IMPACT OF *TRICHODERMA* ENHANCED COMPOSTING TECHNOLOGY IN IMPROVING SOIL PRODUCTIVITY

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Short title: Impact of *Trichoderma* in Improving Soil Productivity

Competing Interest: The authors have declared that no competing interest exists.

ABSTRACT

Objectives: The study was conducted to determine (i) suitable waste, its quantity and dose of *Trichoderma harzianum* suspension and (ii) the impact of tricho-compost application on soil productivity.

Materials and methods: Soil properties were tested before and after application of *Trichoderma* enhanced composting technology at five different districts of North-West Bangladesh. RCBD was used in the experiment where six biodegradable substratum were used and mixed with *Trichoderma* suspension in each pit. These six substratums were mixed with five doses of *Trichoderma* suspension i.e., 0, 250, 500, 750 and 1000ml per 100kg substratum with three replications and therefore 90 pits were prepared to conduct the experiment. Nutrient content like N, P, K, B, S, Zn, soil p^H and organic carbon were analysed in the laboratory.

Results and discussion: Among the composting materials potato plant, water hyacinth, cowdung and household waste produced better compost than rice stubble and bio-slurry. *Trichoderma* suspension dose on 100kg substratum 750 and 1000ml showed better efficacy than other doses in terms of decomposition time, quantity of produced composed and nutrient value. The status of nutrient in soil were compared before and after interventions of *Trichoderma* suspension by means of using paired t-test and found that soil p^H, K, S, Zn, N and B were increased significantly, where as organic carbon slightly increased but not significant changed and P decreased significantly.

Conclusion: There should be ample scope to be created trichocompost everywhere for soil improvement for better crop production towards food security and improved livelihoods.

KeyWords: *Tricho-compost,* Impact, Soil productivity, Composting technology

1. Introduction

1.1. Background of the study

Organic matters in the soil of Bangladesh have declined to less than half of the required level, affecting the target of self-sufficiency in food production and achieving the national food security. The average ratio of organic matters in 100 g of soil has decresed below 1 g against the minimum required level of above 2 g [1]. According to the Government's fertilizer recommendation guideline (2005) fertilizers, manure, Biological Nitrogen Fixation (BNF), deposition flood and irrigation water are regarded as nutrient input, while the crop produce crop residues, leaching, gaseous losses, and soil erosion as nutrient outputs. In such a context, the urgent need for motivating the farmers to use organic fertilizers to improve the soil fertility to be benefited in the long run.

Inorganic fertilizer helps to fetch higher productivity but it has also reported that application of nitrogen fertilizers may deplete soil organic carbon in the long run[2]. Therefore a continuous removal and depletion of nutrients from soil for crop production and yield pose a major threat to sustainability of crop production as well as deterioration of soil's physical and chemical properties. The average OM content in soils of Bangladesh is less than 1%, ranging between 0.05 and 0.9% in most cases affecting the government endeavors to ensure national food security[3]. The ratio of organic matters in soil has decreased to even 0.6% in some places over the past 5-6 decades [4].

The Organic matter can be increased if the organic fertilizer is applied in the soil because bio-origin fertilizers is the products contain living cell of different microorganisms, can prevent the depletion of the organic matter [5]. It has also been observed that application of organic fertilizers increases yield and reduce environmental pollution [6]. In such a context, there is an urgent need for motivating farmers to use organic fertilizer more to improve soil fertility so that they will be able to harvest benefit of accelerated production in the long run.

There is thus a genuine realization that the adoption of ecological and sustainable farming practices can only reverses the declining trend in soil fertility, productivity and environment being friendly to crop production [7-9] and it can only be possible by using compost.

Trichoderma itself is a fungus and effective activator for rapid composting. The Tricho-compost significantly increases soil fertility and fetches higher crop yield. It also acts as bio-pesticides. It is well documented that the interaction of *Trichoderma* strains of Tricho-compost with the plant may promote increase of growth nutrient availability and enhances power of disease resistance [6]. The decomposition process could be enhanced with the application of bio agents like *Trichoderma* which is one of the most important fungi responsible for soil borne diseases of crops. Now farmers are highly eager to peprare make compost using *Trichoderma* as the traditional compost takes 3-4 months where as the Tricho-compost can be easily made within 5-6 weeks. Many farmers are already practicing and securing disease free crop and it is used effectively at the household level for better yield. The Rural Development Academy, Bogra is producing *Trichoderma* enhanced composting technology using cowdung and household waste. It makes a great contribution towards development of safe environment and nutrient enriched fertilizer, a good element for improving soil health. It is very important to look at the performance of such compost on soil health.

1.2. Research objectives

This research is proposed to fulfill the following objectives:

1) To determine the suitable waste, quantity and dose of *Trichoderma* suspension.
2) To anlayze the impact of tricho-compost in improving soil productivity.

1.3. Justification of the study

The development of alternatives to pesticide is one of the greatest challenges in world agriculture today. Owing to their negative effects on the environment and public health, there are strict regulations on chemical pesticide use. In addition, most soil-borne pathogens are difficult to control by conventional strategies such as the use of resistant host cultivars, synthetic fungicides or crop rotation. Soil-borne fungi persist in the soil for long periods because they produce different types of resistant survival structures such as melanized hyphae, chlamydospores, oospores and sclerotia. The lack of reliable chemical controls, the occurrence of fungicide resistance in pathogens and the breakdown and circumvention of host resistance by pathogen populations are some of the reasons underlying efforts to develop new diseases control strategies. Soil-borne diseases can be a major limitation to crop production, particularly for vegetables.

Some strains of *Trichoderma* spp. have been reported to be powerful biological control agents against plant pathogens, which are applied to agricultural crops to achieve plant growth promotion and biocontrol. The mechanisms by which *Trichoderma* strains displace phytopathogenic are essentially of three types: direct competition for space or nutrients; production of antibiotic metabolites, whether volatile or nonvolatile nature; and direct parasitism of certain species of *Trichoderma* on plant pathogenic fungi. *Trichoderma* spp. and other beneficial root-colonizing fungi also enhance plant growth and productivity. Plant growth enhancement by *Trichoderma* spp. has been reported for many crops such as runner beans (*Phaseolus vulgaris*), cucumber (*Cucumis sativus*), sweet pepper (*Capsicum annuum*), carnation (*Dianthus carophyllus*), maize (*Zea mays*) and wheat (*Triticum aestivum*).

Trichoderma spp. is a natural fungus which is responsible to transform soil nutrient into available form to the plant for easy uptake. Decomposition of organic matter in association with *Trichoderma* compost used to increase soil health which ultimately increases production of crops in the field. So the extent of improvement of soil productivity by Tricho compost is a major concern to replace inorganic fertilizers.

2. Materials and Methods

Detailed of the settings, methods and procedure followed in conducting this study are described in this section.

