2- FYM + *Azospirillum* + Phosphobacteria	7.81	0.621
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	8.07	2.353
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	7.07	2.089
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	7.59	0.413
T_6- Fly ash + *Azospirillum* + Phosphobacteria	7.42	0.465
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	7.83	0.061
T_8- Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	8.03	0.732
SEm (±)	0.012	0.003
CD (0.05)	0.04	0.009

(7.07). EC was highest in T_3 (2.353 dS m^{-1}) whereas the lowest was recorded by T_7 (0.061 dS m^{-1}).

4.2.2 Nutritional properties

4.2.2.1 Primary nutrients

The results with respect to content of primary nutrients in pellets after 15 days are presented in Table 9a. Data revealed that there was no significant difference among treatments for ammoniacal and nitrate nitrogen. Results indicated that T_4 recorded the highest P content (1.67 %) and differed significantly from all other treatments. This was followed by T_2 (0.89 %) and T_3 (0.87 %) which were on par. T_5 recorded the lowest value of 0.02 %. K content was highest in T_7 (1.16 %) followed by T_3 (0.84 %). This was followed by T_4 (0.44 %). The lowest K content was observed in T_2, T_5 and T_6 (0.25 %).

4.2.2.2 Secondary nutrients

Secondary nutrient content of pellets after 15 days as influenced by different treatments are depicted in Table 9b. Treatments differed significantly with respect to secondary nutrients. In case of Ca content, the values ranged from 1.08 % (T_7) to 2.56 % (T_4). T_3 registered the highest value for Mg content (1.92 %) while T_7 recorded the lowest value (0.65 %). The S content was highest in T_4 (0.84 %) which differed significantly from all other treatments. This was followed by T_3 (0.27 %) which was on par with T_7 (0.26 %). The lowest S content was observed in T_5 (0.11 %).

4.2.2.3 Micronutrients

Table 9c depicts micro nutrient content of pellets after 15 days. The results indicated that the content of all the micronutrients studied Fe, Mn, Zn, Cu and B were significantly influenced by the treatments.

T_6 registered the highest Fe content (2.97 %) which was followed by T_3 (0.68 %) while T_7 recorded the lowest (0.09 %). The Mn content was highest in T_4 (777.1 mg kg^{-1}) followed by T_6 (446.7 mg kg^{-1}), T_3 (319.0 mg kg^{-1}), T_8

Table 9a. Ammoniacal nitrogen, nitrate nitrogen, phosphorus and potassium content of pellets after 15 days

Treatment	Ammoniacal N (%)	Nitrate N (%)	P (%)	K (%)
T_2- FYM + *Azospirillum* + Phosphobacteria	0.005	0.003	0.89	0.25
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.004	0.003	0.87	0.84
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	0.007	0.003	1.67	0.44
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.006	0.002	0.02	0.25
T_6- Fly ash + *Azospirillum* + Phosphobacteria	0.004	0.003	0.07	0.25
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.003	0.002	0.05	1.16
T_8- Bioslurry + Plant extracts + *Azospirillum*+ Pseudomonas	0.004	0.003	0.39	0.29
SEm (±)			0.011	0.014
CD (0.05)	NS	NS	0.032	0.04

Table 9b. Secondary nutrient content of pellets after 15 days

Treatment	Ca (%)	Mg (%)	S (%)
T_2-FYM + *Azospirillum* + Phosphobacteria	1.20	1.06	0.22
T_3-Vermicompost + *Azospirillum* + Phosphobacteria	1.30	1.92	0.27
T_4-Bioslurry flakes + *Azospirillum* + Phosphobacteria	2.56	1.34	0.84
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	1.20	0.72	0.11
T_6- Fly ash + *Azospirillum* + Phosphobacteria	1.36	1.20	0.13
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	1.08	0.65	0.26
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	1.24	0.96	0.22
SEm (±)	0.082	0.162	0.006
CD (0.05)	0.241	0.475	0.016

Table 9c. Micronutrient content of pellets after 15 days

Treatment	Fe (%)	Mn ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	B ($mg\ kg^{-1}$)
T_2-FYM + *Azospirillum* + Phosphobacteria	0.52	192.7	112.0	18.50	3.24
T_3-Vermicompost + *Azospirillum* + Phosphobacteria	0.68	319.0	180.2	41.80	1.82
T_4-Bioslurryflakes + *Azospirillum* +Phosphobacteria	0.54	777.1	264.1	71.60	1.46
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.22	65.40	48.80	11.60	2.03
T_6- Fly ash + *Azospirillum* + Phosphobacteria	2.97	446.7	85.40	56.10	7.62
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.09	26.70	40.60	28.10	0.27
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	0.19	279.0	96.90	17.00	1.05
SEm (±)	0.013	2.022	2.773	1.25	0.116
CD (0.05)	0.039	5.937	8.141	3.672	0.339

(279.0 mg kg^{-1}), T_2 (192.7 mg kg^{-1}), T_5 (65.40 mg kg^{-1}) and T_7 (26.70 mg kg^{-1}) which were significantly different from one another. Zn content followed the order: T_4- 264.1 mg kg^{-1} > T_3- 180.2 mg kg^{-1} > T_2- 112.0 mg kg^{-1} > T_8- 96.90 mg kg^{-1} >T_6- 85.40 mg kg^{-1} > T_5- 48.80 mg kg^{-1} > T_7- 40.60 mg kg^{-1}. For Cu, the highest value of 71.60 mg kg^{-1} was recorded in T_4 whereas T_5 (11.60 mg kg^{-1}) registered the lowest value. T_6 showed the highest B content (7.62 mg kg^{-1}) followed by T_2 (3.24 mg kg^{-1}). T_7 recorded the lowest value (0.27 mg kg^{-1}).

4.2.3 Enzymatic activity

The data on enzymatic activity of pellets after 15 days presented in Table 10 revealed that the treatments significantly influenced the activity of all the three enzymes studied namely urease, acid phosphatase and dehydrogenase. The highest urease activity was recorded by T_7 (25.70 ppm of urea g^{-1} soil h^{-1}) while the lowest value of 2.25 ppm of urea g^{-1} soil h^{-1} was recorded by T_6. It is clear from the table that acid phosphatase activity was highest in T_7 (109.5 µg of p-nitrophenol g^{-1} soil h^{-1}) while the lowest was registered in T_6 (4.29 µg of p-nitrophenol g^{-1} soil h^{-1}). Dehydrogenase activity was found to be superior in T_3 (383.2 µg of TPF g^{-1} soil 24 h^{-1}) followed by other treatments in the order: $T_7 > T_4 > T_2 > T_8 > T_5 > T_6$.

4.2.4 Organic acid content

There was a significant influence of treatments on organic acid content (humic and fulvic acid) of pellets after 15 days (Table 11). T_3 recorded the highest humic acid content (29.17 %) which was found to be on par with T_4 (27.46 %). The lowest value was registered by T_6 (1.47 %). In case of fulvic acid, T_3 recorded the highest value (23.52%). This was followed by T_4 (21.14 %) which was on par with T_2 (19.59 %). The lowest fulvic acid content was observed in T_6 (1.04 %).

Table 10. Enzymatic activity of pellets after 15 days

Treatment	Urease (ppm of urea g^{-1} soil h^{-1})	Acid phosphatase (µg of p-nitrophenol g^{-1} soil h^{-1})	Dehydrogenase (µg of TPF g^{-1} soil 24 h^{-1})
T_2- FYM + *Azospirillum* + Phosphobacteria	3.21	105.8	134.6
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	11.42	100.4	383.2
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	14.58	80.40	277.8
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	6.37	8.16	5.76
T_6- Fly ash + *Azospirillum* + Phosphobacteria	2.25	4.29	4.99
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	25.70	109.5	312.3
T_8-Bioslurry + Plant extracts + *Azospirillum*+ Pseudomonas	4.50	107.2	121.7
SEm (±)	0.161	0.102	0.554
CD (0.05)	0.472	0.299	1.626

Table 11. Organic acid content of pellets after 15 days

Treatment	Humic acid (%)	Fulvic acid (%)
T_2- FYM + *Azospirillum* + Phosphobacteria	24.64	19.59
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	29.17	23.52
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	27.46	21.14
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	20.86	14.72
T_6- Fly ash + *Azospirillum* + Phosphobacteria	1.47	1.04
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	22.74	16.53
T_8- Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	22.93	18.12
SEm (±)	0.638	0.711
CD (0.05)	1.874	2.09

4.3 GERMINATION ASSAY

The results of germination assay are presented in Table 12a. Germination per cent of all treatments except T_7 were 100 %. T_5 took minimum days (3.75) to attain 50 % germination which was on par with T_3 (4.00), T_4 (4.00), T_8 (4.00) and T_2 (4.50) while it took more days for seeds from T_7 to achieve 50 % germination (9.75).

4.4 SEEDLING STUDIES

The experimental results with respect to seedling studies are depicted in Table 12b. The mean root length was highest for T_2 (12.18 cm) which was comparable with T_3 (11.50 cm). T_2 recorded the highest mean shoot length and seedling length of 31.09 cm and 43.27 cm, respectively. T_7 recorded the lowest values for root, shoot and seedling length. Observations revealed that highest seedling vigour index I (4,326) and II (16,250) were shown by T_2 followed by T_3 and T_4. T_7 recorded the least values of 483.8 and 875.0 respectively.

4.5 FERTILITY PARAMETERS OF SOIL USED FOR EXPERIMENT

Table 13 depicts the original physico-chemical and chemical properties of the soil used for the pot culture experiment. The pH of the soil was very strongly acidic (4.99) and EC was in the safe level (0.291 dS m^{-1}). The soil was medium in OC (0.82 %) and available N (295.0 kg ha^{-1}). Ammoniacal and nitrate nitrogen content of the soil was 22.40 mg kg^{-1} and 16.80 mg kg^{-1}, respectively. The P availabity of soil was found to be high (56.90 kg ha^{-1}) while K availability was low (134.4 kg ha^{-1}). Secondary nutrients such as exchangeable Ca (245.0 mg kg^{-1}) and Mg (48.00 mg kg^{-1}) of the soil were in deficient range while available S was found to be sufficient (9.50 mg kg^{-1}). Among the micronutrients, available Fe (35.04 mg kg^{-1}), Mn (7.43 mg kg^{-1}), Zn (4.23 mg kg^{-1}) and Cu (2.88 mg kg^{-1}) were sufficient while the soil was deficient for B (0.23 mg kg^{-1}).

Table 12a. Effect of organic manure seed pelleting on germination and days to 50 % germination

Treatment	Germination %	Days to 50% germination
T_1- Control (Seeds alone without pelleting)	100	4.75
T_2- FYM + *Azospirillum* + Phosphobacteria	100	4.50
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	100	4.00
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	100	4.00
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	100	3.75
T_6- Fly ash + *Azospirillum* + Phosphobacteria	100	5.50
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	62.5	9.75
T_8- Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	100	4.00
SEm (±)	4.419	0.327
CD (0.05)	12.98	0.959

Table 12b. Effect of organic manure seed pelleting on mean root length, shoot length, seedling length and vigour indices

Treatment	Mean root length (cm)	Mean shoot length (cm)	Seedling length (cm)	Seedling vigour index I	Seedling vigour index II
T_1- Control (Seeds alone without pelleting)	8.15	16.94	25.09	2,509	8,000
T_2- FYM + *Azospirillum* + Phosphobacteria	12.18	31.09	43.27	4,326	16,250
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	11.50	23.58	35.08	3,508	11,750
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	10.00	25.34	35.34	3,534	11,500
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	7.98	18.38	26.36	2,635	4,750
T_6- Fly ash + *Azospirillum* + Phosphobacteria	6.85	11.85	18.70	1,870	5,750
T_7-Pongamia leaf powder+ *Azospirillum* + Phosphobacteria	2.33	5.55	7.88	483.8	875
T_8- Bioslurry+ Plant extracts +*Azospirillum*+ Pseudomonas	5.70	13.30	19.00	1,900	3,750
SEm (±)	0.492	0.747	0.755	79.74	948.9
CD (0.05)	1.444	2.194	2.217	234.1	2786

Table 13. Physico-chemical and chemical characteristics of soil used in the experiment

Parameter	Content
pH	4.99
EC (dS m^{-1})	0.291
OC (%)	0.82
Available N (kg ha^{-1})	295.0
Ammoniacal N (mg kg^{-1})	22.40
Nitrate N (mg kg^{-1})	16.80
Available P (kg ha^{-1})	56.90
Available K (kg ha^{-1})	134.4
Exchangeable Ca (mg kg^{-1})	245.0
Exchangeable Mg (mg kg^{-1})	48.00
Available S (mg kg^{-1})	9.50
Available Fe (mg kg^{-1})	35.04
Available Mn (mg kg^{-1})	7.43
Available Zn (mg kg^{-1})	4.23
Available Cu (mg kg^{-1})	2.88
Available B (mg kg^{-1})	0.23

4.6 EFFECT OF ORGANIC MANURE SEED PELLETING ON BIOMETRIC CHARACTERS OF PLANT

One plant from each replication of all treatments were carefully uprooted at active tillering stage and the roots were separated and washed. Root studies and shoot biomass were carried out.

The treatment effects on root length, root biomass and shoot biomass at active tillering stage are shown in Table 14a. There was significant difference in these characters due to organic manure seed pelleting. The highest root length was recorded in T_4 (33.05 cm) which was on par with T_3 (32.93 cm) and T_2 (31.30 cm). T_7 recorded the lowest root length. With respect to root and shoot biomass, T_4 was significantly superior to all other treatments and recorded values of 18.74 g pot^{-1} and 28.01 g pot^{-1}, respectively.

Plant height and number of tillers were significantly influenced by combinations of pelleting materials (Table 14b). Results revealed that maximum plant height was recorded in T_4 (64.85 cm) which was on par with T_2 (63.95 cm). The shortest plant was observed in T_7 (50.35 cm). For number of tillers, highest value of 18.25 was recorded by T_4 which was on par with T_3 (17.50). This was followed by T_2 (15.50), T_6 (15.25) and T_8 (14.50) which were on par. The least number of tillers was obtained in T_7 (11.50) which was on par with T_5 (12.00) and T_1 (13.00). LAI was highest for T_4 (5.09) which was on par with T_6 (4.38), T_2 (4.01) and T_3 (3.67). The lowest LAI was observed in T_7 (2.69).

The analytical results of chlorophyll content of leaves with respect to various treatments is presented in Table 15.

