Production of quality seeds of chilli using soil amendments

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Abstract. Roy K, Khan AA, Rubayet MT, Haque MM. 2022. Production of quality seeds of chilli using soil amendments. Asian J Agric 6: 7-14. The present investigation was conducted to produce quality chilli seeds using soil amendments. The soil was amended with vermicompost, colonized Trichoderma, mustard oil cake, cow dung, and poultry manure for quality seed production. The fruits yield (3.63 t ha⁻¹) and seed yield (2.40 t ha⁻¹) were higher from colonized Trichoderma amended plot. All the organic amendments such as colonized Trichoderma, vermicompost, poultry manure, mustard oil cake, and cow dung increased the yield of chilli seeds compared to the control. Quality characters of harvested seeds such as germination, vigour, 1000 seeds weight were found higher in colonized Trichoderma amendment plots. Five fungi, namely Aspergillus sp., Fusarium sp., Colletotrichum capsici (Syst. & P.Syd.), E.J. Butler & Bisby, Curvularia sp., and Alternaria alternata (Fr.) Keissl. were found to be associated with seeds and the infection rate of different fungi varied from 1.70 to 9.20%. The lowest (9.80%) total seed-borne infection was also recorded in seeds of colonized Trichoderma amended plot. The highest (3.73) benefit-cost ratio was obtained from colonized Trichoderma, followed by poultry manure (3.39) and vermicompost (3.33) amendment. Thus, soil amendment with colonized Trichoderma or vermicompost or poultry manure is suggested to produce quality chilli seeds with a higher yield.

Keywords: Cow dung, mustard oil cake, poultry manure, seed health, Trichoderma, vermicompost

INTRODUCTION

Chilli is an important spice of the world and it is extensively grown in Bangladesh. It belongs to the genus Capsicum and the family Solanaceae and is a source of vitamin A, E and C. Color and flavor extract from chilli are used in both food and industries. Some varieties are grown all over Bangladesh in Rabi and Kharif season. In 2018-19, the area was 43947 and 195256 acres, the production was 43452 and 10602 tons in Kharif and Rabi season, respectively (BBS 2020). Quality seed is an essential component of crop production. Farmers mainly depend on their seeds of inferior quality. Poor seed quality is an important factor among the various factors responsible for the low yield of the crop. Application of chemical fertilizers may increase its yield. But the imbalanced and excess use of chemical fertilizers degrades the soil and the environment (Higa 1991; Lestari et al. 2017; Jaikhis et al. 2018; Purba et al. 2020). The use of organic amendments with water, such as traditional thermophilic composts, has long been used as an effective method to improve soil structure, increase soil fertility, microbial diversity, populations, activity, improve soil moisture-holding capacity, and increase crop yields (Zink and Allen 1998). Vermicomposting is the best method to recycle solid waste towards achieving sustainable solid waste management. During the passage of organic substrate through the gut, earthworms convert the nutrients from organic matter into bioavailable forms. Various enzymes and hormones are mixed with the digested material, which stimulates plant growth and protects plants from pathogen infestation (Gajalakshmi and Abbasi 2004). Trichoderma is a genus of fungus strains that live as symbionts on plant roots and have qualities that encourage plant growth and development (Harman et al. 2004). Trichoderma species have long been recognized as bio-agent for controlling plant disease and increasing yield by increasing phytohormones production such as jasmonic acid and salicylic acid (Silva et al. 2019). Trichoderma as a biological agent may be a cost-effective and efficient technique. Many studies on Trichoderma are underway, focusing on their ability to alleviate abiotic stress; nevertheless, the specific knowledge of mechanisms related to their ability to modulate diverse plant abiotic stress factors is still lacking. The commercialization of Trichoderma biofertilizer has encouraged farmers. Trichoderma is used in all crops, with or without additives, however, when used as an amendment with compost, Trichoderma biofertilizer may produce greater results than any other fertilizer. The poultry industry is one of the world's largest and fastest-growing agricultural enterprises. The majority of the litter made by the poultry business is currently used as a source of nutrients and soil amendment on agricultural land (Bolan et al. 2010). It has been applied to surrounding crops and pasturelands to recycle nutrients, primarily nitrogen (N), phosphorus (P), and potash (K) (Lorimor and Xin 1999).