2.1. Experimentation with soil properties in the field

Soil properties e.g. p^H, organic carbon, potassium, phosphorus, sufur, zinc, nitrogen and boron were tested in soil before and after application of *Trichoderma* enhanched composting technology at five different districts of Bangladesh i.e., Bogra, Joypurhat, Sirajgonj, Gaibandha and Naogaon.

2.1.1. Experimental design

Randomized Complete Block Design (RCBD) was used to set the experiment. Two experiments e.g. (i) effect of *Trichodermal* decomposition on different substratum, and (ii) effect of different doses of *Trichodermal* decomposition on different substratum was carried out. *Trichoderma herzianum* species were used all through for the experiment.

2.1.2. Treatment, replication and experimental layout

For the first experiment, 6 substratum e.g., water hyacinth, rice stubbles, potato plant, cowdung, household waste and bio-slurry were used for decomposition and mixed with *Trichoderma* suspension in each pit. These six substratums were mixed with 5 doses of *Trichoderma* suspension e.g., 0, 250, 500, 750 and 1000 ml. These treatments had again 3 replications and therefore, a total of 6×5×3=90 pits were prepared to conduct the experiment. The treatments were used in this study have been described in Table 1.

Table 1. Number of treatments with *Trichoderma* dose and composting material used for each replication

Treatment No	***Trichoderma* dose (ml)**	**Composting materials used**
T_1	0	Potato plant
T_2	250	Potato Plant
T_3	500	Potato Plant
T_4	750	Potato Plant
T_5	1000	Potato Plant
T_6	0	Water hyacinth (75%) +Cowdung (25%)
T_7	250	Water hyacinth (75%) +Cowdung (25%)
T_8	500	Water hyacinth (75%) + Cowdung (25%)
T_9	750	Water hyacinth (75%) + Cowdung (25%)
T_{10}	1000	Water hyacinth (75%) + Cowdung (25%)
T_{11}	0	Rice stubble (75%) + Cowdung (25%)
T_{12}	250	Rice stubble (75%) + Cowdung (25%)
T_{13}	500	Rice stubble (75%) + Cowdung (25%)
T_{14}	750	Rice stubble (75%) + Cowdung (25%)
T_{15}	1000	Rice stubble (75%) + Cowdung (25%)
T_{16}	0	Cowdung (100%)
T_{17}	250	Cowdung (100%)
T_{18}	500	Cowdung (100%)
T_{19}	750	Cowdung (100%)
T_{20}	1000	Cowdung (100%)
T_{21}	0	Household waste (75%) +Cowdung (25%)
T_{22}	250	Household waste (75%) +Cowdung (25%)
T_{23}	500	Household waste (75%) +Cowdung (25%)
T_{24}	750	Household waste (75%) +Cowdung (25%)
T_{25}	1000	Household waste (75%) +Cowdung (25%)
T_{26}	0	Bio-slurry (100%)
T_{27}	250	Bio-slurry (100%)
T_{28}	500	Bio-slurry (100%)
T_{29}	750	Bio-slurry (100%)
T_{30}	1000	Bio-slurry (100%)

2.1.3. Pit preparation and filling with substratum

The pit size was 45 inch length, 45 inch width and 20 inch depth which was filled with six different substratums as stated above. Each of the substratums was well mixed with cowdung and first 06 inches layer of the pit was filled and made spray with *Trichoderma* suspension followed by making another 6 inches second layer with the same materials and give a spray, next the third layer was made and give a spray with *Trichoderma* suspension. The remaining 2 inches was filled with the rubbish and the pit was wrapped with polythene sheet and kept for a week. After a week later, the whole materials were mixed well in order to make a uniform decomposition and water was added if the substratum found dry and kept closed with polythene sheet. Such mixture after 5 weeks, the pit is supposed to get ready to provide compost for field application. The whole process has been presented in Figure 1.

Fig-1 : Experimental field preparation

2.1.4. Sample preparation for nutrient analysis

When the substracts were fully decomposed then it was harvested from 90 pits of 3 replication and air dried for one day to keep the moisture level up to 15-20% and stored in gunny sacks. Then the compost was sieved to make it fine powdered form. Five samples were randomly taken from each replication containing 500 g and finally 15 samples were designated as S_1-S_{15} and prepared for analysis of nutrients.

2.1.5. Field application

After preparation, compost was applied to the field to grow boro rice and the yield potentials of the compost were determined through soil analysis by comparing with control plots.

2.2. Data collection and analysis

Data were collected during decomposition in the pit, quantity of compost prepared from each pit and nutrient content like N, P, K, B, S, Zn, soil p^H and organic carbon were analysed in the laboratory. Data were analysed using SPSS (Statistical Package for Social Science) software.

2.2.1. Soil collection and analysis

After field application of *Trichoderma* enhanced compost, the soil properties were supposed to get improved which was done before and after application and also at crop harvest. For this purpose soil was collected from the applied field and brought to the laboratory. The soil p^H, organic carbon, N, P, K, B, S and Zn, etc. were tested in each treatment. Soil analysis was done in the Laboratory of Soil Resources Development Institute (SRDI) and Rural Development Academy, Bogura.

3. Results and Discussion

The findings and discussions have been presented as follows:

a. *Trichoderma* nutrient value and dose determination

b. Impact of *Trichoderma* in improving soil productivity

3.1 *Trichoderma* nutrient value and dose determination

3.1.1. Determination of nutrient value of tricho-compost

Fifteen samples were sent to Soil Resources Development Institute (SRDI) of Rajshahi for lab analysis of the following nutrients.

It is observed that the range of organic carbon was 7.25 to 13.05%. The nitrogen level was found in the range of 0.89-2.87%. The phosphorus level was in the range of 0.39-1.78%. The range of potassium level was 0.39-1.42%. The boron level was in the range of 0.24-0.68%. The sulphur level was in the range of 0.42-0.71%. As zinc level of soil is declining in Bangladesh, so the recycling of this nutrient is not happening. So, as a result the plant is get only very low level of zinc. Thus, the composting material did not contain enough Zn, so the zinc level is very low in case of every sample. The Zn level was found in the range of 0.01-0.02. Clear picture for individual nutrients can be evident in the following graphs.