Chlorophyll a ranged from 0.050 % (T_1) to 0.056 % (T_3). There was no significant difference between the treatments with respect to chlorophyll a content. Chlorophyll b content ranged from 0.019 % (T_1) to 0.033 % (T_4). The treatments did not vary significantly for chlorophyll b content also. Total chlorophyll followed the same trend as chlorophyll a and chlorophyll b and all the treatments were on par.

Table 14a. Effect of organic manure seed pelleting on root length, root biomass and shoot biomass

Treatment	Root length (cm)	Root biomass (g pot^{-1})	Shoot biomass (g pot^{-1})
T_1- Control (Seeds alone without pelleting)	26.83	11.68	15.98
T_2- FYM + *Azospirillum* + Phosphobacteria	31.30	13.47	20.49
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	32.93	12.20	17.08
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	33.05	18.74	28.01
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	25.50	5.88	10.53
T_6- Fly ash + *Azospirillum* + Phosphobacteria	28.48	6.19	11.80
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	21.78	4.41	11.35
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	22.20	4.19	7.30
SEm (±)	0.644	0.364	0.343
CD (0.05)	1.891	1.07	1.008

Table 14b. Effect of organic manure seed pelleting on biometric characters at active tillering stage

Treatment	Height (cm)	Number of tillers	LAI
T_1- Control (Seeds alone without pelleting)	56.95	13.00	2.33
T_2- FYM + *Azospirillum* + Phosphobacteria	63.95	15.50	4.01
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	59.35	17.50	3.67
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	64.85	18.25	5.09
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	53.45	12.00	2.96
T_6- Fly ash + *Azospirillum* + Phosphobacteria	59.58	15.25	4.38
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	50.35	11.50	2.69
T_8-Bioslurry +Plant extracts + *Azospirillum* + Pseudomonas	57.33	14.50	2.77
SEm (±)	0.883	0.535	0.494
CD (0.05)	2.592	1.571	1.449

Table 15. Effect of organic manure seed pelleting on chlorophyll content of leaves at active tillering stage

Treatment	Chlorophyll a (%)	Chlorophyll b (%)	Total chlorophyll (%)
T_1- Control (Seeds alone without pelleting)	0.050	0.019	0.069
T_2- FYM + *Azospirillum* + Phosphobacteria	0.052	0.029	0.081
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.056	0.026	0.082
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	0.053	0.033	0.086
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.051	0.022	0.073
T_6- Fly ash + *Azospirillum* + Phosphobacteria	0.053	0.022	0.075
T_7-Pongamia leaf powder + *Azospirillum*+ Phosphobacteria	0.051	0.022	0.073
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	0.052	0.023	0.075
CD (0.05)	NS	NS	NS

Data in Table 16 show that at panicle initiation stage, plant height was maximum in T_4 (86.63 cm). This was followed by T_2 (83.78 cm) and T_3 (82.78 cm) which were on par. Maximum number of tillers was observed for T_3 (24.00) which was on par with T_4 (23.00). T_1 recorded the lowest number of tillers (16.00).

Table 16 indicates that plant height ranged from 83.20 cm to 92.33 cm at harvest stage. T_4 (92.33 cm) recorded the tallest plant which was comparable with T_3 (92.23 cm) and T_6 (92.05 cm) while T_1 (83.20 cm) registered the lowest value. Number of tillers was found to be highest for T_3 (21.25) which was on par with T_4 (19.50).

4.7 EFFECT OF ORGANIC MANURE SEED PELLETING ON YIELD ATTRIBUTES OF RICE

Table 17a shows the effect of treatments on yield attributes of rice. The treatments significantly influenced number of productive tillers, spikelets per panicle and filled grain per cent however there was no influence on length of panicle and 1000 grain weight.

T_3 registered the maximum number of productive tillers (16.50) while T_1 recorded the lowest value (9.00). T_3 was followed by T_4 (14.50) and T_6 (13.25) which were on par. T_3 recorded the maximum number of spikelets per panicle (159.7) which was on par with T_4 (158.3) while the lowest value of 114.4 was recorded by T_1. Filled grain per cent of different treatments varied from 72.59 % to 94.16 %. T_3 recorded the maximum value which was on par with T_4 (93.71 %). Filled grain per cent was lowest in T_7 (72.59 %) which was on par with T_5 (73.03 %).

The period of retention of flag leaf was significantly influenced by organic manure seed pelleting (Table 17a). It was maximum in T_4 (30.25) which was on par with T_2 (29.17). Flag leaf retention was lowest in T_7 (21.03) which was on par with T_1 (22.33).

Table 16. Effect of organic manure seed pelleting on biometric characters of rice plants at panicle initiation and harvest stages

Treatment	Height (cm)		Number of tillers	
	Panicle initiation	Harvest	Panicle initiation	Harvest
T_1- Control (Seeds alone without pelleting)	77.28	83.20	16.00	11.75
T_2- FYM + *Azospirillum* + Phosphobacteria	83.78	88.88	20.25	16.25
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	82.78	92.23	24.00	21.25
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	86.63	92.33	23.00	19.50
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	76.85	85.33	18.25	15.00
T_6- Fly ash + *Azospirillum* + Phosphobacteria	79.13	92.05	20.00	16.50
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	72.70	88.88	17.50	13.75
T_8- Bioslurry+ Plant extracts + *Azospirillum* + Pseudomonas	80.53	88.20	19.25	16.00
SEm (±)	0.812	1.072	0.671	0.729
CD (0.05)	2.384	3.146	1.971	2.14

Table 17a. Effect of organic manure seed pelleting on yield attributes and period of retention of flag leaf of rice plants

Treatment	Productive tillers	Length of panicle (cm)	Spikelets per panicle	Filled grain %	1000 grain weight (g)	Period of retention of flag leaf (days)
T_1- Control (Seeds alone without pelleting)	9.00	20.08	114.4	80.87	24.22	22.33
T_2- FYM + *Azospirillum* + Phosphobacteria	10.00	21.20	139.8	84.30	25.10	29.17
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	16.50	22.21	159.7	94.16	25.58	26.08
T_4- Bioslurry flakes +*Azospirillum* + Phosphobacteria	14.50	21.69	158.3	93.71	25.55	30.25
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	10.50	20.52	130.7	73.03	25.23	25.34
T_6- Fly ash + *Azospirillum* + Phosphobacteria	13.25	21.71	151.5	92.04	25.38	26.75
T_7-Pongamia leaf powder + *Azospirillum*+ Phosphobacteria	11.75	20.50	139.4	72.59	25.10	21.03
T_8-Bioslurry +Plant extracts + *Azospirillum* + Pseudomonas	11.00	20.83	146.0	80.92	25.48	25.58
SEm (±)	0.582		2.221	0.71		0.661
CD (0.05)	1.708	NS	6.521	2.086	NS	1.941

4.8 EFFECT OF ORGANIC MANURE SEED PELLETING ON YIELD OF RICE

Effect of different treatments on grain yield, straw yield and HI of rice are presented in Table 17b.

Grain and straw yield were significantly influenced due to organic manure seed pelleting. T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) recorded the highest value for grain yield (54.84 g pot^{-1}) and straw yield (66.10 g pot^{-1}) while the lowest was recorded by T_1 (Control) with values 35.63 g pot^{-1} and 43.98 g pot^{-1}, respectively. Organic manure seed pelleting significantly influenced harvest index of rice. T_4, T_5, T_6 and T_8 recorded same values (0.47) and were comparable with T_7 and the lowest was recorded by T_1 and T_2 (0.44).

4.9 SOIL PROPERTIES AFTER THE EXPERIMENT

Soil samples collected from each treatment after harvest were analysed for pH, EC, ammoniacal nitrogen, nitrate nitrogen, available P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B.

4.9.1 pH

Results of pH with respect to various treatments are presented in Table 18. Data indicated that pH of soil after harvest ranged from 5.52 to 5.77. The highest pH was recorded by T_6 which was on par with T_3. Both T_1 and T_8 recorded the lowest value (5.52).

4.9.2 EC

Table 18 revealed that T_4 recorded the highest EC of post-harvest soil (0.363 dS m^{-1}). It was found to be on par with T_3 (0.361 dS m^{-1}) and T_8 (0.359 dS m^{-1}) while T_1 recorded the lowest value (0.344 dS m^{-1}).

Table 17b. Effect of organic manure seed pelleting on grain yield, straw yield and HI of rice

Treatment	Grain yield (g pot^{-1})	Straw yield (g pot^{-1})	HI
T_1- Control (Seeds alone without pelleting)	35.63	43.98	0.44
T_2- FYM + *Azospirillum* + Phosphobacteria	36.82	46.53	0.44
T_3- Vermicompost+ *Azospirillum* + Phosphobacteria	54.84	66.10	0.45
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	51.21	57.58	0.47
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	38.72	44.15	0.47
T_6- Fly ash + *Azospirillum* + Phosphobacteria	46.90	52.08	0.47
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	44.10	51.60	0.46
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	44.03	48.90	0.47
SEm (±)	0.798	0.867	0.007
CD (0.05)	2.343	2.546	0.022

Table 18. Effect of organic manure seed pelleting on pH and EC of post-harvest soil

Treatment	pH	EC ($dS\ m^{-1}$)
T_1- Control (Seeds alone without pelleting)	5.52	0.344
T_2- FYM + *Azospirillum* + Phosphobacteria	5.65	0.355
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	5.71	0.361
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	5.58	0.363
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	5.67	0.351
T_6- Fly ash + *Azospirillum* + Phosphobacteria	5.77	0.353
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	5.55	0.358
T_8- Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	5.52	0.359
SEm (±)	0.021	0.001
CD (0.05)	0.06	0.003

4.9.3 Nutrient analysis of soil

4.9.3.1 Primary nutrients

Effect of treatments on ammoniacal N, nitrate N, available P and available K of post-harvest soil are presented in Table 19a.

4.9.3.1.1 Ammoniacal and Nitrate Nitrogen

The treatments significantly influenced ammoniacal N content. T_2 (50.40 mg kg^{-1}) was significantly superior to all other treatments. Control treatment T_1 (16.80 mg kg^{-1}) recorded the lowest value. All other treatments were on par. There was no significant influence of treatments on nitrate nitrogen content.

4.9.3.1.2 Available Phosphorus

There was a significant influence of treatments on available P of soil. T_4 recorded the highest (76.97 kg ha^{-1}) available P which was on par with T_2 (76.33 kg ha^{-1}). Control treatment (T_1) showed the lowest value (46.03 kg ha^{-1}).

4.9.3.1.3 Available Potassium

Organic manure seed pelleting had a significant influence on available K of post- harvest soil. It ranged from 89.60 kg ha^{-1} in T_1 to 190.4 kg ha^{-1} in T_4. T_4 was found to be on par with T_5 and were significantly higher than all other treatments.

4.9.3.2 Secondary nutrients

Data on exchangeable Ca, Mg and available S are presented in Table 19b.

4.9.3.2.1 Exchangeable Calcium

There was a significant influence in available Ca of soil due to seed pelleting. T_4 recorded the highest available Ca of 285.0 mg kg^{-1} which was on par with all other treatments except T_1 (177.5 mg kg^{-1}).

Table 19a. Effect of organic manure seed pelleting on availability of primary nutrients in post-harvest soil

Treatment	Ammoniacal N (mg kg^{-1})	Nitrate N (mg kg^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1- Control (Seeds alone without pelleting)	16.80	19.60	46.03	89.60
T_2- FYM + *Azospirillum* + Phosphobacteria	50.40	28.00	76.33	168.0
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	28.00	25.20	66.16	165.2
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	25.20	25.20	76.97	190.4
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	22.40	22.40	65.24	176.4
T_6- Fly ash + *Azospirillum* + Phosphobacteria	22.40	33.60	62.83	159.6
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	22.40	22.40	72.24	137.2
T_8-Bioslurry +Plant extracts + *Azospirillum* + Pseudomonas	19.60	25.20	69.83	145.6
SEm (±)	3.024		0.118	5.238
CD (0.05)	8.88	NS	0.778	15.38

Table 19b. Effect of organic manure seed pelleting on availability of secondary nutrients in post-harvest soil

Treatment	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
T_1- Control (Seeds alone without pelleting)	177.5	43.50	10.00
T_2- FYM + *Azospirillum* + Phosphobacteria	262.5	45.00	13.00
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	267.5	67.50	11.38
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	285.0	70.50	16.50
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	272.5	60.00	14.50
T_6- Fly ash + *Azospirillum* + Phosphobacteria	255.0	73.50	15.38
T_7-Pongamia leaf powder+ *Azospirillum* + Phosphobacteria	270.0	55.50	10.50
T_8-Bioslurry +Plant extracts +*Azospirillum* + Pseudomonas	265.0	52.50	13.75
SEm (±)	13.99		0.596
CD (0.05)	41.09	NS	1.751

4.9.3.2.2 Exchangeable Magnesium

Available Mg ranged from 43.50 mg kg^{-1} to 73.50 mg kg^{-1}. There was no significant influence of treatments on available Mg.

4.9.3.2.3 Available Sulphur

The available S of post- harvest soil showed significant variation due to organic manure seed pelleting. T_4 registered the highest available sulphur content (16.50 mg kg^{-1}) which was comparable with T_6 (15.38 mg kg^{-1}). The lowest value was recorded by T_1 (10.00 mg kg^{-1}).

4.9.3.3 Micronutrients

The status of available micronutrients in soil are presented in Table 19c. The treatments significantly influenced available Fe, Mn, Zn and B in soil while there was no significant influence on available Cu.

4.9.3.3.1 Available Iron

The highest available Fe of 41.08 mg kg^{-1} was recorded by T_3 which was on par with T_6 (39.85 mg kg^{-1}) whereas T_1 recorded the lowest value (36.07 mg kg^{-1}).

4.9.3.3.2 Available Manganese

Available Mn content ranged from 7.36 mg kg^{-1} to 11.31 mg kg^{-1}. T_3 registered the highest value and was on par with T_4 (11.04 mg kg^{-1}).

4.9.3.3.3 Available Zinc

T_3 registered the highest available Zn content (5.26 mg kg^{-1}) and differed significantly from other treatments. Lowest value of 3.42 mg kg^{-1} was recorded by T_1 and T_6.

4.9.3.3.4 Available Copper

There was no significant difference in available Cu content between treatments.