Cow dung is important organic manure. It is also called soil life and plays an important role in sustainable soil fertility and crop productivity. The biggest benefit of cycling and recycling of organic matter in soils is the
overall improvement in soil environment and supplying nutrients, especially N, P, K and S. It provides nutrients and improves the physical and chemical properties of soil like porosity and water-holding capacity. In addition, cow dung is a harbour of rich microbial diversity, containing different species of bacteria (Bacillus sp., Corynebacterium sp., and Lactobacillus sp.), protozoa and yeast (Saccharomyces and Candida) (Nene and Thapliyal 2002). Mustard oil cake, about 60% of the seed, is generated as a by-product during oil extraction. It is a rich source of nitrogen (4.8%), potassium (as K₂O-1.3%), and phosphorous (as P₂O₅-2%) which are essential requirements to maintain the fertility of the soil and proper growth of a plant. Organic manure provides several benefits by minimizing production costs and is an environment-friendly cultivation method. Consumers are increasingly expecting high-quality, safe food in recent times and are particularly interested in organic items (Ouda and Mahadeen 2008). Inorganic fertilizer is made up of synthetic materials, when an excess of the application occurs, the soil becomes toxic. However, organic crop additives are becoming more popular as people become more aware of the harmful impacts of inorganic fertilizers on crop productivity and growing environmental and ecological concerns. Considering the above facts, the study was aimed to know the effect of various soil amendments on the quality of chilli seed production.

MATERIALS AND METHODS

Location of the experimental field

The experiment was conducted from November 2018 to May 2019 at Bangabandhu Sheikh Mujibur Rahman Agricultural University's Plant Pathology field in Gazipur, Bangladesh. The experimental site was located at 24°09’N latitude and 90°26’E longitudes, with an elevation of 8.4 m. The soil of the study site was silty clay loam to clay loam in texture and belonged to the Madhupur Tract's Agro-Ecological Zone (AEZ No. 28).

Climate of the experimental area

In the experimental area, the minimum and maximum air temperature varied between 11 to 27°C and 14 to 34°C, soil temperature in 10 cm, 20 cm and 30 cm depth varied between 16 to 27.5°C, 16.5 to 28°C, and 17 to 28.5°C, respectively, groundwater table varied between 15.60 m and 18.56 m and total amount of rainfall was 2.92 mm during the entire cropping period.

Soil of the experimental field

The soil of the study site was silty clay loam to clay loam in texture and belonged to the Madhupur tract's AEZ No. 28, with a pH of 5.8 to 6.5 and an ECE of 25.28 (Haider 1991). The organic carbon and organic matter of the soil sample collected from the experimental area were 0.75 and 1.12, respectively, which was determined with the help of the Soil Science Department of BSMRAU before the application of soil amendments.

Materials collection

Chandra Mukhi chilli seeds of Lal Teer, mustard oil cake and chemical fertilizers were collected from a retailer at Joydebpur in Gazipur. Vermicompost was collected from Pajulia Village at Gazipur. Trichoderma culture was taken from the Plant Pathology division of the Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, and poultry manure and cow dung were gathered from the BSMRAU's nearby farm. The chickpea meal substrate was prepared and inoculated with Trichoderma harzianum Rifai. The T. harzianum was allowed to colonize in chickpea meal for 21 days (Arefin et al. 2019). After 21 days, the colonized chickpea meal substrate was air-dried and stored in a conical flask a 10°C (Liton et al. 2019; Das et al. 2019). The mustard oil cake was soaked in water for 24 hours and kept into a hole for adjusting soil temperature (Rubayet and Bhuiyan 2016). After 3 days, mustard oil cake was ready to incorporate into soil.

Raising of seedlings

Seedlings of chillies were cultivated in a seedbed. The seedbed was (1.2 m × 3 m) in size. The soil was well prepared and turned into a loose friable and dry mass by using good tillth. All weeds and stubbles were removed, and the soil was amended with well-decomposed cow manure. On 1st November 2018, ten-gram seeds were sown and then covered with light dirt. Within six days of sowing, the seedlings emerged. Weeding and irrigation were performed as needed. Plants were ready for transplanting after 35 days of seed sowing.

Design and layout of the experiment

The experiment was set up in a three-replication randomized complete block design (RCBD). The total area was divided into three equal blocks. Each block consisted of 6 plots where 6 treatments were allotted randomly. There were 18-unit plots in the experiment. The area of a unit plot was 4 m², which contained 16 plants at a spacing of 40 cm × 40 cm. The distance between two blocks and two plots was kept at 1.00 m and 0.50 m, respectively.