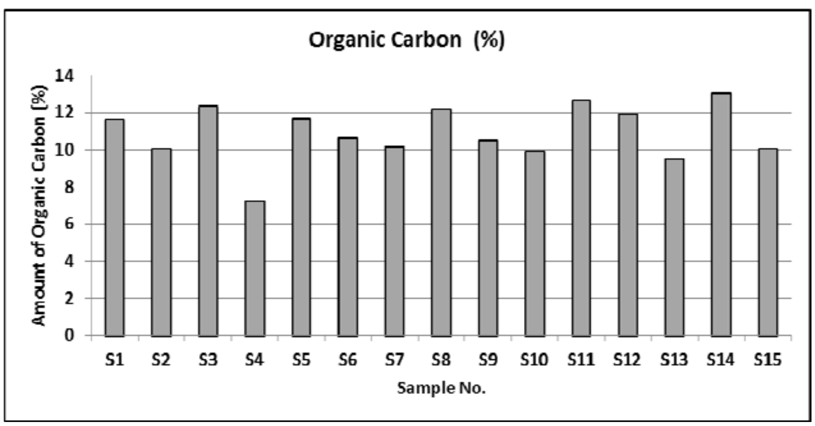

Fig-2: Quantity of organic elements in different samples

From the graph in Figure 2, it was observed that, the lowest amount of organic carbon was found in S_4 (7.25%) and the highest amount of organic carbon was found in S_{14} (13.05%) from each 500 g trichocompost sample. From other samples which contained 500 g trichocompsot each, the amount of organic carbon was found in the range of 9.5-12.65%.

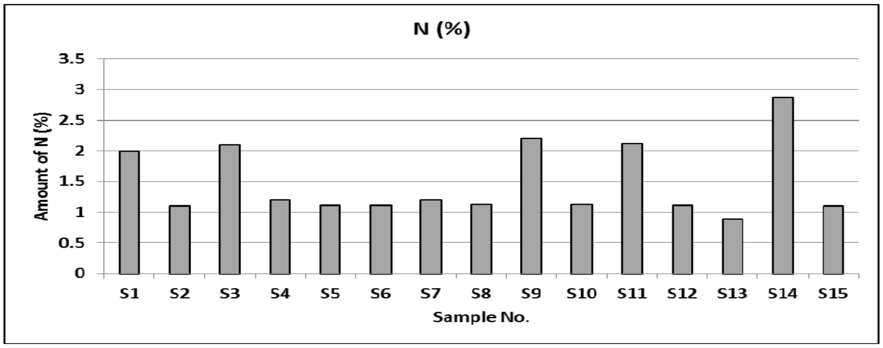

Fig-3: N level in different samples

From the graph in Figure-3, it was observed that, the lowest percentage of nitrogen was found as S13 (0.89%) and the highest percentage of nitrogen was found in S_{14} (2.87%) from each 500 g trichcompost sample. From other samples, each sample contains 500 g trichocompost percentage of nitrogen was in the range of 1.1- 2%.

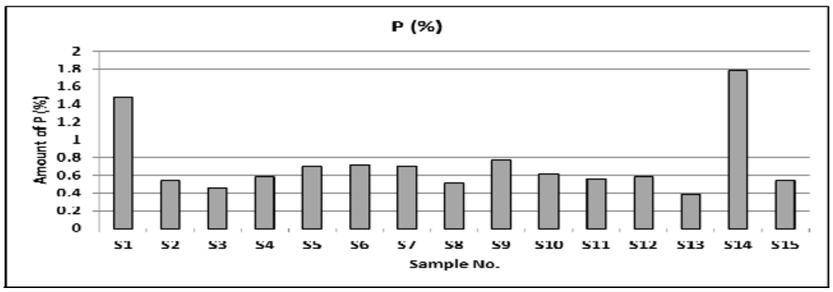

Fig-4: Phosphorus content in different samples

From the graph in Figure- 4, it was observed that, the lowest percentage of phosphorus was found to be in S_{13} (0.39%) and the highest percentage of phosphorus was found in S_{14} (1.78%) from each 500 g trichcompost sample. From other samples, each sample contains 500 g trichocompsot percentage of phosphorus was in the range of 0.46-1.48%.

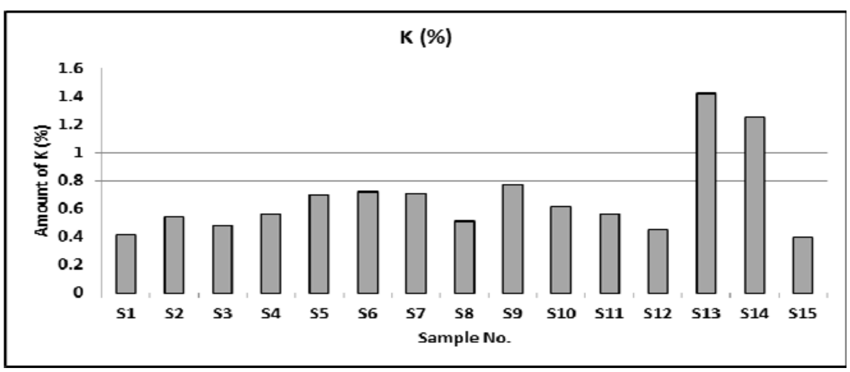

Fig-5: Potassium content in different samples

From the graph in Figure-5, it was observed that, the lowest percentage of potassium was found to be in S_{15} (0.39%) and the highest percentage of potassium was found in S_{13} (1.42%) from each 500 g trichcompost sample. From other samples in which every sample contain 500 g trichocompsot potassium was in the range of 0.41 - 1.25%.

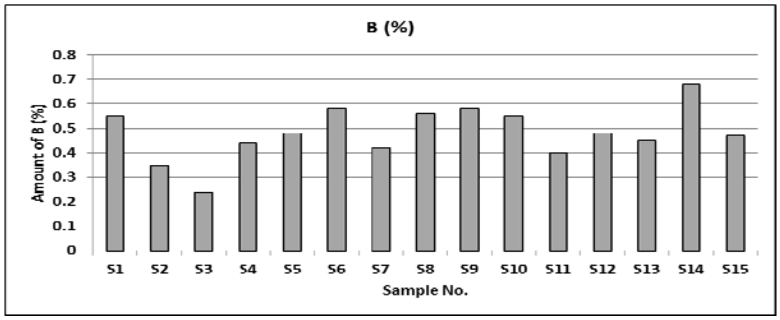

Fig-6: Boron content in different samples

From the graph in Figure- 6, it was observed that, the lowest percentage of boron was found to be in S_3 (0.24%) and the highest percentage of boron was found in S_{14} (0.68) from each 500 g trichcompost sample. From other samples in which every sample contain 500 g trichocompsot nitrogen was in the range of 0.35 - 0.58%.