Table 19c. Effect of organic manure seed pelleting on availability of micronutrients in post-harvest soil

Treatment	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})
T_1- Control (Seeds alone without pelleting)	36.07	7.36	3.42	1.51	0.11
T_2- FYM + *Azospirillum* + Phosphobacteria	38.76	8.61	4.07	1.57	0.22
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	41.08	11.31	5.26	1.68	0.22
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	38.84	11.04	5.10	1.66	0.22
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	37.67	10.65	5.01	1.56	0.21
T_6- Fly ash + *Azospirillum* + Phosphobacteria	39.85	7.60	3.42	1.63	0.20
T_7-Pongamia leaf powder+ *Azospirillum* + Phosphobacteria	37.75	10.07	4.93	1.61	0.12
T_8-Bioslurry +Plant extracts +*Azospirillum* + Pseudomonas	36.18	10.57	4.92	1.52	0.20
SEm (±)	0.48	0.187	0.038		0.015
CD (0.05)	1.408	0.549	0.111	NS	0.045

4.9.3.3.5 Available Boron

Available B ranged from 0.11 mg kg^{-1} to 0.22 mg kg^{-1}. T_2, T_3 and T_4 registered same values (0.22 mg kg^{-1}) and were on par with T_5, T_6 and T_8.

4.10 EFFECT OF ORGANIC MANURE SEED PELLETING ON GRAIN QUALITY PARAMETERS

Organic manure seed pelleting significantly influenced starch and amylose content of rice grain (Table 20).

The starch content of rice grain ranged from 57.27 % to 64.32 %. T_4 recorded the highest value. T_4 was on par with T_3, T_6 and T_2 and they differed significantly from other treatments. The highest amylose content was recorded by T_4 (21.26 %) which was on par with T_6 (20.98 %). No significant variation was observed in amylopectin content among different treatments.

4.11 EFFECT OF ORGANIC MANURE SEED PELLETING ON NUTRIENT CONTENT AND UPTAKE BY GRAIN AND SHOOT

4.11.1 Nitrogen

The experimental results with respect to N content and uptake by grain and shoot are presented in Table 21.

The treatments varied significantly with respect to N content and uptake in grain and shoot. The lowest N content of 1.54 % was observed in T_1. All other treatments were on par and T_4 registered the highest value of 2.03 %.

Data on the effect of different treatments on N content in shoot revealed that T_2 differed significantly from other treatments and recorded the highest value (1.36 %) while T_1 registered the lowest (0.83 %).

Results on N uptake by grains indicated that T_3 recorded the highest value (0.99 g pot^{-1}) which was on par with T_4 (0.98 g pot^{-1}). These values were significantly higher than control as well as other treatments.

Table 20. Effect of organic manure seed pelleting on grain quality parameters of rice

Treatment	Starch (%)	Amylose (%)	Amylopectin (%)
T_1- Control (Seeds alone without pelleting)	57.27	15.67	41.60
T_2- FYM + *Azospirillum* + Phosphobacteria	63.60	18.05	45.55
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	63.94	20.68	43.26
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	64.32	21.26	43.06
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	59.86	17.81	42.05
T_6- Fly ash + *Azospirillum* + Phosphobacteria	63.76	20.98	42.78
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	60.18	17.56	42.62
T_8-Bioslurry +Plant extracts+ *Azospirillum* + Pseudomonas	60.69	18.07	42.62
SEm (±)	0.763	0.157	
CD (0.05)	2.239	0.461	NS

Table 21. Effect of organic manure seed pelleting on the content and uptake of N in grain and shoot

Treatment	N content (%)		Uptake (g pot^{-1})	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	1.54	0.83	0.52	0.26
T_2- FYM + *Azospirillum* + Phosphobacteria	2.02	1.36	0.69	0.48
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	1.92	0.94	0.99	0.51
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	2.03	1.02	0.98	0.46
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	1.88	0.87	0.63	0.28
T_6- Fly ash + *Azospirillum* + Phosphobacteria	1.82	0.92	0.71	0.35
T_7 -Pongamia leaf powder + *Azospirillum* + Phosphobacteria	1.79	0.91	0.67	0.35
T_8-Bioslurry +Plant extracts + *Azospirillum* + Pseudomonas	1.90	1.09	0.77	0.42
SEm (±)	0.085	0.049	0.041	0.026
CD (0.05)	0.251	0.143	0.119	0.078

N uptake by shoot ranged from 0.26 g pot^{-1} (T_1) to 0.51 g pot^{-1} (T_3). T_3 recorded the highest value which was on par with T_2 (0.48 g pot^{-1}) and T_4 (0.46 g pot^{-1}).

4.11.2 Phosphorus

The effect of different treatments on the content and uptake of P in grain and shoot are presented in Table 22.

The treatments were not having significant difference for phosphorus content in grain.

The P content in shoot was significantly influenced by the treatments. As evident from the data, P content was recorded the highest by T_3 (0.26 %) and T_1 showed the lowest value (0.11 %).

Data revealed that T_4 recorded the highest P uptake by grain (0.08 g pot^{-1}) while T_1 recorded the lowest (0.03 g pot^{-1}). All other treatments were on par.

The P uptake by shoot was maximum in T_3 (0.14 g pot^{-1}) which was significantly more than all other treatments. The lowest value of 0.03 g pot^{-1} was recorded by T_1.

4.11.3 Potassium

Impact of various treatments on the content and uptake of K in grain and shoot is given in Table 23.

Data revealed that T_6 which recorded the highest K content in grain (0.57 %) was on par with T_4 (0.55 %), T_3 (0.53 %), T_2 (0.52 %) and T_5 (0.50 %) whereas T_1 and T_7 recorded the lowest (0.43 %).

With respect to K content of shoot, both treatments T_4 and T_6 recorded the highest value (2.40 %) which was on par with T_5 (2.36 %), T_2 (2.28 %) and T_3 (2.28 %) while the lowest was recorded by T_1 (1.88 %).

Results indicated that K uptake by grain ranged from 0.14 g pot^{-1} to 0.28 g pot^{-1}. T_3 registered the highest value and was on par with T_4 (0.26 g pot^{-1}).

Table 22. Effect of organic manure seed pelleting on the content and uptake of P in grain and shoot

Treatment	P content (%)		Uptake (g pot^{-1})	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	0.01	0.11	0.03	0.03
T_2- FYM + *Azospirillum* + Phosphobacteria	0.15	0.15	0.05	0.05
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.11	0.26	0.06	0.14
T_4- Bioslurry flakes +*Azospirillum* + Phosphobacteria	0.15	0.17	0.08	0.08
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.15	0.13	0.05	0.04
T_6- Fly ash + *Azospirillum* + Phosphobacteria	0.11	0.13	0.05	0.05
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.15	0.11	0.06	0.04
T_8- Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	0.14	0.12	0.06	0.05
SEm (±)		0.016	0.006	0.008
CD (0.05)	NS	0.048	0.017	0.022

Table 23. Effect of organic manure seed pelleting on the content and uptake of K in grain and shoot

Treatment	K content (%)		Uptake (g pot^{-1})	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	0.43	1.88	0.14	0.58
T_2- FYM + *Azospirillum* + Phosphobacteria	0.52	2.28	0.18	0.80
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.53	2.28	0.28	1.25
T_4- Bioslurry flakes +*Azospirillum* + Phosphobacteria	0.55	2.40	0.26	1.09
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.50	2.36	0.17	0.77
T_6- Fly ash + *Azospirillum* + Phosphobacteria	0.57	2.40	0.22	0.91
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.43	2.15	0.16	0.84
T_8-Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	0.49	2.17	0.20	0.83
SEm (±)	0.026	0.073	0.012	0.052
CD (0.05)	0.075	0.214	0.034	0.152

Observations revealed that T_3 differed significantly from other treatments and recorded maximum K uptake in shoot (1.25 g pot^{-1}) while T_1 recorded the lowest value (0.58 g pot^{-1}).

4.11.4 Calcium

Calcium content and uptake by grain and shoot is presented in Table 24.

Data on Ca content in grain and shoot revealed that the influence of treatments was non-significant.

Results revealed that in grain, T_3 differed significantly from other treatments in Ca uptake and recorded the highest value (0.30 g pot^{-1}) whereas T_1 had the lowest value (0.14 g pot^{-1}).

The highest Ca uptake by shoot was recorded in T_3 (0.20 g pot^{-1}) which was on par with T_4 (0.17 g pot^{-1}) and T_6 (0.16 g pot^{-1}). T_1 registered the lowest value (0.09 g pot^{-1}).

4.11.5 Magnesium

The results of Mg content of grain and shoot as well as uptake are presented in Table 25.

The treatments had no significant difference in Mg content of grain and shoot as well as uptake by grain and shoot.

4.11.6 Sulphur

The treatments had a significant influence on S content and uptake by grain and shoot as shown in Table 26.

T_3 recorded the highest S content in grain (0.06 %) which was on par with T_5 (0.05 %), T_2 (0.05 %) and T_4 (0.05 %). T_1 and T_8 recorded the lowest value (0.02 %).

Table 24. Effect of organic manure seed pelleting on the content and uptake of Ca in grain and shoot

Treatment	Ca content (%)		Uptake (g pot^{-1})	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	0.40	0.28	0.14	0.09
T_2- FYM + *Azospirillum* + Phosphobacteria	0.42	0.42	0.15	0.15
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.58	0.36	0.30	0.20
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	0.42	0.36	0.21	0.17
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.48	0.42	0.16	0.14
T_6- Fly ash + *Azospirillum* + Phosphobacteria	0.40	0.42	0.16	0.16
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.42	0.34	0.16	0.13
T_8- Bioslurry + Plant extracts + *Azospirillum*+ Pseudomonas	0.48	0.30	0.20	0.12
SEm (±)			0.028	0.015
CD (0.05)	NS	NS	0.081	0.045

Table 25. Effect of organic manure seed pelleting on the content and uptake of Mg in grain and shoot

Treatment	Mg content (%)		Uptake (g pot^{-1})	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	0.19	0.17	0.07	0.06
T_2- FYM + *Azospirillum* + Phosphobacteria	0.38	0.34	0.14	0.12
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.24	0.36	0.13	0.20
T_4- Bioslurry flakes +*Azospirillum* + Phosphobacteria	0.22	0.29	0.11	0.13
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.26	0.34	0.09	0.11
T_6- Fly ash + *Azospirillum* + Phosphobacteria	0.36	0.29	0.14	0.11
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.29	0.31	0.11	0.13
T_8- Bioslurry + Plant extracts + *Azospirillum* + Pseudomonas	0.24	0.24	0.10	0.09
CD (0.05)	NS	NS	NS	NS

Table 26. Effect of organic manure seed pelleting on the content and uptake of S in grain and shoot

Treatment	S content (%)		Uptake (g pot^{-1})	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	0.02	0.02	0.007	0.006
T_2- FYM + *Azospirillum* + Phosphobacteria	0.05	0.08	0.017	0.029
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	0.06	0.08	0.029	0.045
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	0.05	0.06	0.022	0.028
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.05	0.06	0.017	0.019
T_6- Fly ash + *Azospirillum* + Phosphobacteria	0.04	0.02	0.015	0.008
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.04	0.05	0.015	0.019
T_8- Bioslurry + Plant extracts + *Azospirillum*+ Pseudomonas	0.02	0.03	0.009	0.011
SEm (±)	0.005	0.005	0.002	0.002
CD (0.05)	0.014	0.015	0.006	0.006

Both T_2 and T_3 registered same values (0.08 %) for S content in shoot and they differ significantly from other treatments while T_1 recorded the lowest (0.02%).

Data revealed that maximum S uptake in grain and shoot were observed in T_3 with values of 0.029 g pot^{-1} and 0.045 g pot^{-1}, respectively and it was statistically superior to all other treatments.

4.11.7 Zinc

The significant influence of treatments observed on content and uptake of Zn in grain and shoot is presented in Table 27.

It is clear from the table that T_3 registered the highest value (74.00 mg kg^{-1}) of Zn content in grain which was on par with T_4 (72.00 mg kg^{-1}) while T_1 recorded the lowest (22.30 mg kg^{-1}).

Observations revealed that T_4, T_6 and T_3 were on par with each other with respect to Zn content in shoot where in T_4 recorded the highest value (87.00 mg kg^{-1}) and T_1 the lowest (57.80 mg kg^{-1}).

Zn uptake of grain ranged from 0.75 mg pot^{-1} (T_1) to 3.81 mg pot^{-1} (T_3). T_3 differed significantly from all other treatments.

Uptake of Zn in shoot indicated that T_3 differed significantly from all other treatments and recorded the highest value (4.47 mg pot^{-1}) whereas T_1 registered the lowest (1.77 mg pot^{-1}).

4.11.8 Copper

Copper content and uptake in grain and shoot is presented in Table 28.

Results indicated that Cu content of grain was significantly higher for T_3 (19.30 mg kg^{-1}) compared to other treatments while T_1 recorded the lowest (5.97 mg kg^{-1}).

Table 27. Effect of organic manure seed pelleting on the content and uptake of Zn in grain and shoot

Treatment	Zn content ($mg\ kg^{-1}$)		Zn Uptake ($mg\ pot^{-1}$)	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	22.30	57.80	0.75	1.77
T_2- FYM + *Azospirillum* + Phosphobacteria	42.50	59.00	1.46	2.08
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	74.00	81.30	3.81	4.47
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	72.00	87.00	3.47	3.94
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	29.50	67.80	0.99	2.21
T_6- Fly ash + *Azospirillum* + Phosphobacteria	68.20	86.20	2.66	3.23
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	22.60	79.30	0.84	3.10
T_8- Bioslurry + Plant extracts + *Azospirillum*+ Pseudomonas	41.40	62.40	1.67	2.38
SEm (±)	0.865	2.058	0.052	0.127
CD (0.05)	2.541	6.044	0.151	0.374

Table 28. Effect of organic manure seed pelleting on the content and uptake of Cu in grain and shoot

Treatment	Cu content ($mg\ kg^{-1}$)		Cu Uptake ($mg\ pot^{-1}$)	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	5.97	10.50	0.20	0.32
T_2- FYM + *Azospirillum* + Phosphobacteria	18.60	20.30	0.64	0.71
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	19.30	26.90	1.00	1.48
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	18.20	29.70	0.88	1.35
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	11.48	23.20	0.39	0.75
T_6- Fly ash + *Azospirillum* + Phosphobacteria	17.55	14.80	0.69	0.56
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	12.49	20.80	0.46	0.82
T_8- Bioslurry + Plant extracts + *Azospirillum*+ Pseudomonas	14.36	21.10	0.58	0.81
SEm (±)	0.233	0.556	0.016	0.038
CD (0.05)	0.684	1.634	0.047	0.111

In case of Cu content of shoot, T_4 was statistically superior to other treatments and recorded the highest value of 29.70 mg kg^{-1} whereas the lowest was recorded by T_1 (10.50 mg kg^{-1}).

T_3 differed significantly from other treatments in Cu uptake by grain. Data indicated that T_3 resulted in maximum grain uptake (1.00 mg pot^{-1}) while T_1 recorded the lowest (0.20 mg pot^{-1}).