Land preparation

For agricultural production, the soil was thoroughly prepared and tilled was ensured. The trial field land was ploughed with a motorized tiller and then laddered to achieve the desired tilled. Larger clods were broken into smaller pieces and the land corners were spaded. After ploughing and laddering, all the stubbles and uprooted weeds were removed and then the land was made ready. The field layout and design of the experiment were followed after land preparation.

Application of fertilizers

According to Fertilizer Recommended Guide Bangladesh Agricultural Research Council (BARC), a generalized dose of 1.60 kg TSP, 1.2 kg MoP, 0.78 kg (half dose) urea fertilizer were given in all units plots at the rate of 223 kg ha⁻¹, 167 kg ha⁻¹ and 218 kg ha⁻¹. Rest of half dose (0.78 kg) of urea fertilizer was applied after 30 days of transplanting.
Treatments of the experiment
The experiment had five treatments of soil amendment. Control was maintained where no soil amendment was included. Thus, the experiment had six treatments altogether. In each 4 m² plot 2.00 kg vermicompost (@ 5 t ha⁻¹), 0.27 kg colonized Trichoderma (@ 0.90 t ha⁻¹), 0.80 kg mustard oil cake (@ 2 t ha⁻¹), 4.00 kg cow dung (@ 10 t ha⁻¹) and 2.00 kg poultry manure (@ 5 t ha⁻¹) were applied during final land preparation in respective plot as per layout of the experiment.

Transplanting of seedlings
Health and uniform 35 days old seedlings were uprooted from the seedbed and were transplanted in the experimental plots in 6th December 2018.

Intercultural operations
After transplanting the seedlings, different intercultural operations were accomplished for better growth and development of the plants. Weeding was accomplished whenever necessary to keep the crop free from weeds. Irrigations were given throughout the growing period by garden pipe and watering cane. The first irrigation was given immediately after the transplantation, while the second irrigation was done per requirement.

Harvesting
Fruits were harvested at 6 to 7 days intervals during an early ripening stage when they attained marketable size. Harvesting was started from 15th March 2019 and was continued up to 25th May 2019.

Data collection
Five plants were randomly selected from each plot for data collection to prevent the border effect and achieve the best level of precision. Data on the following parameters were collected from the sample plants during the experiment.

Plant height
The plant height of the selected five plants was measured in cm from the base of plant to the terminal growth point of main stem at 65 days of planting up to observe the growth of plants and the average height was computed.

Number of branches per plant
The number of branches per plant was counted at 65 days after transplanting from tagged plants. The average of five plants was computed and expressed in an average number of branches per plant.

Number of fruits per plant
The total number of fruits produced in a plant was counted and recorded.

Dry weight of fruits
After harvesting, the fruits were dried in sunshine. The moisture content was maintained 9.00%. A digital weighing balance was used to measure the fruit weight of each plot.

Dry weight of seeds
The exocarp was cut with a sharp blade and the seeds of the chilli were taken out from the fruit. A digital weighing balance was used to measure the seed weight of each plot.

Disease incidence
After transplanting the seedlings, data of various diseases like Cercospora leaf spot, Fusarium wilted plants, anthracnose of fruits were recorded in each field plot. Percentage of disease incidence was calculated following the formula given below:

\[ \% \text{ disease incidence} = \frac{\text{No. of infected leaves/plants/fruits}}{\text{Total no. leaves/plants/fruits investigated}} \times 100 \]

The infected samples of leaves, plants and fruits were collected in the laboratory and associated pathogens were isolated and identified.

Quality of harvested seeds
Germination capacity
Germination capacity was determined from four hundred seeds (4×100) into replicates of 100 seeds of each sample sown in blotting paper in a petri dish. After seven days of sowing results were recorded as a percentage by the number of seeds germinated on the Petri dish, and the average percentage was recorded to the nearest whole number. Germination percentage was computed using the following formula:

\[ \text{Germination} (\%) = \frac{\text{Number of seeds germinated}}{\text{Number of seeds tested}} \times 100 \]

Seed vigour index
The rate of germination measured vigour index (VI). Normal germinated seeds were removed and counted daily. This was started on the first day of seeding and continued up to 14 days. An index was computed for each replication by dividing the number of germinated seeds removed each day by the day they were removed (Sen and Ghosh 1999). Seed VI can be computed by the following formula (AOSA 1983):

\[ \text{Vigour index} = \frac{\text{No. of germinated seeds in first count}}{\text{No. of days to first count}} \times \frac{\text{No. of germinated seeds in last count}}{\text{No. of days to last count}} \]

Electrical conductivity
Four replications of 50 seeds of each sample were weighted (to nearest mg) and then soaked in 50 mL de-ionized water for 24 hours at 25±1°C. After 24 hours, water of the beaker containing seeds was decanted to separate the seeds. Then electrical conductivity of the decanted water containing seed leachate was then measured with a conductivity meter (Model-CM-30ET). The electrical conductivity (EC) was expressed in μS/cm.