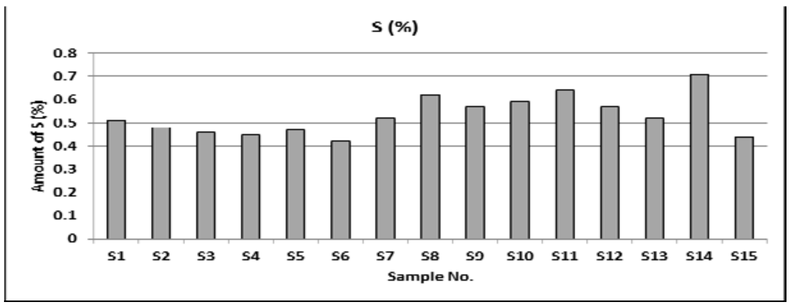

Fig-7: Sulphur content in different samples

From the graph in Figure- 7, it was observed that, the lowest percentage of sulphur was found to be in S_6 (0.42%) and the highest percentage of phosphorus was found in S_{14} (0.71%) from each 500 g trichocompost sample. Each of the other samples, contains 500 g trichocompsot percentage of sulphur was in the range of 0.44 - 0.64%.

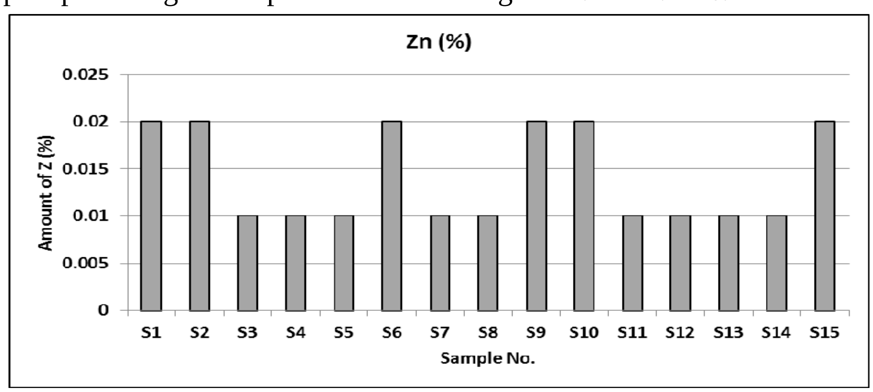

Fig-8: Percentage of zinc in different samples

From the graph in Figure-8, it was observed that, The lowest percentage of zinc (0.01) was found in most samples and the highest percentage of zinc (0.02) was only found in $S_{1,}$ S_2, S_6, $S_{9,}$ S_{10} and S_{15} from each 500 g trichcompost samples.

3.1.2. Decomposition time of waste material

Ninety (90) treatments were set to carry out this experiment. Various kind of materials were used as composting material such as potato plant, water hyacinth, rice stubble, cowdung, household waste, bio-slurry. These materials were used as with different combination and alone.

Five types of *Trichoderma* doses such as 0, 250, 500, 750 and 1000 ml were used in this experiment. Here 0 ml doses are mainly used as control treatment. Among the thirty treatment of three replication in some cases the composting materials were decomposed in due time while the others took one or two weeks more than the desired time. The cause may be that we used different types of materials in different combinations of dosage. Some materials were green and perishable waste in nature while some were dry. During the experiment time the rice stubble which collected was dry and the rice stubbles chopped and wetted. But during dry weather, it may be again dry although wetted. The green materials were decomposed quickly because it contained enough moisture which supported the growth of decomposing fungus *Trichoderma* that helped in rapid decomposition. As mixed and single combination of waste materials were used and the variation of decomposition time can be a potential cause for variation of efficacy. The variation in decomposition time in different types of composting material due to different dosages can be clear from the following graphs-

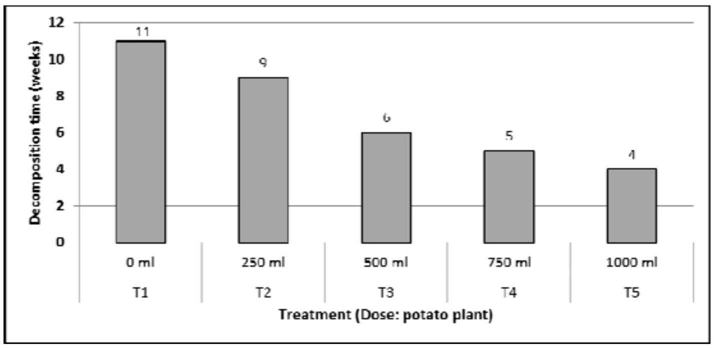

Fig-9. Decomposition time in different dosages of 1st composting material (potato plant)

From the graph in Figure-9, it was observed that, in the first treatment (0 ml) it was observed that at first treatment the decomposition time (11 weeks) was really higher than other doses. In the last treatment (1000 ml) it is only 4 weeks. The decomposition span in case of potato plant varied from 5-9 weeks.

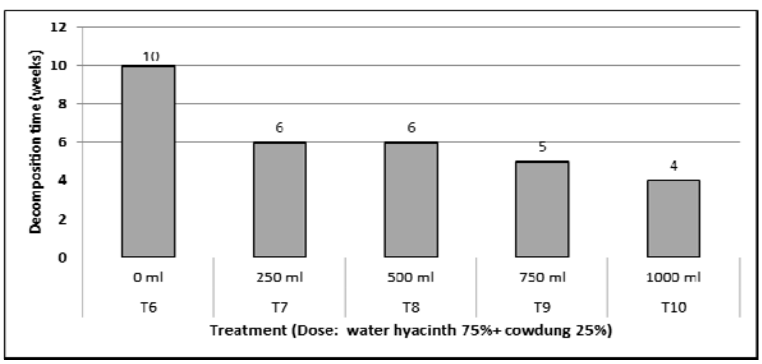

Fig 10. Decomposition time in different doses of 2nd composting material (water hyacinth 75%+ cowdung 25%)

From the graph in Figure-10, it was observed that, in the first treatment (0 ml), it was observed that the decomposition time (10 weeks) was evidently higher than other doses. In the last treatment (1000 ml) it was only 4 weeks. The time of decomposition in case of water hyacinth and cowdung varied from 5-8 weeks.

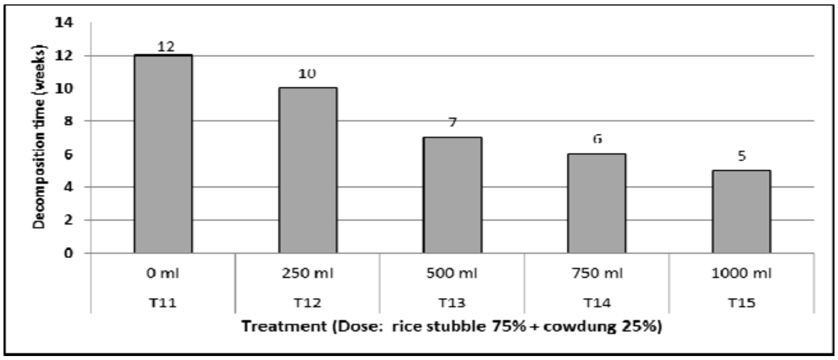

Fig 11. Decomposition time in different doses of 3rd composting material (rice stubble 75% + cowdung 25%)

From the graph in Figure-11, it was observed that, in the first treatment (0 ml), it was observed that the decomposition time (12 weeks) was significantly higher than other doses. In the last treatment (1000 ml) it was only 5 weeks. The decomposition time in case of rice stubble and cowdung varied from 6-10 weeks.