T_3 registered the highest value of Cu uptake by shoot (1.48 mg pot^{-1}). It differed significantly from other treatments and the lowest Cu uptake in shoot was in the control treatment T_1 (0.32 mg pot^{-1}).

4.11.9 Boron

Boron content and uptake in grain and shoot with respect to various treatments is given in Table 29.

T_4 recorded the highest B content in grain (1.65 mg kg^{-1}) which was on par with T_3 (1.46 mg kg^{-1}). These treatments were significantly higher than other treatments and control (0.14 mg kg^{-1}).

There was significant difference among treatments on B content of shoot. Data presented show that T_4 recorded the highest value (2.03 mg kg^{-1}) which was on par with T_3 (1.71 mg kg^{-1}) while T_1 recorded the lowest (0.25 mg kg^{-1}).

Observations on the uptake of B in grain indicated that T_3 recorded the highest value (0.079 mg pot^{-1}) which was on par with T_4 (0.076 mg pot^{-1}) and differed significantly from other treatments while T_1 recorded the lowest value (0.005 mg pot^{-1}).

As evident from the table, highest B uptake by shoot was recorded in T_3 (0.094 mg pot^{-1}). It was on par with T_4 (0.092 g pot^{-1}) and significantly higher compared to others whereas T_1 recorded the lowest value (0.008 mg pot^{-1}).

4.11.10 Silicon

The Si content and uptake by grain and shoot is presented in Table 30.

Table 29. Effect of organic manure seed pelleting on the content and uptake of B in grain and shoot

Treatment	B content ($mg\ kg^{-1}$)		B Uptake ($mg\ pot^{-1}$)	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	0.14	0.25	0.005	0.008
T_2- FYM + *Azospirillum* + Phosphobacteria	0.74	1.53	0.026	0.054
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	1.46	1.71	0.079	0.094
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	1.65	2.03	0.076	0.092
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	0.65	1.49	0.022	0.048
T_6- Fly ash + *Azospirillum* + Phosphobacteria	1.08	1.65	0.042	0.062
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	0.52	0.92	0.019	0.036
T_8- Bioslurry + Plant extracts + *Azospirillum*+ Pseudomonas	0.78	1.19	0.032	0.046
SEm (±)	0.096	0.125	0.004	0.005
CD (0.05)	0.282	0.367	0.012	0.016

Table 30. Effect of organic manure seed pelleting on the content and uptake of Si in grain and shoot

Treatment	Si content (%)		Uptake ($g\ pot^{-1}$)	
	Grain	Shoot	Grain	Shoot
T_1- Control (Seeds alone without pelleting)	3.20	6.03	3.20	6.03
T_2- FYM + *Azospirillum* + Phosphobacteria	4.08	7.93	4.08	7.93
T_3- Vermicompost + *Azospirillum* + Phosphobacteria	4.83	8.20	4.83	8.20
T_4- Bioslurry flakes + *Azospirillum* + Phosphobacteria	4.58	8.68	4.58	8.68
T_5-Charcoal powder + *Azospirillum* + Phosphobacteria	4.23	7.60	4.23	7.60
T_6- Fly ash + *Azospirillum* + Phosphobacteria	5.12	8.81	5.12	8.81
T_7-Pongamia leaf powder + *Azospirillum* + Phosphobacteria	3.22	7.42	3.22	7.42
T_8- Bioslurry + Plant extracts + *Azospirillum*+ Pseudomonas	3.42	6.80	3.42	6.80
SEm (±)	0.073	0.062	0.073	0.062
CD (0.05)	0.22	0.18	0.22	0.18

Si content of grain varied from 3.20 % (T_1) to 5.12 % (T_6). T_6 gave significantly higher value than all other treatments.

Highest Si content in shoot of 8.81% was recorded with T_6 which was on par with T_4 (8.68%) and significantly higher than other treatments. The lowest value was registered by T_1 (6.03%).

Grain and shoot uptake of Si was maximum in T_3 with values of 2.49 g pot^{-1} and 4.50 g pot^{-1}, respectively which was significantly higher than all other treatments.

DISCUSSION

5. DISCUSSION

The results obtained from the present study entitled 'Organic manure seed pelleting for enhancing soil health and productivity of rice' are discussed in this chapter.

5.1. CHARACTERIZATION OF ORGANIC MANURE SEED PELLETING MATERIALS

5.1.1 Physical properties

There was a significant influence of treatments on bulk density and WHC (Table 4a). T_6 (Fly ash + *Azospirillum* + Phosphobacteria) recorded the highest bulk density. This might be due to the high bulk density of fly ash. Bulk density of fly ash (1-1.8 Mg m^{-3}) depends on particle size, mineral composition and type of coal which undergone combustion to produce ash (Kishor *et al.*, 2010). T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) showed an intermediate bulk density of 0.57 Mg m^{-3}. The highest water holding capacity was recorded by T_7 (Pongamia leaf powder + *Azospirillum* + Phosphobacteria) and this might be due to the presence of functional groups having more affinity towards water as well as hydration of colloids in pongamia leaf powder (Prakash *et al.,* 2018).

5.1.2 Physico-chemical properties

5.1.2.1 pH and EC

All treatments had near neutral to slightly alkaline pH (Table 4b). The highest EC was recorded by T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) and T_6 (Fly ash + *Azospirillum* + Phosphobacteria) recorded the lowest value. High EC in T_4 might be due to the release of various mineral salts such as phosphate, potassium etc. The results are in line with FAI (2017) which supports that the pH of good quality organic manures lies within the range of 6.5-7.5 while EC ranges below 4 dS m^{-1}.

5.1.3 Nutritional properties of pelleting materials

There was no significant difference among the treatments for ammoniacal and nitrate nitrogen (Table 5a). The P content of pelleting materials varied significantly and the highest was estimated in T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria). This might be due to the higher P content in bioslurry (Jeptoo *et al.*, 2013). The highest K content was in T_7 (Pongamia leaf powder + *Azospirillum* + Phosphobacteria). Ramanjaneyulu *et al.* (2017) observed that pongamia leaves have a K content of 1.30 per cent.

With respect to secondary nutrients (Table 5b), the highest content of Ca, Mg and S were recorded by T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria). This might be due to the presence of secondary nutrients in bioslurry. It was reported that digested bioslurry contains nutrients such as Ca, Mg and S (Malav *et al.*, 2015).

Table 5c shows that T_6 (Fly ash + *Azospirillum* + Phosphobacteria) recorded the highest value for Fe. This is possibly due to the presence of Fe in fly ash. Chemically, 95-99 per cent of fly ash consists of oxides of Si, Al, Fe and Ca and remaining 0.5-3.5 per cent is Na, P, K, Mg, Mn and S (Nawaz, 2013). Mn, Zn and Cu content were highest in T_4 (Bioslurry flakes +*Azospirillum* + Phosphobacteria). Malav *et al.* (2015) reported that biogas slurry contains micronutrients such as Cu (0.004 ppm), Mn (0.088 ppm) and Zn (0.023 ppm). The B content was the highest in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria).

5.1.4 Enzymatic activity of pelleting materials

Enzymatic activity of pelleting materials was significantly influenced by the treatments (Table 6). T_7 (Pongamia leaf powder + *Azospirillum* + Phosphobacteria) registered the highest urease and acid phosphatase activity. This might be due to the presence of specific substrate in pongamia leaf powder which would have favoured the colonization of microbes enhancing urease and acid phosphatase activities. The results are in line with the findings of Subramanian *et al.* (2016) who reported that enzymatic activity indicates microbial dynamics and is higher in organic manure.

Dehydrogenase activity was maximum in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) whereas T_6 (Fly ash + *Azospirillum* + Phosphobacteria) recorded the lowest value. Generally, dehydrogenase activity indicates the overall microbial load. The results are also similar to the findings of Carpenter-Boggs *et al.* (2000) who reported that microbial biomass, respiration and dehydrogenase activity increased with addition of compost. Addition of organic manures supply C as well as energy for multiplication of microbes which may be the reason behind the increased enzymatic activities (Tate, 2000). Similar results were reported by Zhen *et al.* (2014). Kanchikerimath and Singh (2001) reported that application of manure increases the organic matter content thereby enhancing enzymatic activity.

5.1.5 Organic acid content of pelleting materials

Fig. 3 indicates that humic and fulvic acid content were highest in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) which was on par with T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria). The castings of red worm contain high per cent of humic acid and this serves as binding sites for nutrients such as Ca, Fe, K, S and P (Adhikary, 2012). Similar results were also reported by Atiyeh *et al.* (2002) and Arancon *et al.* (2006). The per cent of humic acid remained high in all treatments as humic acid fraction is more stable than fulvic acid fraction.

5.2. ANALYSIS OF ORGANIC MANURE SEED PELLETS AFTER 15 DAYS

Seedlings raised from pellets were separated after 15 days and pellets were analysed. As evident from Tables 8, 9a, 9b, 9c, 10 and 11, pH and EC were highest in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria). In case of nutritional properties, no treatments influenced ammoniacal and nitrate nitrogen. T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) recorded the highest values for all nutrients except for Mg and B. T_3 recorded the highest Mg content and T_6, the highest B content. This variation might be due to the difference in the nutrient

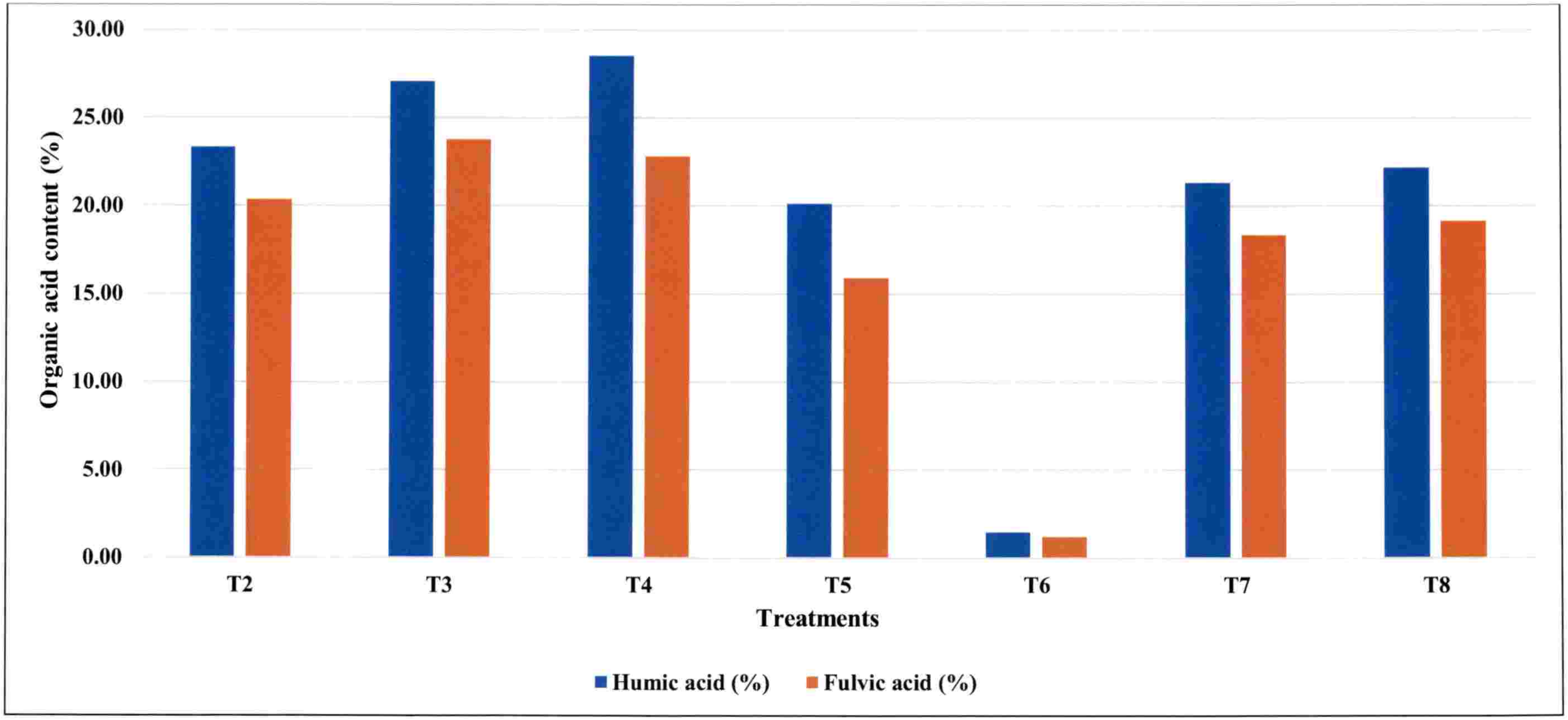


Fig. 3. Organic acid content of pelleting materials

content of the manure sources and the difference in mineralization as a result of microbial activity. Enzymatic activities and organic acid content followed similar trend as initial.

5.3 GERMINATION ASSAY

Germination per cent of seeds was 100 per cent from all treatments except T_7 (Pongamia leaf powder + *Azospirillum* + Phosphobacteria). T_5 (Charcoal powder + *Azospirillum* + Phosphobacteria) attained 50 per cent germination in an average of 3.75 days. However, it was on par with T_3, T_4, T_8 and T_2 and more number of days for 50 per cent germination was taken by T_7 (Table 12a). Slow rate of germination of seeds from T_7 might be due to more water holding capacity exhibited by T_7 that could inhibit germination. The hindrance in germination and emergence of seeds from T_7 might also be due to the hardiness of pongamia leaf powder pelleted seed.

5.4 SEEDLING STUDIES

As indicated in Table 12b, T_2 (FYM + *Azospirillum* + Phosphobacteria) recorded significantly higher mean root length, mean shoot length, seedling length and vigour indices. This might be attributed to the effect of FYM. Saraf and Tiwari (2004) observed that phytohormones extracted from FYM promote splendid plant growth. Similar results were reported by Ibrahim *et al.* (2010) who opined that FYM application significantly increased root length and volume of rice. Also seeds treated with *Azospirillum* would have increased shoot and root length by stimulating the production of plant growth promoting substances. The results are in line with the findings of Hossain (2015). The enhancement in seedling parameters might be due to the combined application of *Azospirillum* and phosphate solubilizer along with FYM.