Thousand seed weight
Thousand seed weight was calculated for each seed sample. The seed sample was divided into 3 sub-samples and 10 replicates of 100 seeds from each sub-sample were
counted at random. Thus, the weight of replicates (100x10x3 replicates) were added together and the resulting mean weight was recorded at the 1000 seeds weight of the seed sample (ISTA 2006).

Seed health test

In terms of fungi associated with chilli seeds, seed health was tested following International Rules for Seed Health Testing (ISTA 1976). A sub-sample of 400 seeds was randomly selected from each sample. Seeds were plated on sterilized and moist blotter paper in 9 cm Petri dish. Twenty-five seeds were plated in each Petri dish, maintaining equal distances from seed to seed. After plating, the seeds were incubated at 25±2°C temperature. The filter paper was kept moist by adding sterilized water whenever necessary. Data on the prevalence of seed-borne fungi grown on the planted seeds were recorded after seven days of incubation. Fungi associated with the seeds were observed under a binocular microscope. Based on the morphological characters, fungi were identified using appropriate keys (Mathur and Kongsdal 2003). When the fungus identification was not possible by observing the growth characteristics under stereo-microscope, temporary mounts were prepared and examined under a compound microscope for detailed morphology. Seeds exhibiting different fungi were expressed in percentage based on total seeds plated.

Statistical analysis

All data were subjected to statistical analysis by analysis of variance (ANOVA). Microsoft Excel and Statistix 10 software programs were used wherever appropriate, and means were compared according to least significant difference (LSD) test.

RESULTS AND DISCUSSION

Effect of soil amendment on chilli seed production

Plant height

The result showed that significantly higher plant height was found in colonized Trichoderma amended plot (79.70 cm), followed by vermicompost (75.10 cm), poultry manure (74.6 cm), mustard oil cake (73.00 cm) and cow dung (71.40 cm) amended plots. There were no significant differences among vermicompost, poultry manure and mustard oil cake amended plots in the context of plant height. The lowest (66.80 cm) plant height was found in the control (Table 1).

Number of branches/plant

A significant maximum number of branches per plant was found in colonized Trichoderma treated plot (17.00), followed by vermicompost (15.00), poultry manure (14.00), mustard oil cake (14.00) and cow dung (13.00) amended plots. There were no significant differences in the number of branches/plant in vermicompost, poultry manure and mustard oil cake treated plots. The minimum (10.00) number of branches was found in the control treatment (Table 1).

Number of fruits/plant

The maximum number of fruits per plant was found in colonized Trichoderma applied plot (171.00), followed by vermicompost (161.00), poultry manure (149.00), mustard oil cake (144.00) and cow dung (140.00) applied plots. There was no significant difference in some fruits per plant in colonized Trichoderma and vermicompost applied plots. The minimum (120.00) number of fruits per plant was found in control (Table 1).

Fruits and seed yield (t ha⁻¹)

The highest fruit yield was recorded in the colonized Trichoderma applied plot (3.63 t ha⁻¹), which was statistically similar to the vermicompost applied plot (3.53 t ha⁻¹). The yield of chilli was statistically similar with vermicompost (3.53 t ha⁻¹), poultry manure (3.50 t ha⁻¹), mustard oil cake (3.35 t ha⁻¹) applied plot. The lowest (2.08 t ha⁻¹) yield was found in the control. The highest seed yield was recorded in colonized Trichoderma applied plot (2.40 t ha⁻¹), followed by the vermicompost applied plot (2.18 t ha⁻¹). The seed yield was statistically similar with vermicompost (2.18 t ha⁻¹) and poultry manure (2.12 t ha⁻¹) applied plots. The lowest (1.35 t ha⁻¹) seed yield was found in the control (Table 1).