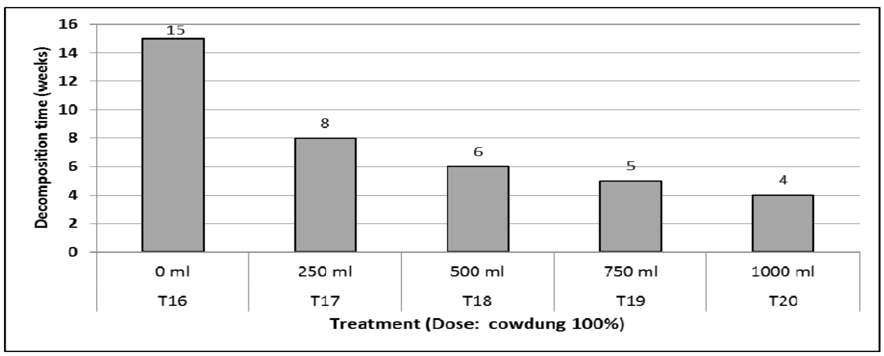

Fig 12. Decomposition time in different doses of 4th composting material (cowdung 100%)

From the graph in Figure-12, it was observed that, in the first treatment (0 ml), it was observed that the decomposition time (15 weeks) was really higher than other doses. In the last treatment (1000 ml) it was only 4 weeks. The decomposition time in case of cowdung only varied from 5-8 weeks.

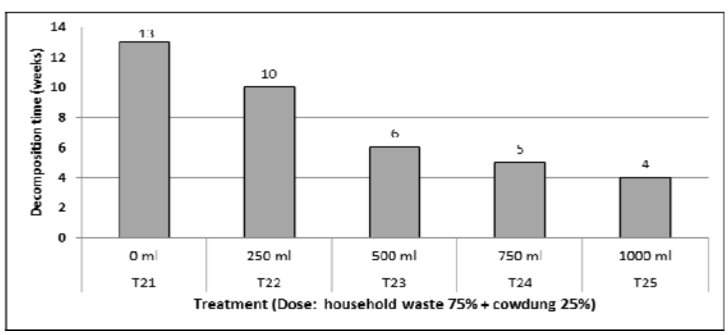

Fig 13. Decomposition time in different dosage of 5th composting material (household waste 75% + cowdung 25%).

From the graph in Figure- 13, it was observed that, in the first treatment (0 ml) it was observed that the decomposition time (13 weeks) is really higher than other doses. In the last treatment (1000 ml) it is only 4 weeks. The other decomposition time of household waste and cow-dung varies from 5 to 10 weeks.

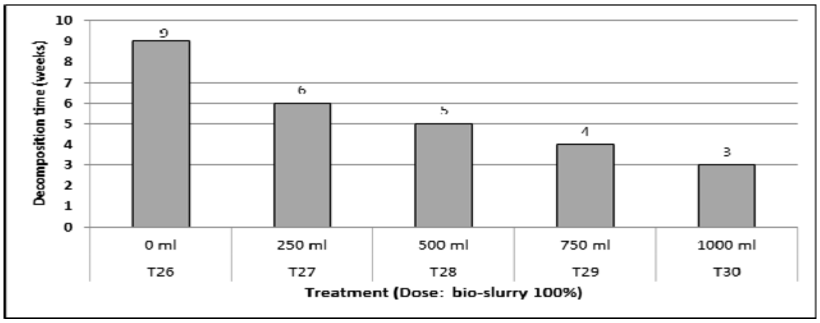

Fig 14. Decomposition time in different doses of 6th composting material (bio-slurry 100%).

From the graph in Figure-14, it was observed that, in the first treatment (0 ml), it was observed that the decomposition time (9 weeks) was really higher than other doses. In the last treatment (1000 ml) it was only 3 weeks. The other decomposition time in case of bio-slurry varied from 4 to 6 weeks.

3.1.3. Quantity of compost

There were ninety (90) treatments in RCBD design with three replications which produced different quantity of tricho-compost. Table 2 showed that the highest quantity of compost prepared from T_{26} and the lowest quantity in case of T_{15} and T_5 in 1^{st} replication. In case of potato plant treatment the quantity varied from 48-78 kg. In water hyacinth and cowdung treatment the quantity of compost produced in the range of 45-75 kg. In rice stubble and cowdung treatment the quantity of compost produced in the range of 46-79 kg. In cowdung treatment, the quantity of compost produced in the range 68-87 kg. In household waste and cowdung treatment, the quantity of compost produced in the range of 50-80 kg. In bio-slurry treatment the quantity of compost produced 74-92 kg.

The following graph shows the overall picture in terms of quantity of compost produced from various treatments in various doses.

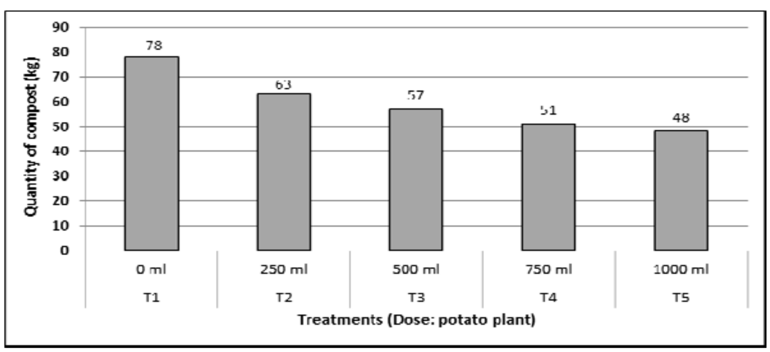

Fig 15. Quantity of compost produced from potato plant in different dosage.

From the graph in Figure- 15, it was observed that, in the first treatment (0 ml) the quantity of undecomposed compost produced was 78 kg. In 1000 ml dosage the quantity of compost was only produced 48 kg. In other dosage the quantity of compost produced in the range of 51-63 kg. In 1000 ml, the quantity of compost produced was low as the *Trichoderma* fungus decomposed the potato plants very efficiently. On the other hand, in control as no *Trichoderma* fungus was present in this treatment so it produced sizeable quantity of non-decomposed compost.