5.5 EFFECT OF ORGANIC MANURE SEED PELLETING ON BIOMETRIC CHARACTERS OF PLANT

5.5.1 Root length, root and shoot biomass

The results revealed (Table 14a) that root length, root and shoot biomass were significantly influenced by the treatments and T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) registered the highest values. This might be due to the impact of bioslurry. Garg *et al.* (2005) revealed that there is an increase in root length of wheat and rice when amended with bioslurry. Increased shoot and root biomass recorded by T_4 might be attributed to the higher nutrient content of bioslurry. Prominent root length of T_4 would have also aided in the absorption of essential nutrients from soil which in turn favoured shoot and root growth. The increase in dry biomass in T_4 might be attributed to an increase in number of leaves per plant by the effect of bioslurry. The use of *Azospirillum* could have improved the root growth by the production of various growth stimulating substances thus providing availability of minerals (Murthy and Ladha, 1988). The positive interaction of phosphate solubilizing bacteria and *Azospirillum* with bioslurry could have resulted in an increase in root length as well as biomass.

5.5.2 Height of plants

Plant height was significantly influenced by the treatments (Tables 14b and 16). Maximum plant height was recorded in T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) at active tillering, panicle initiation and harvest stages. T_4 was on par with T_2 (FYM + *Azospirillum* + Phosphobacteria) at active tillering stage whereas it was comparable with T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) and T_6 (Fly ash + *Azospirillum* + Phosphobacteria) at harvest stage. This might be due to the higher nutrient content of bioslurry. This is in accordance with the reports of FAO (1996) that plant height was increased due to the contribution of various nutrients in bioslurry which improved plant growth by promoting soil nutrient level. Higher N content in bioslurry result in maximum plant height. Similar results were reported by Islam *et al.* (2010). Application of bioslurry contributed the maximum plant height for fodder maize (Rahman *et al.*, 2008). Increase in plant height might also be due to the synergistic effect of organic manures and biofertilizers. Application of *Azospirillum* and PSB might have enhanced root growth, proliferation and expansion of cells eventually resulting in increased height of plants. Anand and Kamaraj (2017) reported that rice seeds recorded maximum plant height when treated with *Azospirillum* + Phosphobacteria + VAM.

5.5.3 Number of tillers

Organic manure seed pelleting significantly influenced the number of tillers in rice (Tables 14b and 16). Maximum number of tillers at active tillering stage was in T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) which was on par with T_3 (Vermicompost + *Azospirillum* + Phosphobacteria). At panicle initiation and harvest stages, T_3 recorded the maximum number of tillers which were on par with T_4. The highest nutrient content associated with treatments T_3 and T_4 could have contributed to more vegetative growth and more number of tillers. Increase in tiller number at panicle initiation and harvest stages might be contributed by the influence of vermicompost which modifies the rhizosphere region thereby providing available nutrients. Similar results were reported by Roy and Singh (2006) in barley.

5.5.4 Leaf Area Index

As evident from Table 14b, the highest value of LAI was recorded in T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria). However, it was on par with T_6 (Fly ash + *Azospirillum* + Phosphobacteria), T_2 (FYM + *Azospirillum* + Phosphobacteria) and T_3 (Vermicompost + *Azospirillum* + Phosphobacteria). This might be attributed to an increase in vegetative growth and leaf area due to the effect of bioslurry. Similar results were reported by Rahman *et al.* (2008) and Garg *et al.* (2005) who observed that application of bioslurry increased leaf area index, root length density and plant height of wheat and rice. The inoculation of *Azospirillum sp.* would have contributed to significant increase in number of leaves per plant, length and breadth of leaves. Similar findings were also reported by Hossain (2015). A positive synergistic effect of *Azospirillum* and PSB might have also contributed to an increment in LAI.

5.6 EFFCT OF ORGANIC MANURE SEED PELLETING ON YIELD ATTRIBUTES AND YIELD

The effect of organic manure seed pelleting on yield attributes like productive tillers, spikelets per panicle and filled grain per cent are shown in Table 17a.These characters were significantly influenced by T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) which might be due to N mineralization and more availability of nutrients from vermicompost. Vermicompost contains significant quantities of nutrients and N mineralization activates various enzymes and produce hormones which are involved in cell expansion which might have contributed to higher yield characters. This was in line with the findings of Gopalreddy (1997) and Atiyeh *et al.* (2002) who reported that vermicompost improves microbes such as N-fixers, P-solubilizers thereby increasing the nitrogenase and urease enzyme activity. Increment of yield attributes in T_3 might be due to higher uptake of nutrients and more dry matter content. Singh *et al*. (2010) revealed that higher uptake of nutrients increased the number of panicles, panicle mass and grains per panicles of rice. Similar results were reported by Thirunavukkarasu and Vinoth (2013) who observed that addition of vermicompost increased the number of productive tillers in rice and was attributed to the higher availability of nutrients from vermicompost. Combined application of biofertilizers and vermicompost might have resulted in available N eventually increasing yield attributes such as productive tillers, spikelets per panicle and filled grain per cent. This was in conformity with results of Patel (2012) who reported higher values of yield attributing characters like number of effective tillers, filled grains panicle^{-1}, panicle length, panicle weight and test weight with application of vermicompost along with PSB + *Azospirillum* and some other growth promoting substances.

There was no significant influence of treatments on length of panicle and 1000 grain weight of rice.

Period of retention time of flag leaf was influenced by T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria). This might be due to prolonged N availability from bioslurry flakes. However, it was on par with T_2 (FYM + *Azospirillum*+ Phosphobacteria) (Table 17a). Tuyishime *et al.* (2011) found that nutrient release from organic manure is slow leading to sustained nutrient availability.

T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) significantly influenced grain and straw yield (Fig. 4). Higher grain and straw yields in T_3 might be due to the positive influence of T_3 on productive tillers, number of spikelets per panicle and filled grain per cent. This substantiates with the findings of Thirunavukkarasu and Vinoth (2013) that addition of vermicompost increased yield attributing characters and finally yield. Influence of T_3 on high nutrient uptake as well as dry matter content could also increase grain and straw yields. This was in conformity with the results and findings of Barik *et al.* (2008) that higher uptake facilitated by increased availability of nutrients resulted in higher dry matter production and yields. Higher grain and straw yields of rice might be due to greater content of humic acid in T_3. This might be due to the presence of humic acid in vermicompost. Similar findings were reported by Canellas *et al.* (2002) who found that humic acid stimulated plant growth thereby improving maize yield. This also agrees with the findings of Arancon *et al.* (2005) and Jeyabal and Kuppuswamy (2001) who got higher yields in rice- legume cropping system when vermicompost and biofertilizers were applied together.

Regarding harvest index of rice (Table 17b), T_4, T_5, T_6 and T_8 recorded same values (0.47) and were comparable with T_7 and the lowest was recorded by T_1 and T_2 (0.44).

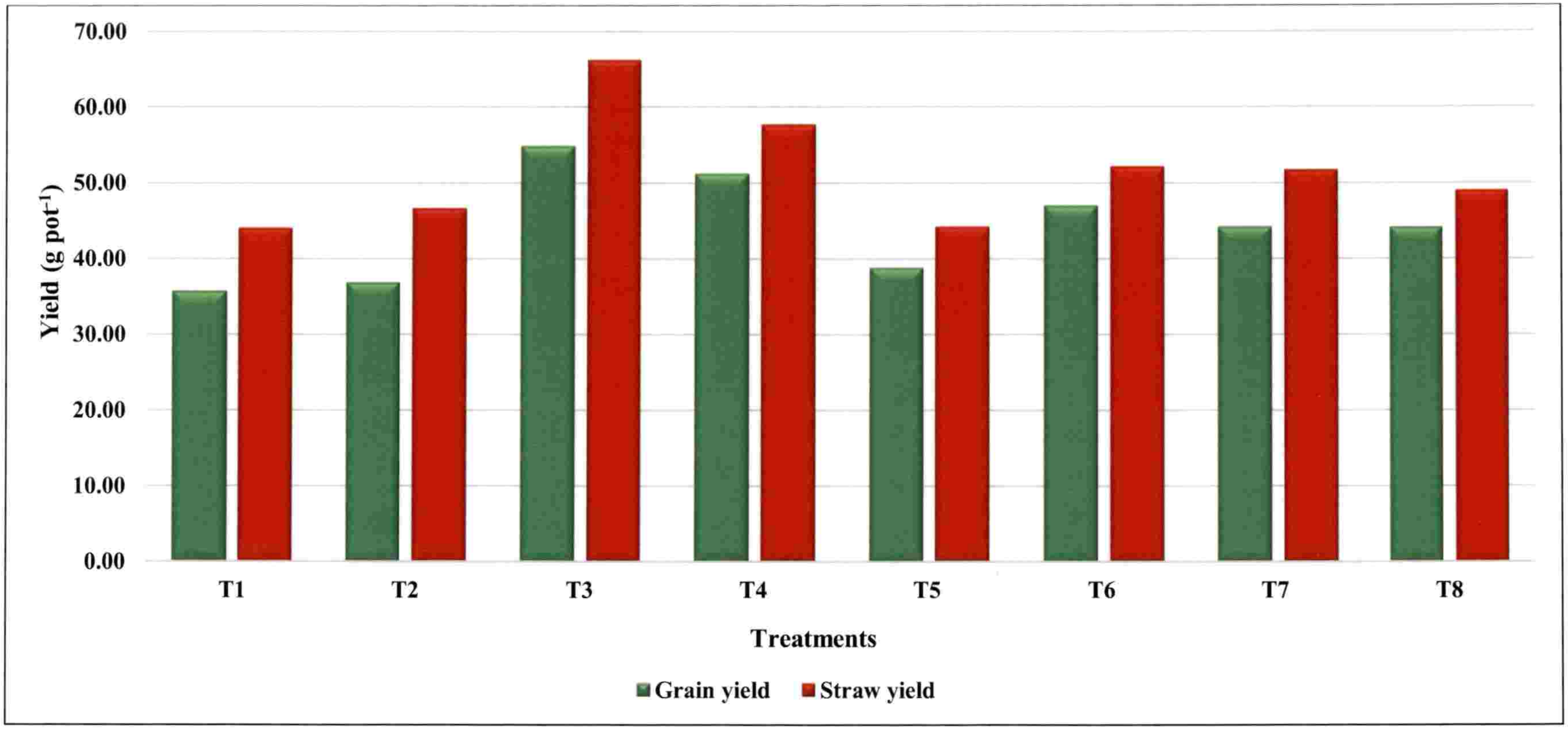


Fig. 4. Effect of organic manure seed pelleting on grain and straw yield of rice

5.7 POST HARVEST SOIL CHEMICAL PROPERTIES AND NUTRIENT STATUS

The effect of treatments on post-harvest analysis of soil was studied and it was found that pH, EC, ammoniacal nitrogen, P, K, Ca, S, Fe, Mn, Zn and B were significantly influenced by the treatments while the effect on nitrate nitrogen, Mg and Cu were found to be non-significant.

The results presented in Table 18 revealed that pH and EC of post-harvest soil were influenced by treatments. T_6 (Fly ash + *Azospirillum* + Phosphobacteria) recorded the highest value of soil pH and was on par with T_3. This might be due to the presence of carbonates and hydroxide salts in fly ash which would have reduced soil acidity by neutralising hydrogen ions in the soil solution (Das, 2011). T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) had the highest value of EC. However, T_4 was on par with T_3 and T_8. The higher EC might be due to the release of soluble salts from bioslurry flakes.

As evident in Table 19a, T_2 (FYM + *Azospirillum* + Phosphobacteria) recorded maximum value for ammoniacal N and differed significantly from other treatments. This might be attributed by decomposition and gradual mineralization of nutrients from FYM. Also, the N in FYM would have undergone hydrolysis to produce ammoniacal N. Similar results were reported by Sommer and Hutchings (2011) and Parewa *et al.* (2014). The treatments did not have significant influence on nitrate nitrogen content of soil. Available P and K content were highest in T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria). This might be due to mineralization leading to availability of nutrients in rhizosphere. This was in conformity with the findings of Islam *et al.* (2016) that release of P from the decomposition of bioslurry resulted in higher available P in soil. Application of mineral fertilizer and bioslurry aided availability of potassium content in soil (Muhammad, 2011). Exchangeable Ca and available S were maximum in T_4 (Table 19b). This might be due to the high Ca and S content in bioslurry. The results are in line with the findings of Islam *et al.* (2010) who observed that addition of bioslurry apparently increased the availability of soil nitrogen and other macro and micronutrients. In a similar study, Jared *et al.* (2016) found that bioslurry could restore soil as it contains several nutrients.

T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) influenced micronutrients such as Fe, Mn and Zn (Table 19c). In case of Fe, T_3 was on par with T_6 whereas it was comparable with T_4 for Mn content. This might be due to the release of micronutrients from vermicompost leading to increased availability. This is in accordance with the findings of Srivastava *et al.* (2011) that earthworms promote microbial activities leading to mineralization thereby providing high amount of available form of nutrients. T_2 (FYM + *Azospirillum* + Phosphobacteria), T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) and T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) registered highest values for B and were on par with T_5, T_6 and T_8.

5.8 EFFECT OF ORGANIC MANURE SEED PELLETING ON GRAIN QUALITY PARAMETERS

The results presented in Fig. 5 revealed that grain quality parameters such as starch and amylose were significantly influenced by T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria). This might be due to the higher P content in T_4. This is in conformity with the findings of Davari and Sharma (2010) who reported that application of phosphorus, N and P biofertilizers significantly improves carbohydrate content. Similar results were reported by Hargilas and Sharma (2015) who found that combination of organic and bio-inoculants resulted in better grain quality. Though amylopectin content was not significant, it was higher than amylose content. This is because the ratio of amylose to amylopectin within the starch depend on the cereal and its variety. In rice, 25–27 per cent of starch is present as amylose and most of the starch is amylopectin.