Table 1. Effect of different soil amendments on growth and yield parameters of chilli

| Soil amendments       | Height of plants (cm) | Number of branches/plants | Number of fruits/plants | Weight of fruits (t ha⁻¹) | Weight of seeds (t ha⁻¹) |
|-----------------------|-----------------------|---------------------------|-------------------------|--------------------------|--------------------------|
| Control               | 66.80d                | 10.00d                    | 120.00d                 | 2.08d                    | 1.35 e                   |
| Vermicompost          | 75.10b                | 15.00b                    | 161.00ab                | 3.53ab                   | 2.18b                    |
| Colonized Trichoderma | 79.70a                | 17.00a                    | 171.00a                 | 3.63a                    | 2.40a                    |
| Mustard oil cake      | 73.00bc               | 14.00bc                   | 144.00c                 | 3.35b                    | 2.00c                    |
| Cow dung              | 71.40c                | 13.00c                    | 140.00c                 | 2.45c                    | 1.55d                    |
| Poultry manure        | 74.60b                | 14.00b                    | 149.00bc                | 3.50ab                   | 2.12b                    |
| CV (%)                | 2.29                  | 5.44                      | 6.21                    | 4.06                     | 4.78                     |

Note: Means followed by the same letter (s) in a column are not significantly different at 5% level
Percentage of increase of fruit and seed yield of chilli

Results revealed that all the treatments under soil amendments increased the fruit and seed yield significantly compared to control, but their efficacy was not similar. The highest fruit yield was increased in colonized Trichoderma (74.00%) treated plot, followed by vermicompost (69.00%), poultry manure (68.00%) and mustard oil cake (61.00%) treated plots. The lowest (17.00%) fruit yield increase was recorded in cow dung treated plot (Figure 1). The highest seed yield increase was recorded in colonized Trichoderma (77.00%) treated plot, followed by vermicompost (61.00%), poultry manure (57.00%) and mustard oil cake (48.00%) treated plots. The lowest (15.00%) seed yield increase was recorded in cow dung treated plot (Figure 2). Molla et al. (2012) reported that above 200% yield increase was recorded by BioF/Compost (household/ kitchen/wastes composted by Trichoderma) over control, but 30.40% yield increase was recorded by BioF/Compost over standard dose of N:P:K. Rahaman et al. (2012) conducted an experiment and 18% yield increase was recorded by cow dung over standard dose of N:P:K in field studies of chilli. Hassan et al. (2013) showed that 35.00% yield was increased by poultry manure as soil amendment over standard dose of N:P:K. The present experimental results agreed with the previous findings of various researchers (Molla et al. 2012; Rahman et al. 2012; Simi et al. 2019) as the soil amendment increases the yield of chilli fruits and seeds.

Disease incidence

Three diseases, namely Cercospora leaf spot, Fusarium wilt and anthracnose of fruits, were recorded in the experimental field of chilli. The causal organism of diseases identified Cercospora capsici Heald & F.A.Wolf, Fusarium oxysporum Schldt. and Colletotrichum capsici (Syd. & P.Syd.) E.J.Burter & Bisby, respectively (Table 2).

Incidence of Cercospora leaf spot

The highest Cercospora leaf spot was recorded in control plot (10.83%), followed by cow dung (8.41%), mustard oil cake (6.83%) and poultry manure treated plot (4.50%). The lowest incidence of Cercospora leaf spot was recorded in colonized Trichoderma (3.00%) treated plot, followed by vermicompost (4.42%) treated plot (Table 2).

Incidence of wilt infected plants

The highest Fusarium infected plants were observed in control plot (18.75%), followed by cow dung (10.40%), poultry manure (8.30%), mustard oil cake (6.25%) and vermicompost (6.25%) treated plot. The disease incidence was statistically similar in vermicompost, poultry manure and mustard oil cake treated plot. The lowest (2.10%) Fusarium infected plant was observed in colonized Trichoderma treated plot (Table 2).

Incidence of anthracnose of chilli fruits

The highest anthracnose-infected fruits were recorded in control plot (11.41%), followed by cow dung (7.91%), mustard oil cake (6.91%), poultry manure and vermicompost (5.16%) applied plot. The lowest anthracnose was recorded in colonized Trichoderma (2.91%) applied plot, followed by vermicompost (5.16%) applied plot (Table 2).