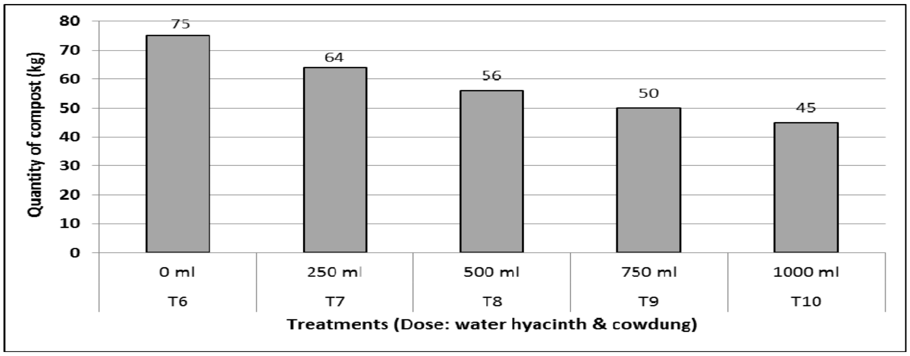

Fig 16. Quantity of compost produced from water hyacinth & cowdung.

From the graph in Figure- 16, it was observed that, in the first treatment (0 ml) the quantity of undecomposed compost produced was 75 kg. In 1000 ml dosage the quantity of compost was only produced 45 kg. In other dosage the quantity of compost produced in the range of 50-64 kg. In 1000 ml the quantity of compost produced was low as the *Trichoderma* fungus decomposed the water hyacinth and cowdung very efficiently. On the other hand, in control as no *Trichoderma* fungus was present in this treatment so it produced high quantity of undecomposed compost.

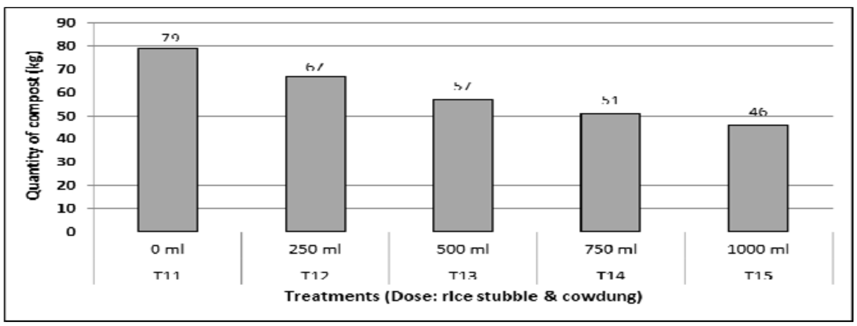

Fig 17. Quantity of compost produced from rice stubble & cowdung in different dosage.

From the graph in Figure- 17, it was observed that, in the first treatment (0 ml), the quantity of undecomposed compost produced was 79 kg. In 1000 ml dosage, the quantity of compost was only produced 46 kg. In other dosage, the quantity of compost produced in the range of 51-67 kg. In 1000 ml, the quantity of compost produced was low as the *Trichoderma* fungus decomposed the rice stubble and cowdung very efficiently. On the other hand, in control as no *Trichoderma* fungus was present in this treatment so it produced high quantity of undecomposed compost.

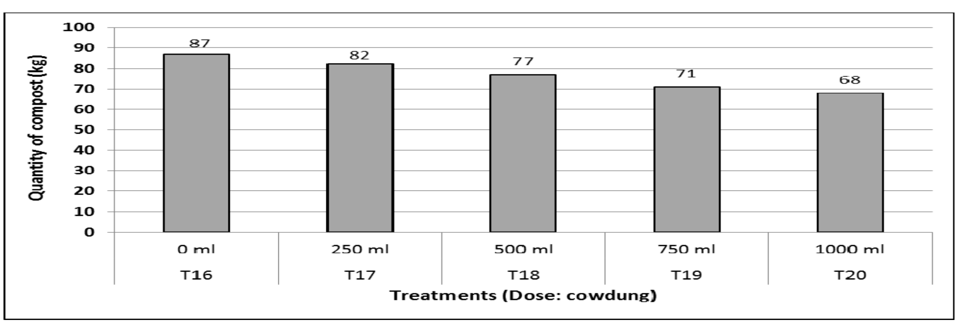

Fig 18. Quantity of compost produced from cowdung in different doses.

From the graph in Figure- 18, it was observed that, in the first treatment (0 ml) the quantity of undecomposed compost produced was 87 kg. In 1000 ml dosage the quantity of compost was only produced 68 kg. In other dosage the quantity of compost produced in the range of 70.5-82 kg. In 1000 ml the quantity of compost produced was low as the *Trichoderma* fungus decomposed the cowdung very efficiently. On the other hand, in control as no *Trichoderma* fungus was present in this treatment so it produced high quantity of undecomposed compost.

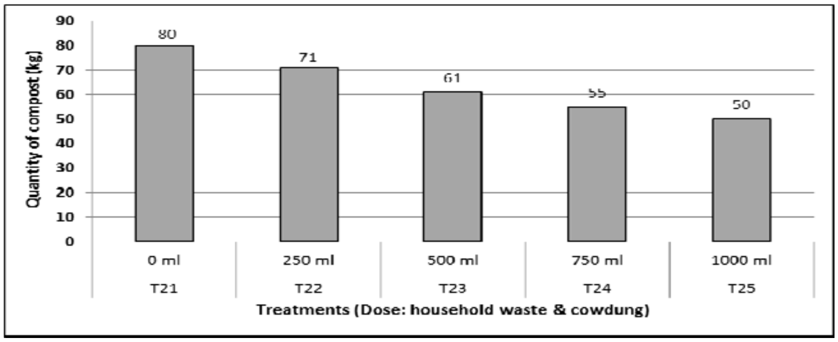

Fig. 19. Quantity of compost produced from household waste & cowdung in different dosage.

From the graph in Figure- 19, it was observed that, in the first treatment (0 ml) the quantity of undecompsoed compost produced was 80 kg. In 1000 ml dosage the quantity of compost was only produced 50 kg. In other dosage the quantity of compost produced in the range of 55-71 kg. In 1000 ml the quantity of compost produced was low as the *Trichoderma* fungus decomposed the household waste and cowdung very efficiently. On the other hand, in control as no *Trichoderma* fungus was present in this treatment so it produced high quantity of undecomposed compost.

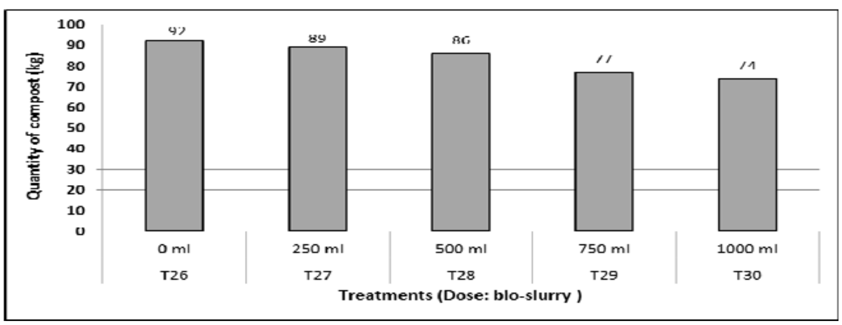

Fig-20. Quantity of compost produced from bio-slurry in different doses.