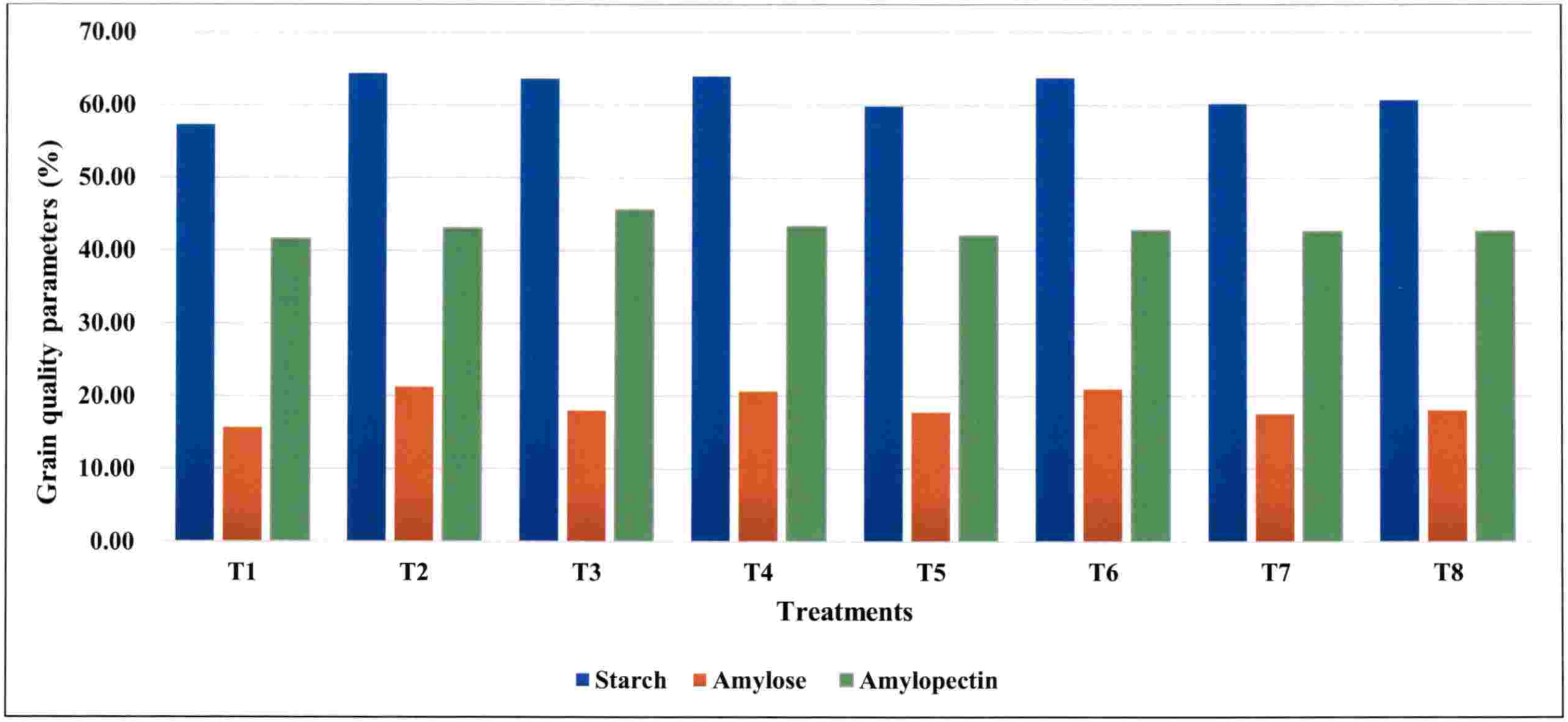


Fig. 5. Effect of organic manure seed pelleting on grain quality parameters of rice

5.9 EFFECT OF ORGANIC MANURE SEED PELLETING ON NUTRIENT UPTAKE BY GRAIN AND SHOOT

N uptake by grain and shoot was significantly influenced by the treatments (Fig. 6). T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) recorded the highest value for grain uptake which was on par with T_4. T_3 also recorded the highest value for N uptake by shoot which was on par with T_2 and T_4. The increase in N uptake might be due to the enhanced availability of N in vermicompost. P uptake by grain was highest in T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria). The high uptake of P in grain might be due to higher content of P in T_4. P uptake in shoot was maximum in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) and this might be due to the presence of PSB in T_3 which enhances phosphatase activity and increases the availability of P (Fig. 7). T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) registered maximum K uptake by grain and shoot. However, it was on par with T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) (Fig. 8).

Ca uptake by grain and shoot was highest in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) (Fig. 9). There was no significant difference in Mg uptake by grain and shoot (Fig. 10). S uptake by grain and shoot was maximum in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) and it was statistically superior to all other treatments (Fig. 11). T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) differed significantly from all other treatments in Zn uptake of grain and shoot (Fig. 12). Cu uptake by grain and shoot was significantly influenced by T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) (Fig. 13). The uptake of B by grain and shoot was maximum in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) and both were on par with T_4 (Bioslurry flakes + *Azospirillum* + Phosphobacteria) (Fig. 14). Grain and shoot uptake of Si was maximum in T_3 (Vermicompost + *Azospirillum* + Phosphobacteria) and was significantly higher than all other treatments (Fig. 15).

The higher uptake of nutrients in grain and shoot in T_3 might be due to increased tiller number, dry matter, higher yield attributes as well as grain and straw