Quality of harvested seeds under soil amendments

Germination percentage

The highest germination was recorded in seeds collected from Trichoderma amended plot (77.00%), followed by vermicompost (70.00%). The germination percentage of harvested seeds collected from soil amended plot with poultry manure, mustard oil cake and cow dung was 69.00%, 67.00% and 65.00%, respectively. The germination percentage of harvested seeds collected from vermicompost and poultry manure amended plot was statistically similar. The lowest germination percentage was recorded in seeds of control plot (63.00%) which was statistically similar to the cow dung (65.00%) amended plot (Table 3).

Vigour index (VI)

Vigour indices of seeds collected from six treatments ranged from 28.50-40.50. The highest VI was recorded in colonized Trichoderma (40.50) amended plot, followed by vermicompost (37.58), poultry manure (35.40), mustard oil cake (33.84) and cow dung (29.40) amended plots. But VI of seeds harvested from poultry manure and mustard oil cake amended plots was statistically similar. The control plot recorded the lowest (28.50) VI of harvested seeds (Table 3).

![Figure 1. Increased percentage of fruits yield under different soil amendments over control](image1)

![Figure 2. Increased percentage of seed yield under different soil amendments over control](image2)
Electrical conductivity

The electrical conductivity of seeds harvested from soil amended field varied from 0.11 to 0.18 μS cm⁻¹. The lowest electrical conductivity was recorded in colonized Trichoderma treated plot (0.11 μS cm⁻¹), followed by vermicompost (0.13 μS cm⁻¹), poultry manure (0.14 μS cm⁻¹), mustard oil cake (0.14 μS cm⁻¹) and cow dung (0.15 μS cm⁻¹) treated plots. In terms of electrical conductivity, there was no significant difference among vermicompost, poultry manure and mustard oil cake treated plot. The electrical conductivity of seeds harvested from poultry manure, mustard oil cake and cow dung treated plot was also statistically similar. The maximum (0.18 μS cm⁻¹) electrical conductivity was recorded in control plot (Table 3).

Thousand seed weight

The thousand seed weights of harvested seeds collected from soil amended field ranged from 3.90 to 4.80 g. The highest thousand seed weight was obtained from colonized Trichoderma amended plot (4.80 g), followed by vermicompost (4.60 g), poultry manure (4.53 g), mustard oil cake (4.40 g) and cow dung (4.10 g) amended plot. The thousand seed weights of vermicompost and poultry manure amended plots were statistically similar. The lowest (3.90 g) thousand seed weight was recorded in the control plot (Table 3).

Prevalence of seed-borne fungi of harvested seeds

Total seed-borne fungal infection in harvested chilli seeds ranged from 9.80 to 39.70%. The highest infection was recorded in the control plot (39.70%), followed by cow dung (30.10%), mustard oil cake (23.50%), poultry manure (17.75%), and vermicompost (16.60%) amended plot. The lowest (9.80%) fungal infection was recorded in seeds of colonized Trichoderma amended plot. The identified fungal species were Aspergillus sp., Fusarium sp., Curvularia sp., Co. capsici and Alternaria alternata (Fr.) Keissl. (Table 4). The most predominant fungus was Aspergillus sp., ranging between 4.50 to 9.00%. The highest Aspergillus sp. was found in control (9.00%), followed by the amended plot of cow dung (7.50%). Prevalence of Aspergillus sp., in seeds, was statistically similar in cow dung (7.50%) and mustard oil cake (6.30%) amended plots and vermicompost (3.90%) and poultry manure (4.50%) amended plot. The lowest (2.00%) Aspergillus sp. infection was recorded in colonized Trichoderma amended plot (Table 4). The second most fungi recorded in seeds was Fusarium sp. ranging from 2.10 to 9.20%. The highest Fusarium sp., infection was recorded in seeds of control plot (9.20%), followed by cow dung (6.10%), mustard oil cake (4.90%), vermicompost (3.90%), poultry manure (3.30%) amended plot. The lowest (2.10%) fungal infection was recorded in colonized Trichoderma amended plot (Table 5). The highest incidence of Co. capsici was recorded in seeds harvested from the control plot (7.70%), followed by cow dung (5.80%), mustard oil cake (4.20%), poultry manure (3.10%), vermicompost (2.80%), amended plot. Among them, mustard oil cake (4.20%), poultry manure (3.10%), vermicompost amended plot (2.80%) were statistically similar. The lowest incidence of Co. capsici was recorded in seeds of colonized Trichoderma (1.70%) amended plot, which was statistically similar with vermicompost (2.80%) amended plot. The prevalence of Curvularia sp. in seeds was varied from 1.90-6.80%. The highest incidence of Curvularia sp. was found in the control plot (6.80%), followed by cow dung (4.80%), mustard oil cake (4.00%), poultry manure (3.25%) amended plot. The lowest (1.90%) incidence of Curvularia sp. was recorded in seeds of colonized Trichoderma amended plot. The prevalence of Alternaria was varied from 2.10 to 7.00%. The highest A. alternata infection was noted in seeds of control plot (7.00%), followed by cow dung (5.90%), mustard oil cake (3.90%), poultry manure (3.60%) vermicompost (3.10%) amended plot. Among them, vermicompost and colonized Trichoderma amended plot were statistically similar. The lowest (2.10%) Alternaria infection was recorded in seeds of colonized Trichoderma amended plot (Table 4).