From the graph in Figure- 20, it was observed that, in the first treatment (0 ml), the quantity of undecomposed compost produced was 92 kg. In 1000 ml dosage the quantity of compost was only produced 74 kg. In other dosage the quantity of compost produced in the range of 76.5-79 kg. In 1000 ml, the quantity of compost produced was low as the *Trichoderma* fungus decomposed the bio-slurry very efficiently. On the other hand, in control as no *Trichoderma* fungus was present in this treatment so it produced high quantity of undecomposed compost.

3.2. Impact assessment

This section deals with the impact of *Trichoderma* composting technology to the farmers' field. The intervention given to the farmers field consecutively several times and in return it help improves the soil health. The nutrient content of the soil greatly determine the characteristics of soil which is responsible for growth and development for the plant bodies. After application of *Trichoderma* compost in the farmers field, the status of soil p^H, organic carbon and nutrients such as potassium, phosphorus, sulfur, zinc, nitrogen and boron were determined. The same was determined before application of the compost. These before and after interventions were compared by means of using paired t-test and shown in Table 2. The impact assessment was done in two parts, the first part deals with the soil characteristics and the second part deals with the personal and socio-economic characteristics of the respondents.

Table 2. Status of soil nutrient after application of trichoderma compost to the farmers field

Soil nutrient	Mean score		t-value	df	Level of significance
	Before	After			
p^H	5.83	6.02	-4.445	398	0.000
Organic carbon (%)	1.82	3.29	-1.270	398	0.205
Potassium (%)	0.245	0.171	4.707	398	0.000
Phosphorus (%)	26.76	24.44	0.619	398	0.536
Sulfur (%)	7.59	13.19	-7.559	398	0.000
Zinc (%)	0.68	1.68	-11.85	398	0.000
Nitrogen (%)	0.088	0.127	-3.245	398	0.000
Boron (%)	0.104	0.340	-10.602	398	0.000

3.2.1. Soil p^H

Data presented in Table 2. indicated that, after intervention with *Trichoderma* compost in the farmers field, the soil p^H slightly increase which is 6.20 that seems to close to neutral bust still acidic in nature than previously it was more acidic (soil p^H 5.83). The change was found to be significant. Therefore, it could be concluded from the fact that application of *Trichoderma* compost can help greatly to minimize the acidity of soil and help improve the soil health.

Attanandana and Vacharotyan (1984) [10] compared rock phosphate (RP) with triple superphosphate (TSP) on rice growth and yield in pots and in the field on acid sulphate soils. They found that RP gave better response than TSP. They also suggested that mild liming was necessary for good yields on very acid soils (p^H 4.5) but high rates reduced P availability from PR. According to them PR gave the best residual effect.

3.2.2. Organic carbon

Total organic carbon influences many soil characteristics including colour, nutrient holding capacity (cation and anion exchange capacity), nutrient turnover and stability, which in turn influence water relations, aeration and workability. Data presented in Table 2. indicated that, after intervention given in farmers' field the organic carbon seems to be increased from 1.82 to 3.29% but statistically not significant. The physical characteristics of soil definitely improve by increasing organic carbon which also helps microbial activities and thereby increases soil aeration and water holding capacity. Tricho-compost, therefore, can be used as a fertilizer substitute to enhance fertility and productivity.

Heng (1989) [11] reported that the treatment of humic and acid with Al or Fe resulted in greater adsorption of P by the acid. At higher level of Al or Fe, the level of P associated with humic acid was lower suggesting that P in the humic acid could be held by adsorption on the organometallic complexes.

3.2.3. Potassium

Data presented in Table 2. indicated that, content of potassium was found to decrease from 0.245 to 0.171% which was statistically significant. This might be due to uptake nature of rice plant. In post intervention, the rice was cultivated in the land and perhaps rice plant used to uptake potassium and therefore, the status of potassium in the soil was found reduced even *Trichoderma* application. The inherent quality of a soil is to contain some essential nutrient and potassium is one of them. Tricho-compost helps to improve soil characteristics but not essential nutrients. Therefore, potassium fertilizers are needed to apply into the soil for potassium.

Yogesh and Aora (2001) [12] found that seed yield increased with the increase in N rate, was not significantly affected by P rate. The highest number of seed per pod (57.0) and seed yield per plot (2.94 kg) was obtained with the application of 120 kg ha^{-1} and 80 kg P ha^{-1}, along with sowing on 25 June.

3.2.4. Phosphorus

Content of phosphorus was found remarkably decreased from 26.76 to 24.44% (Table 2). The application of tricho compost apparently seems to improve soil health through but the level of phosphorus did not increase rather it was found decreased. This might be due to phosphorus fixation in soil and eventually reduces the total amount even after *Trichoderma* application. It could be concluded that, tricho-compost is not suitable to enhance phosphorus content of soil.

Khan *et al.* (2002) [13] suggested that the number of pods per plant increase with increasing phosphorus fertilizer up to a certain limit. Masthan *et al.* (1999) [14] stated that number of pods per plant of summer mungbean cv. LGG 127 increased with increasing phosphorus levels. Mitra *et al.* (1999) [15] reported that mungbean grown in acid soils gave the maximum number of pods per plant was recorded with application of 50 kg P_2O_5 ha^{-1}. Singh *et al.* (1999) [16] studied that number of pods $plant^{-1}$ of mungbean. NDM^{-1} grown at Faisalabad, Uttar Pradesh, India in summer 1996 generally increased with up to 26.4 kg P ha^{-1}. Sharma and Sing (1997) [17] carried a field experiment during 1989-90 to study the effects of various levels of phosphorus (0, 25, 50 and 75 kg ha^{-1}) on the growth, yield and yield attributes of mungbean. They observed that application of phosphorus at 50 kg ha^{-1} significantly enhanced the number of pods per plant.

3.2.5. Sulfur

If sulfur is applied in the form of manure, it become easy for plants to uptake. From that viewpoint to mitigate the sulfur deficiency symptoms could be minimized by the application of manure. Data presented in Table 2. indicated that, there has been remarkable increase of sulfur in soil due to application of tricho compost (7.59% at baseline and after intervention it was increased to 13.19) and found statistically significant.

Lalitha *et al.* (2000) [18] showed that, potassium fertilizer application reduce the nitrogen concentration, HPS-1/13 produce more dry matter than KufriJyothi. It had more nitrogen, phosphorus, potassium and sulfur content than HPS-1/13.