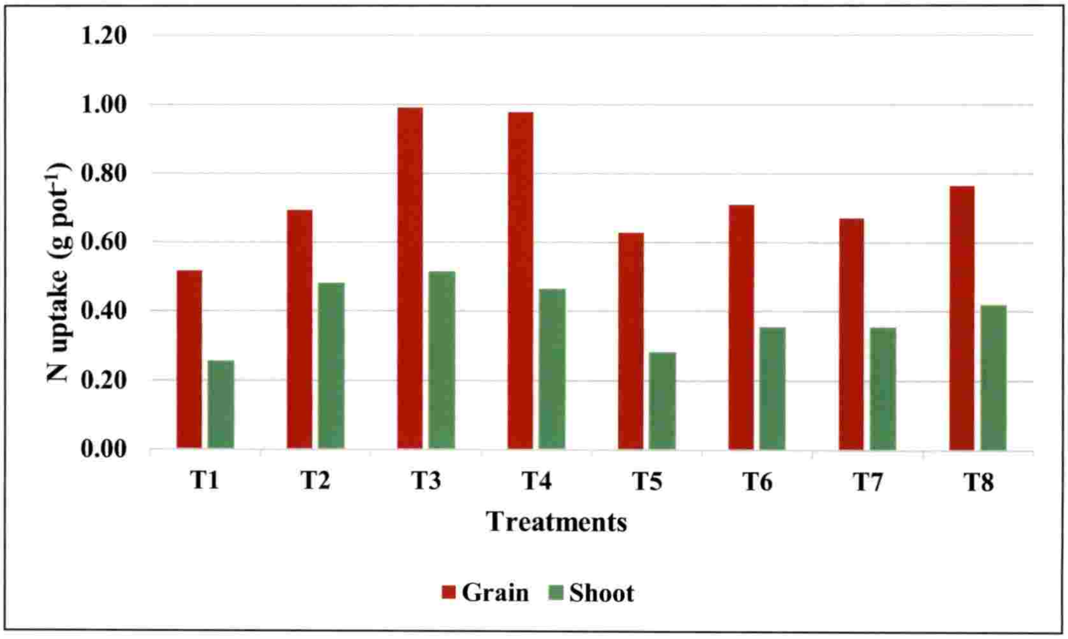


Fig.6. Effect of organic manure seed pelleting on N uptake by grain and shoot

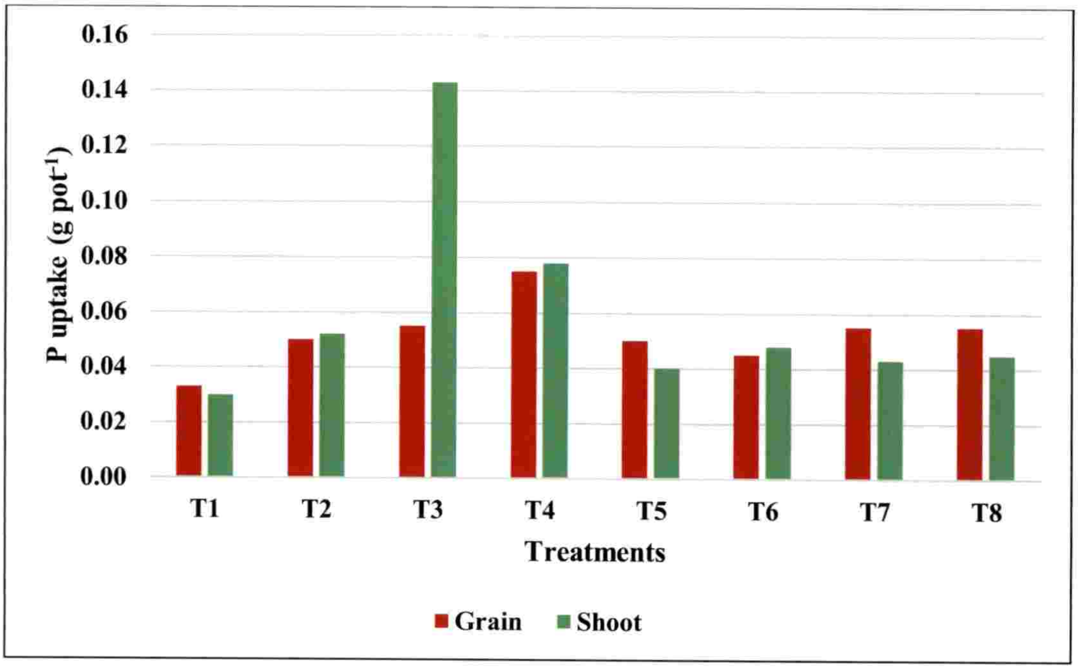


Fig. 7. Effect of organic manure seed pelleting on P uptake by grain and shoot

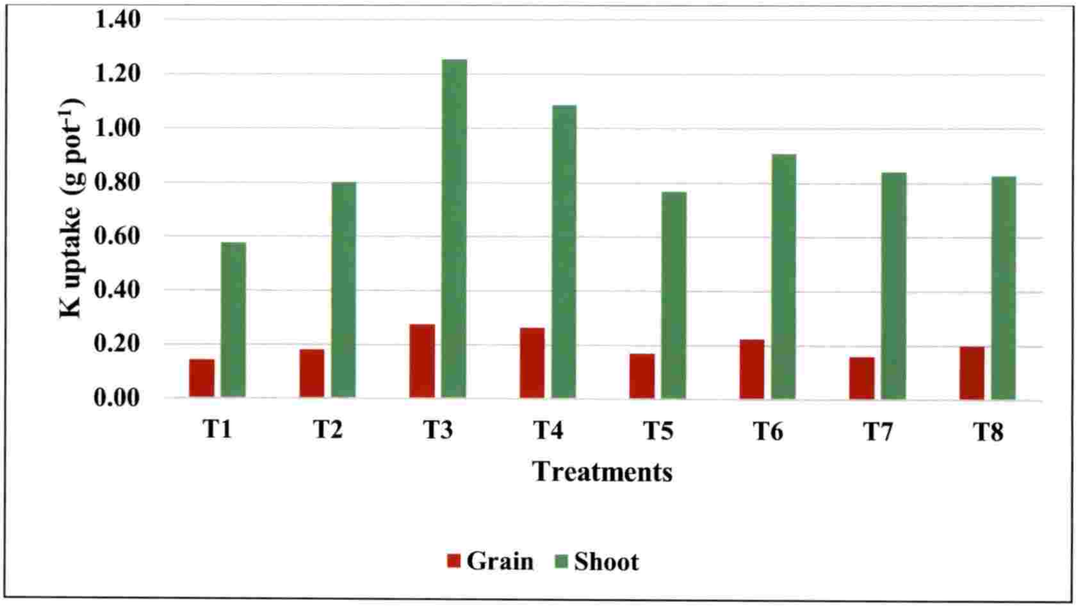


Fig. 8. Effect of organic manure seed pelleting on K uptake by grain and shoot

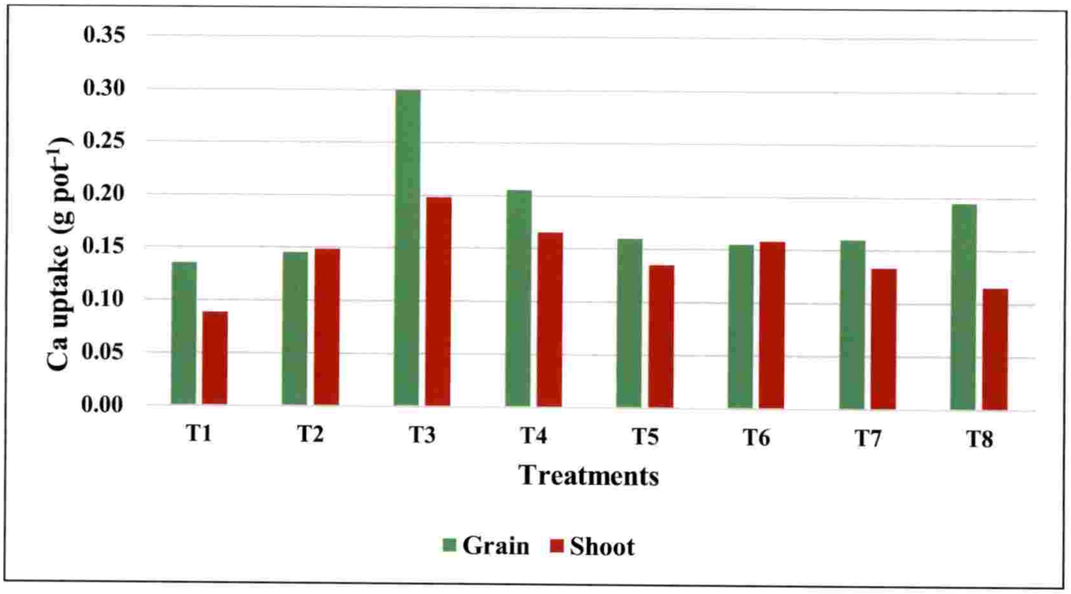


Fig. 9. Effect of organic manure seed pelleting on Ca uptake by grain and shoot

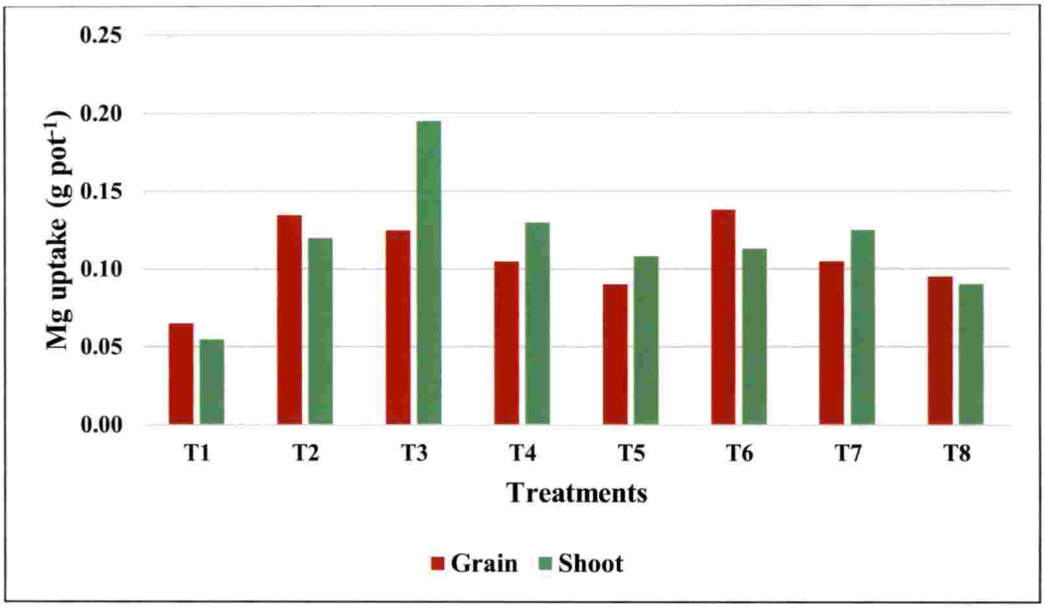


Fig. 10. Effect of organic manure seed pelleting on Mg uptake by grain and shoot

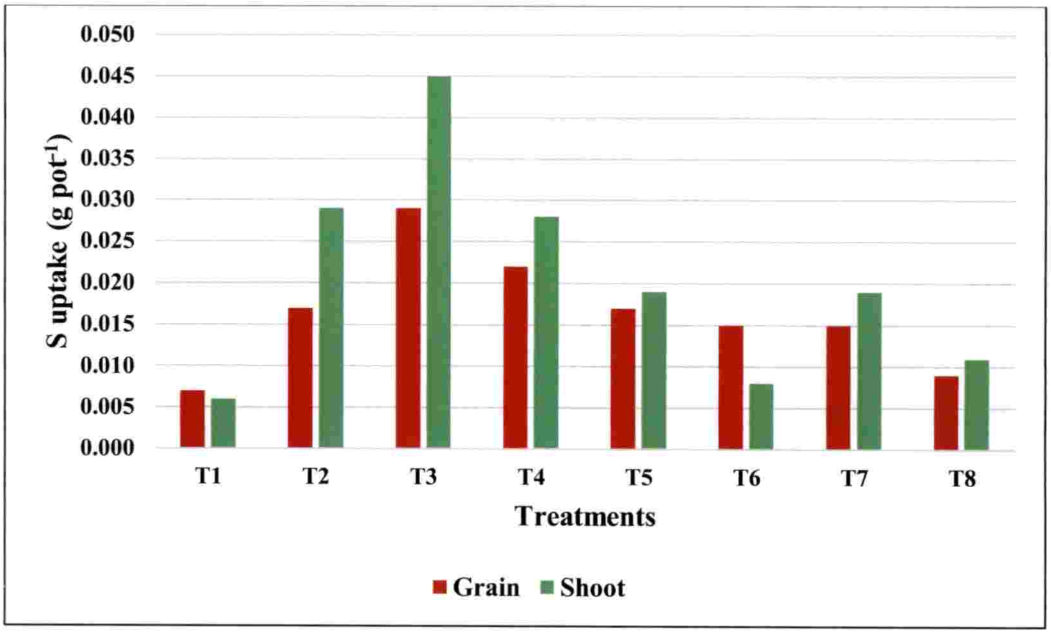


Fig. 11. Effect of organic manure seed pelleting on S uptake by grain and shoot

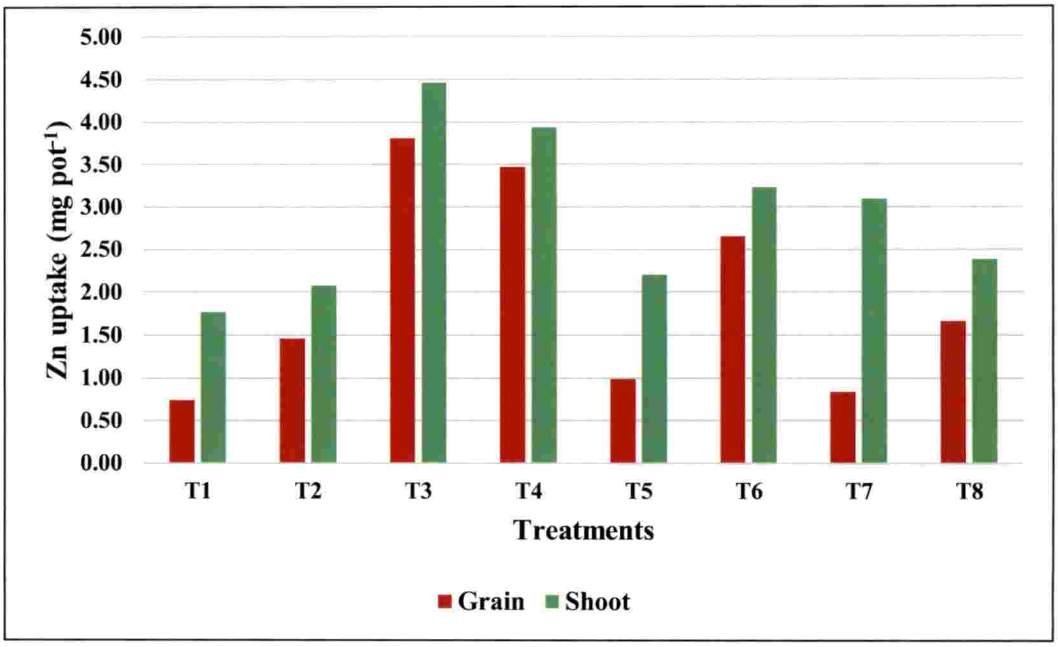


Fig. 12. Effect of organic manure seed pelleting on Zn uptake by grain and shoot

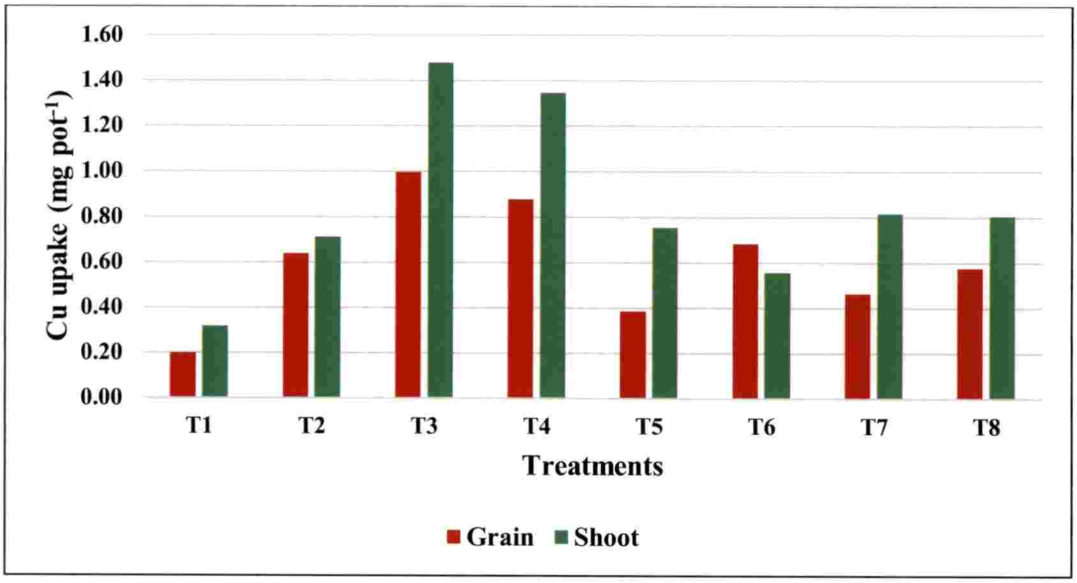


Fig. 13. Effect of organic manure seed pelleting on Cu uptake by grain and shoot

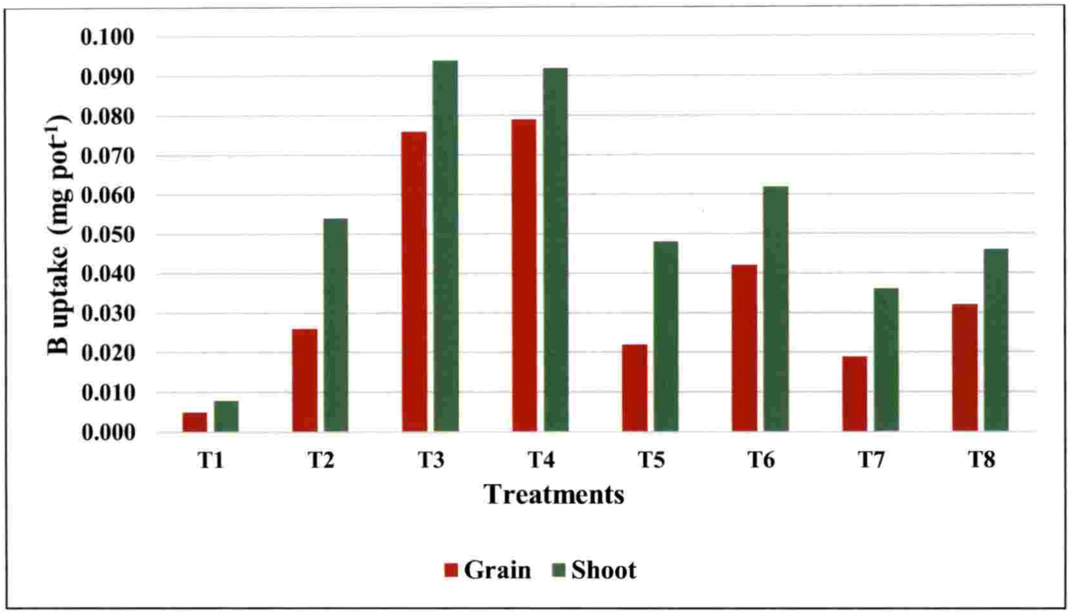


Fig. 14. Effect of organic manure seed pelleting on B uptake by grain and shoot

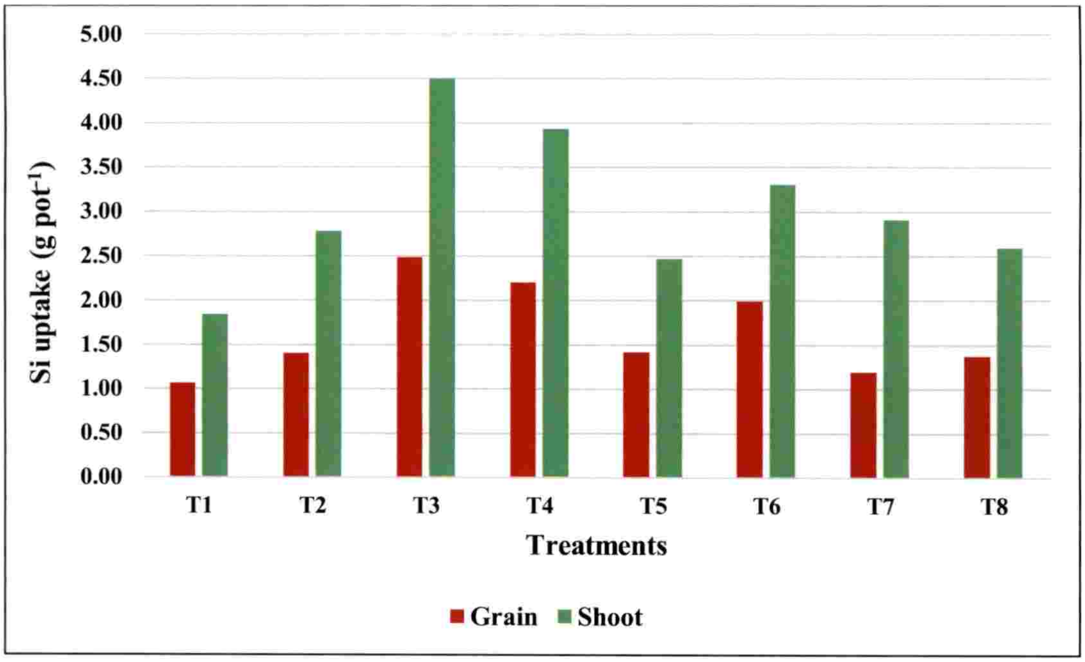


Fig. 15. Effect of organic manure seed pelleting on Si uptake by grain and shoot

yield. Higher nutrient uptake by T_3 might be also due to the influence of vermicompost. Vermicompost has the ability to hold more nutrients due to the presence of microsites facilitated by high surface area of vermicompost (Atiyeh *et al.*, 2002). Vermicompost application promotes microbial activity resulting in nutrient mobilization leading to more uptake of nutrients. This is in accordance with the findings of Ansari *et al.* (2008) who observed that application of vermicompost improved microbial activity which led to mobilization of nutrients, both macro and micro, thus enhancing uptake. Similar results were reported by Prasad *et al.* (2010). Thirunavukkarasu and Vinoth (2013) also reported similarly. Release of nutrients due to the production of organic acids by decomposition of vermicompost and release of various substances promoting growth would have resulted in more dry matter yield leading to higher nutrient uptake (Prakash and Bhadoria, 2003). Hartenstein and Rothwell (1973) observed there was an increase in uptake of all nutrients in sorghum when pelletised garbage composts were used as nutrient source. A positive synergistic effect of vermicompost with *Azospirillum* and PSB might also have contributed to an increase in dry matter thereby leading to higher uptake of nutrients.

SUMMARY

6. SUMMARY

The salient findings obtained from the study on 'Organic manure seed pelleting for enhancing soil health and productivity of rice' are summarized in this chapter.

The study was conducted from October 2018 to February 2019 at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, with the objective to develop seed pellets of rice using organic manures and microbial inoculants and to study its effect on soil properties, seedling vigour, growth and yield of rice. The study consisted of preparation and characterization of organic manure seed pellets and a pot culture experiment to evaluate the organic manure seed pellets.

Preparation of organic manure seed pellets

Organic manure seed pelleting materials tried were FYM + *Azospirillum* + Phosphobacteria (T_2), vermicompost + *Azospirillum* + Phosphobacteria (T_3), bioslurry flakes + *Azospirillum* + Phosphobacteria (T_4), charcoal powder + *Azospirillum* + Phosphobacteria (T_5), fly ash + *Azospirillum* + Phosphobacteria (T_6), pongamia leaf powder + *Azospirillum* + Phosphobacteria (T_7) and bioslurry + plant extracts + *Azospirillum* + Pseudomonas (T_8: Farmer practice). Carrier based inoculum of *Azospirillum* and Phosphobacteria were used at the rate of 5 g kg^{-1} and fenugreek paste was added at the rate of 25 g kg^{-1} as adhesive. Seeds alone without pelleting was used as control (T_1).