Table 2. Percentage of different disease incidence of chilli in the field under soil amendments

| Soil amendments     | Cercospora affected leaves (%) | Fusarium wilted plants (%) | Anthracnose affected fruits (%) |
|---------------------|-------------------------------|----------------------------|--------------------------------|
| Control             | 10.83a                        | 18.75a                     | 11.41a                         |
| Vermicompost        | 4.42d                         | 6.25b                      | 5.16d                          |
| Colonized           | 3.00e                         | 2.10c                      | 2.91e                          |
| Trichoderma         |                               |                            |                                |
| Mustard oil cake    | 6.83c                         | 6.25bc                     | 6.91c                          |
| Cow dung            | 8.41b                         | 10.4b                      | 7.91b                          |
| Poultry manure      | 4.50d                         | 8.30bc                     | 5.25d                          |
| CV (%)              | 7.07                          | 48.33                      | 8.71                           |

Table 3. Effect of different soil amendments on quality parameters of harvested chilli seeds

| Soil amendments | Germination (%) | Vigour index | Electrical conductivity (μS cm⁻¹) | Thousand seed weight (g) |
|-----------------|-----------------|--------------|----------------------------------|--------------------------|
| Control         | 63.00d          | 28.50c       | 0.18a                            | 3.90e                    |
| Vermicompost    | 70.00b          | 37.58b       | 0.13c                            | 4.60b                    |
| Colonized       | 77.00a          | 40.50a       | 0.11d                            | 4.80a                    |
| Trichoderma     | 67.00c          | 33.65c       | 0.14bc                           | 4.40c                    |
| Mustard oil cake| 65.00d          | 29.40d       | 0.15b                            | 4.10d                    |
| Cow dung        | 69.00bc         | 35.40c       | 0.14bc                           | 4.53b                    |
| Poultry manure  | 1.45            | 3.71         | 7.0                              | 1.33                     |

Note: Means followed by the same letter (s) in a column are not significantly different at 5% level.
Percentage of reduction in total seed-borne fungi of chilli

Results of soil amendments with six treatments, namely vermicompost, colonized Trichoderma, poultry manure, mustard oil cake and cow dung against seed-borne fungi of chilli are presented in Figure 3. All the soil amendments significantly reduced the percent seed-borne infection of total fungi (Aspergillus sp., Co. capsici, Fusarium sp., Curvularia sp., and A. alternata) compared to the control plot. The reduction percentage of fungi varied from 24.00 to 75.00%. The highest reduction percentage was obtained by colonized Trichoderma amendment (75.00%), followed by vermicompost (59.00%), poultry manure (55.00%), mustard oil cake (41.00%) and cow dung amendment (24.00%) (Figure 3). The experiment results suggested that organic soil amendments and application of colonized Trichoderma in soil reduced disease incidence of chilli in the field and reduced the seed-borne pathogens in harvested seeds. Different researchers also reported that organic soil amendments and colonized Trichoderma reduce disease incidence (Kapoor 1996; Punja et al. 2002; Prasad et al. 2002; Kashem et al. 2005; Hassan et al. 2013; Sultan and Guffar 2013; Tapwal et al. 2015). Sultan and Ghaffar (2013) reported that maximum increase in plant size (20.00 cm), seed germination (86.00%) and up to 2.20% reduction in seedling mortality caused by Fusarium sp., in cucumber by mustard oil cake in the field study. Kapoor (1996) found groundnut and mustard oil cake at 2.00 percent concentration of soil (w/w) was most effective in reducing pathogen population (>70%) and disease incidence. Hassan et al. (2013) reported that 63.30% anthracnose and 5.00% Cercospora leaf spot reduction was obtained using poultry manure as a soil amendment. Punja et al. (2002) evaluated greenhouse waste, windrow dairy solids, vermicompost dairy solids and commercially available biological control agents to reduce disease incidences of Fusarium root and stem rot caused by F. oxysporum f.sp. radicis-cucumerinum, and Pythium damping-off and crown rot, caused by Pythium aphanidermatum (Edson) Fitzp. They reported that all three composts reduced root and stem rots to some degree, and autoclaved compost lost its suppression effect suggesting the microbial antagonism involved. Prasad et al. (2002) found that soil treated with T. harzianum showed 61.50% diseases control in chickpea, while Kashem et al. (2005) observed about 30.00% disease control in lentil seed. Tapwal et al. (2015) found that T. harzianum recorded maximum growth inhibition (34.20%) against A. alternata, followed by F. oxysporum (27.04%), Cochliobolus lunatus R.R.Nelson & F.A.Haasis (25.64%), Colletotrichum gloeosporioides (Penz.) Penz. & Sacc. (15.00%) and minimum for Rhizoctonia solani J.G.Kühn (5.10%). Bhat et al. (2016) reported that T. harzianum inhibited mycelia growth by 40.00 to 50.00% in vitro and increased yield up to 30.00% in the Haveri District, while at Bellary, T. harzianum reduced wilt incidence by 39.70%.