3.2.6. Zinc

Zinc (Zn) is an essential nutrient required in some fertilizer programs for crop production. While some soils are capable of supplying adequate amounts for crop production, addition of zinc fertilizers is needed for others. Data in Table 2. showed that, an increase of Zn in the soil was found due to application of tricho compost. At the baseline status there was zinc level at 0.68% which was increased to 1.68% and statistically significant at 0 level. Although Zn is a trace element and need in a very small quantity for the balanced growth and development of plant bodies, there is no need to be supplemented through application of Zn fertilizer since the tricho-compost playing a significant role in this regard.

Kazemi (2014) [19] has shown iron, calcium and zinc sulfate increased dry weight, leaf area, length of roots of strawberry. Foliar application of 150 mg l^{-1} zinc sulfate provided 5.1 number of runner, 46.3 cm 2 leaf area, 15.7 flowers, 18.3 primary fruit and 16.3 secondary fruit. Sprays of zinc sulfate at 150 mg l^{-1}, iron at 1000 mg l^{-1} and calcium at 10 mM improved number of flowers, weight of primary and secondary fruit.

3.2.7. Nitrogen

Data presented in the Table 2. showed that, there was an increasing level of nitrogen found against baseline due to application of tricho-compost. The baseline was 0.088% and after intervention it was reached to 0.127% which was also statistically significant at 00 level of probability as t value was -3.245. Therefore, it can be concluded that, for nitrogen supplement tricho-compost could be the best option to deal with farming business.

Saini and Thakur (1996) [20] stated that nitrogen at 30 and 40 kg ha^{-1} significantly increased the plant height of blackgram compared with no N. Jamro *et al.* (1990) [21] observed that application of 90 kg N ha^{-1} is significantly increased the plant height of blackgram. Yein *et al.* (1981) [22] conducted a field experiment on nitrogen in combination with phosphorus fertilizer to blackgram. They revealed that application of 40 kg N ha^{-1} increased plant height. Asaduzzaman (2006) [23] found that plant height of mungbean was significantly increased by the application of nitrogen fertilizer at 30 kg ha^{-1}. Akhtaruzzaman (1998) [24] conducted a field experiment on mungbean where plant height increased almost linearly up to 40 kg N ha^{-1} although response of 30 and 40 kg N ha^{-1} was identical. Suhartatik (1991) [25] in a study observed that increased application of NPK fertilizers significantly increased the plant height of mungbean. Hamid (1988) [26] conducted a field experiment to investigate the effect of nitrogen and carbon on the growth and yield performance of mungbean (*Vigna radiata* L. wilczek). He found that the plant height of mungbean. Mubarik was found to be increased with nitrogen at 40 kg ha^{-1}.

3.2.8. Boron

Data in the Table 2. indicated that, at baseline the boron status of soil was 0.104% which is increased to 0.34% after application of tricho-compost to the farmers' field. The change was found statistically significant (t = -10.602, p<00). From the findings it could be concluded that, additional boron is not necessary to apply if the soil is applied by tricho-compost which can be considered as the best source of boron.

Palkovics and Gyori (1984) [27] found that the critical level of B was 60 mg kg^{-1} of foliage and above this, B content depressed yield. Omer *et al.* (1982) [28] stated that the boron at any concentration had little effect on plant and tuber number; but marketable tuber yield was increased with increasing concentration of boron. Awasthi and Grewal (1977) [29] worked with potatoes on slightly acidic soils at Shillong, India, using soil application of 25 kg $ZnSO_4$ ha^{-1} or foliar application of 0.1% boron solution.

Discussion

All these initiatives suggest that the reserach have received different quantities of compost from the pits of 90 treatments. The figure varies in some cases as used various treatments in different combinations and single with different doses. In most of the treatments, desired level of compost from the pit of each treatment was found. The cause may be due to that the elements which used as composting material was highly decomposed by the decomposing agent *Trichoderma* and the weight loss of the composting material was very high. In some cases, composting material decomposition was very slow due to absence of nutrients. Hence we found maximum amount of composting material un-decomposed in some treatments for the reasons stated above.

Actually in control treatment the decomposition was slow. In 250 ml doses the decomposition was better than control treatment and we got less amount of compost than control treatment. In 500 ml treatment was almost better than the two pre-doses. In 750 and 1000 ml, it was found better decomposition than the above stated dosage.

4. Conclusions

On the basis of findings, discussion and interpretation the following conclusions were made.

1. The soil characteristics become changed after application of *Trichoderma* enhanced composting technology. Soil p^H was become slight alkaline from acidic, organic carbon, N, P, K, Zn and B content of the soil was greatly increased which is favorable for better crop production and therefore it could be concluded that, there should be scope to be created everywhere for soil improvement for better crop production towards food security and improved livelihoods.

2. The rerserch revealed that 750 ml and 1000 ml tricho-suspension is better efficacy than other doses in terms of decomposition time, quantity of compost and nutrient value.

3. Among the composting material potato plant, water hyacinth, cowdung and household waste showed best performance than other biodegradable material. The rice stubble showed lower performance as the material was dry although wetted it 6-12 hours before piling but may be the moisture was less to support the growth of *Trichoderma*. Bio-slurry was already half decomposed so the decomposing agents find less nutrient support for growth and as a result it did not perform well for decomposition purpose of bio-slurry.

4.1. Recommendations for policy implication

Based on experience, observation and conclusion drawn from the findings, the following recommendations are made to the concerned authority, planners and executioners.

1. Among the six biodegradable composting materials potato plant, water hyacinth, cowdung and household waste could be recommended to use these materials as the suitable waste material in order to prepare tricho-compost.

2. Among several doses of *Trichoderma* suspension 750 ml and 1000 ml tricho-suspension were found to have better efficacy than other doses in terms of decomposition time, quantity of compost and nutrient value. From the findings, it could be recommended that 750 and 1000 ml tricho-suspension should be used by the farmers for quick decomposition.

3. Motivational campaign by the GOs and NGOs towards adoption of trichoderma enhanced composting technology for maximizing crop production and thereby makes improvement of livelihood status of the farmers.

4.2. Recommendations for further study

1. The present study was conducted in the northern part of the country. Similar study should be undertaken to find the efficacy of tricho-suspension in the saline soil as well as acid soil of the country.

2. Only soil characteristics have been studied. Study is also necessary to examine the yield potential of different crops after application of tricho-compost in the farmers' field.

3. Study is also necessary to find the efficacy towards fungicidal action of tricho-compost in order to free the crops from pests and diseases.

SIGNIFICANCE STATEMENT

The study discovered the impact of trichoderma enhanced compost in improving the productivity of soil. Soil is the foundation of crop cultivation which is depleted over time. So the main focus of the research is to rescue soil to care its health. This piece of research re-formulated the doses and treatments of application of bio-organic matter to enhance the life span of soil. As a result of soil health management the total production of the country will boost up which will be the main output of the study.

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