Characterization of organic manure seed pellets

- Pelleting material prepared using fly ash, *Azospirillum* and Phosphobacteria (T_6) gave significantly higher bulk density while WHC was highest in the treatment bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4).
- The pH of all pelleting materials was near neutral to slightly alkaline and EC of all pelleting materials were within safe limits.

- There was no significant difference between the treatments for ammoniacal and nitrate nitrogen. The highest P content of 1.36 per cent was registered by the treatment bioslurry flakes, *Azospirillum* and Phosphobacteria while highest K content was recorded by pongamia leaf powder, *Azospirillum* and Phosphobacteria (T_7).
- Pelleting material prepared with bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) registered the highest content of Ca (3.46 %), Mg (2.57 %) and S (1.03 %).
- With respect to micro nutrient content of pelleting materials, pelleting material prepared using fly ash, *Azospirillum* and Phosphobacteria (T_6) recorded the highest Fe content. T_4 had the highest Mn, Zn and Cu content whereas B content was highest for pelleting material prepared with vermicompost, *Azospirillum* and Phosphobacteria (T_3) and was comparable with T_6.
- Regarding enzymatic activity, there was significant influence of treatments on enzymatic activity. Urease and acid phosphatase activities were highest in pelleting material prepared with pongamia leaf powder, *Azospirillum* and Phosphobacteria (T_7) while treatment containing vermicompost, *Azospirillum* and Phosphobacteria (T_3) had maximum dehydrogenase activity.
- Pelleting material prepared using vermicompost, *Azospirillum* and Phosphobacteria (T_3) had the highest humic and fulvic acid content.
- Seedlings raised from pellets were separated after 15 days and pellets were analysed. pH and EC were highest in T_3. In case of nutritional properties, nutrients were highest in T_4 except for Mg and B where T_3 recorded the highest Mg content and T_6 the highest B content. Enzymatic activities and organic acid content followed similar trend as initial.

Germination assay

- Germination per cent in all treatments except the treatment pongamia leaf powder, *Azospirillum* and Phosphobacteria (T_7) were 100 per cent.

Treatment prepared with charcoal powder, *Azospirillum* and Phosphobacteria (T_5) took few days (3.75) to attain 50 per cent germination while it took more days for T_7 to achieve 50 per cent germination (9.75).

Seedling studies

- The treatment FYM, *Azospirillum* and Phosphobacteria (T_2) was superior to all other treatments in mean root length, mean shoot length, seedling length and vigour indices.

Pot culture experiment

- The soil used for the study was very strongly acidic, EC was safe, medium in OC and available N. Ammoniacal and nitrate nitrogen were 22.40 mg kg^{-1} and 16.80 mg kg^{-1}, respectively. The soil was high in available P, low in available K, deficient in exchangeable Ca, Mg and available B content. It was sufficient in available S, Fe, Mn, Zn and Cu content.
- Root studies revealed that root length was highest for the treatment bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) which was on par with T_3 and T_2. With respect to root and shoot biomass, T_4 differed significantly from other treatments and recorded high values.
- Maximum plant height was recorded in T_4 at active tillering, panicle initiation and harvest stages with values 64.85 cm, 86.63 cm and 92.33 cm, respectively. Leaf Area Index (LAI) was highest for T_4 (5.09) which was on par with T_6, T_2 and T_3. Maximum number of tillers were observed in T_4 at active tillering stage and in T_3, at panicle initiation and harvest stages. Chlorophyll content was not significantly influenced by the treatments.
- Organic manure seed pelleting significantly influenced yield attributes. The treatment vermicompost, *Azospirillum* and Phosphobacteria (T_3) recorded maximum number of productive tillers, number of spikelets per

panicle and filled grain per cent. T_3 was on par with T_4 for number of spikelets per panicle and filled grain per cent. However, treatments had no influence on length of panicle and 1000 grain weight.

- The period of retention of flag leaf was significantly influenced by organic manure seed pelleting and was maximum in T_4 which was on par with T_2.
- Grain and straw yield were significantly influenced by organic manure seed pelleting. Highest grain and straw yield were recorded by the treatment vermicompost, *Azospirillum* and Phosphobacteria (T_3) with values of 54.84 g pot^{-1} and 66.10 g pot^{-1}, respectively. There was 54 per cent and 50 per cent increase in grain and straw yield over control.
- Organic manure seed pelleting significantly influenced harvest index of rice. T_4, T_5, T_6 and T_8 recorded same values (0.47) and were comparable with T_7 and the lowest was recorded by T_1 and T_2 (0.44).
- The post-harvest soil analysis revealed that the highest pH was recorded by the treatment fly ash, *Azospirillum* and Phosphobacteria (T_6) which was on par with T_3 while EC was safe for all treatments.
- The treatments significantly influenced ammoniacal N content. FYM, *Azospirillum* and Phosphobacteria (T_2) was significantly superior to all other treatments. There was no significant influence of treatments on nitrate nitrogen content. The treatment bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) recorded the highest available P and available K.
- With respect to secondary nutrients, exchangeable Ca and available S were highest for the treatment bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4). The treatments had no significant difference between them for exchangeable magnesium.
- Regarding micronutrients, T_3 registered the highest available Fe, Mn and Zn content. None of the treatments influenced available Cu content. For available B, T_2, T_3 and T_4 registered higher values and were on par with T_5, T_6 and T_8.
- Organic manure seed pelleting significantly influenced starch and amylose content of rice grain. The starch and amylose content of rice grain were

highest for the treatment bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4). No significant variation was observed in amylopectin content among different treatments.

- Regarding the uptake of nutrients, the treatment vermicompost, *Azospirillum* and Phosphobacteria (T_3) registered the highest uptake of N, K, Ca, S, Zn, Cu, B and Si in grain and shoot. P uptake in grain was highest in T_4 while T_3 had the maximum uptake in shoot. Mg uptake in grain and shoot were not significant.

From the study, it can be concluded that organic manure seed pelleting material prepared using bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) contained significantly higher quantities of nutrients compared to others. Enzyme activity (dehydrogenase) and organic acid content (humic and fulvic acid) were highest in the pellets prepared using vermicompost, *Azospirillum* and Phosphobacteria (T_3). Organic manure seed pelleting significantly increased the growth characters of rice compared to conventional dibbling method. Among the various treatment combinations, organic manure seed pelleting with bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) and vermicompost, *Azospirillum* and Phosphobacteria (T_3) were found to be effective in improving growth characters of rice such as plant height, number of tillers and LAI. The yield, yield attributes and nutrient uptake were highest in the treatment where vermicompost, *Azospirillum* and Phosphobacteria (T_3) were used as the pelleting material. Seed pelleting using vermicompost, *Azospirillum* and Phosphobacteria (T_3) and bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) were able to maintain significantly higher quantities of available nutrients in the post-harvest soil.

Future line of work

- The best treatment obtained from pot culture experiment can be followed in field
- Comparison of organic and inorganic pelleting material can be assessed

- Combination of organic and inorganic pelleting material need to be investigated
- Microbial studies need to be undertaken.

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ORGANIC MANURE SEED PELLETING FOR ENHANCING SOIL HEALTH AND PRODUCTIVITY OF RICE

by

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(2017-11-046)

ABSTRACT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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KERALA, INDIA

2019

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ABSTRACT

A study entitled 'Organic manure seed pelleting for enhancing soil health and productivity of rice' was conducted from 2017 to 2019 in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, with the objective to develop seed pellets of rice using organic manures and microbial inoculants and to study its effect on soil properties, seedling vigour, growth and yield of rice var. Uma. The study consisted of two parts namely preparation and characterization of organic manure seed pellets and pot culture experiment to evaluate the organic manure seed pellets.

Organic manure seed pelleting materials used were FYM + *Azospirillum* + Phosphobacteria (T_2), vermicompost + *Azospirillum* + Phosphobacteria (T_3), bioslurry flakes + *Azospirillum* + Phosphobacteria (T_4), charcoal powder + *Azospirillum* + Phosphobacteria (T_5), fly ash + *Azospirillum* + Phosphobacteria (T_6), pongamia leaf powder + *Azospirillum* + Phosphobacteria (T_7) and bioslurry + plant extracts + *Azospirillum* + Pseudomonas (T_8: Farmer practice). Seeds alone without pelleting (T_1) was used as control. Carrier based inoculum of *Azospirillum* and Phosphobacteria were used at the rate of 5 g kg^{-1} and fenugreek paste was added at the rate of 25 g kg^{-1} as adhesive.

Pelleting materials were analysed for their physical, chemical and nutritional properties as well as enzymatic activity and organic acid content. The results on characterization of pelleting materials revealed that T_6 recorded the highest bulk density of 1.07 Mg m^{-3}. Highest water holding capacity was recorded by T_7 (380.8 %). All treatments had near neutral to slightly alkaline pH. T_4 recorded the highest EC of 3.502 dS m^{-1}. Regarding the nutritional properties, there was no significant difference among the treatments for ammoniacal and nitrate nitrogen. T_4 had the highest content of P (1.36 %), Ca (3.46 %), Mg (2.57 %), S (1.03 %), Mn (398.6 mg kg^{-1}), Zn (128.6 mg kg^{-1}) and Cu (57.00 mg kg^{-1}) while K content was highest in T_7 (1.18 %), Fe content in T_6 (1.62 %) and B content in T_3 (4.80 mg kg^{-1}). T_7 recorded the highest urease and acid phosphatase activity and T_3,

the highest dehydrogenase activity (312.0 µg of TPF g $^{-1}$ soil $24h^{-1}$). Humic and fulvic acid content were maximum in T_3 with 28.52 % and 23.76 %, respectively.

Seedlings raised from pellets were separated after 15 days and pellets were analysed. pH and EC were highest in T_3. Availability of nutrients were highest in T_4 except for Mg and B where T_3 recorded the highest Mg content and T_6 the highest B content. Enzymatic activity and organic acid content followed similar trend as initial. Germination per cent in all treatments except T_7 were 100 per cent. T_5 took few days to attain 50 per cent germination while it took more days for T_7 to achieve 50 per cent germination. Seedling studies revealed that T_2 was superior to all other treatments for mean root length, mean shoot length, seedling length and vigour indices.

The second part of the experiment was conducted to find the effect of organic manure seed pelleting on growth and yield of rice. At active tillering stage, T_4 registered the highest root length (33.05 cm) which was on par with T_3 and T_2. It also recorded maximum root and shoot biomass. Maximum plant height was recorded in T_4 at active tillering, panicle initiation and harvest stages with values of 64.85 cm, 86.63 cm and 92.33 cm, respectively. Maximum number of tillers were observed in T_4 at active tillering stage and in T_3, at panicle initiation and harvest stages. Leaf Area Index (LAI) was highest for T_4 (5.09) which was on par with T_6, T_2 and T_3. With respect to chlorophyll content, there was no significant difference among the treatments. The yield attributes, namely, number of productive tillers (16.50), number of spikelets per panicle (159.7) and filled grain per cent (94.16 %) as well as grain yield (54.84 g pot^{-1}) and straw yield (66.10 g pot^{-1}) were highest in T_3. T_4, T_5, T_6 and T_8 recorded same values (0.47) and were comparable with T_7 and the lowest was recorded by T_1 and T_2 (0.44). There was no significant difference in length of panicle and 1000 grain weight.

T_4 registered the maximum period of retention of flag leaf. However, the treatments had no significant effect on length of panicle and 1000 grain weight.

The post-harvest analysis of soil revealed that pH and EC varied significantly among the treatments. Ammoniacal nitrogen was highest in T_2 while nitrate nitrogen showed no significant difference. The highest available P (76.97 kg ha^{-1}), K (190.4 kg ha^{-1}), Ca (285.0 mg kg^{-1}) and S (16.50 mg kg^{-1}) were observed in T_4. Available Mg was not significantly influenced by treatments. The available micronutrients Fe, Mn and Zn were significantly influenced by the treatment T_3 recording the highest value of 41.08 mg kg^{-1}, 11.31 mg kg^{-1} and 5.26 mg kg^{-1}, respectively. There was no significant influence on available Cu. The treatments had a significant influence on available B with T_4, T_2 and T_3 recording highest value of 0.22 mg kg^{-1}. T_4 recorded the highest starch and amylose content in grain whereas there was no significant influence of treatments on amylopectin content. Regarding the uptake of nutrients, T_3 registered the highest uptake of N, K, Ca, S, Zn, Cu, B and Si in grain and shoot. P uptake in grain was highest in T_4 while T_3 had the maximum uptake in shoot. Mg uptake in grain and shoot were not significant.

From the study, it can be concluded that organic manure seed pelleting material prepared using bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) contained significantly higher quantities of nutrients compared to others. Enzyme activity (dehydrogenase) and organic acid content (humic and fulvic acid) were highest in the pellets prepared using vermicompost, *Azospirillum* and Phosphobacteria (T_3). Organic manure seed pelleting significantly increased the growth characters of rice compared to conventional dibbling method. Among the various treatment combinations, organic manure seed pelleting with bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) and vermicompost, *Azospirillum* and Phosphobacteria (T_3) were found to be effective in improving growth characters of rice such as plant height, number of tillers and LAI. The yield, yield attributes and nutrient uptake were highest in the treatment where vermicompost, *Azospirillum* and Phosphobacteria (T_3) were used as the pelleting material. Seed pelleting using vermicompost, *Azospirillum* and Phosphobacteria (T_3) and bioslurry flakes, *Azospirillum* and Phosphobacteria (T_4) were able to maintain significantly higher quantities of available nutrients in the post-harvest soil. The beneficial effect of organic manure seed pelleting may be due to enrichment of rhizosphere region of seeds thereby promoting seed and soil relationship aiding in better growth and development.

APPENDIX

Appendix I

Weather data during the cropping period

(October, 2018 to February, 2019)- Weekly averages of temperature, relative humidity and weekly sum rainfall

Standard weeks	Temperature (° C)		Relative Humidity (%)	Rainfall (mm)
	Maximum	Minimum		
43	31.40	24.24	85.07	11.30
44	31.77	24.27	85.29	71.50
45	31.06	24.27	86.16	59.20
46	31.67	23.80	82.71	51.20
47	31.60	24.11	83.50	51.80
48	31.89	23.66	82.86	0.00
49	31.90	23.74	83.36	17.20
50	32.24	23.80	84.07	26.10
51	31.96	22.94	82.14	2.20
52	31.89	23.47	82.21	6.00
1	31.80	19.64	79.29	0.00
2	31.57	22.14	80.29	0.00
3	32.20	20.86	79.86	0.00
4	32.04	23.00	79.71	0.00
5	32.46	22.14	78.57	2.40
6	32.89	24.31	78.29	0.50
7	33.29	24.10	75.50	0.00
8	35.30	23.44	74.36	0.00
9	33.60	23.00	74.00	0.00