Benefit-cost ratio

The benefit-cost ratio obtained from different soil amendments, including control, varied from 1.98 to 3.73. The highest (3.73) benefit-cost ratio was obtained from colonized Trichoderma amendment soil, followed by poultry manure (3.39), vermicompost (3.33), mustard oil cake (2.83) and cow dung (2.31) amendment and the lowest (1.98) benefit-cost ratio was obtained from control (Table 5).

Table 4. Incidence of fungi associated with seeds produced by soil amendments

| Soil amendments       | Aspergillus sp. | Colletotrichum capsici sp. | Fusarium oxysporum sp. | Curvularia lunata sp. | Alternaria alternata | Total |
|-----------------------|----------------|---------------------------|------------------------|-----------------------|----------------------|-------|
| Control               | 9.00a          | 7.70a                     | 9.20a                  | 6.80a                 | 7.00a                | 39.70 |
| Vermicompost          | 3.90c          | 2.80cd                    | 3.90d                  | 2.60c                 | 3.10d                | 16.30 |
| Colonized Trichoderma | 2.00d          | 1.70d                     | 2.10c                  | 1.90f                 | 2.10e                | 9.80  |
| Mustard oil cake      | 6.30b          | 4.20c                     | 4.90c                  | 4.00c                 | 3.90c                | 23.30 |
| Cow dung              | 7.50b          | 5.80b                     | 6.10b                  | 4.80b                 | 5.90b                | 30.10 |
| Poultry manure        | 4.50c          | 3.10c                     | 3.30d                  | 3.25d                 | 3.60cd               | 17.75 |
| CV (%)                | 12.32          | 17.23                     | 9.49                   | 8.41                  | 10.78                |       |

Note: Means followed by the same letter(s) in a column are not significantly different at 5% level

Table 5. Benefit-cost ratio of soil amendments and control

| Soil amendments       | Cost (Tk. ha⁻¹) | Selling price (Tk. ha⁻¹) | Benefit-cost ratio |
|-----------------------|-----------------|--------------------------|--------------------|
| Control               | 136561          | 270000                   | 1.98               |
| Vermicompost          | 166561          | 555000                   | 3.33               |
| Colonized Trichoderma | 160861          | 600000                   | 3.73               |
| Mustard oil cake      | 176561          | 500000                   | 2.83               |
| Cow dung              | 156561          | 362500                   | 2.31               |
| Poultry manure        | 156561          | 530000                   | 3.39               |
In conclusion, growth characteristics like plant height, number of branches, fruit and seed yield were the highest in the colonized Trichoderma amended plot, followed by vermicompost amended plot. The disease incidence of Cercospora leaf spot, Fusarium wilt and anthracnose of fruits was minimum in colonized Trichoderma amended plot. The highest seed yield was increased by colonized Trichoderma soil amendment (77.00%), followed by vermicompost (61.00%) and poultry manure (57.00%) amendment. The quality of harvested seeds was better in colonized Trichoderma and vermicompost amended plots.

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