



RESEARCH ARTICLE

Evaluation of vesicular-arbuscular mycorrhiza and organic amendments for improving growth and yield of chilli (*Capsicum annuum* L. cv. Priyanka) in compacted clay soil

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Abstract

Clay soil with high bulk density is a major physical constraint that limits root growth, water infiltration, aeration and nutrient uptake, ultimately reducing crop productivity in the study area. This study evaluated the effectiveness of vermicompost, paddy husk, cocopeat and arbuscular mycorrhizal fungi (AMF) in reducing the bulk density of clay soil and improving soil physical properties under chilli (*Capsicum annuum* L.) cultivation. A pot experiment was conducted using different treatment combinations of these organic amendments and AMF. After the cropping period, soil bulk density, porosity, moisture retention, root colonisation and plant growth parameters were assessed. The combined application of vermicompost, cocopeat, paddy husk and AMF significantly reduced soil bulk density compared with the untreated control and increased soil porosity, water-holding capacity and root development. Enhanced AMF colonisation further improved nutrient uptake and promoted plant growth through better soil aggregation and root-soil interactions. Among the treatments, the integrated application of all three organic amendments with AMF produced the greatest improvement in soil physical properties and chilli growth. The results demonstrate that the synergistic use of vermicompost, paddy husk and mycorrhiza offer an effective and sustainable strategy for alleviating soil compaction, restoring soil health and enhancing crop productivity. This integrated approach has considerable potential for improving the management of compacted agricultural soils while reducing dependence on synthetic soil conditioners.

Keywords: arbuscular mycorrhizal fungi; chilli; cocopeat; paddy husk; soil bulk density; soil health; sustainable agriculture; vermicompost

Introduction

The fundamental role of soil is to supply essential nutrients in a suitable environment for crop production. This role depends entirely on the soil's physical, chemical and biological properties that enable it to provide water, aeration and physical support. Root growth, biopore formation and the availability and mobilisation of water and nutrients largely depend on soil physical properties. Soil compaction is a physical property of soil, expressed in terms of bulk density and is associated with fine texture, poor drainage, low aeration and restricted root development (1). Soil quality parameters determine crop selection and yield in specific regions (2). Organic amendments such as vermicompost, paddy husk and cocopeat improve soil aggregation and porosity, enhance water-holding capacity and stimulate microbial activity (3, 4). Vermicompost improves soil structure and nutrient availability (5). Paddy husk enhances aeration (6), while cocopeat improves moisture retention (7). The application of arbuscular mycorrhizal fungi (AMF) plays a crucial role in supplying nutrients, extending the root network and forming biopores that contribute to soil aeration. Further, AMF produce glomalin, a biological glue that favours soil aggregation and reduces bulk density (8). Chilli (*Capsicum annuum* L.) is one

of the spice crops widely cultivated in India, particularly in Tamil Nadu. In the study area, chilli cultivation is affected by surface runoff, low water infiltration and poor aeration, which are essential for root growth. Therefore, the use of organic amendments and bio-fertilisers has been explored as a sustainable, eco-friendly approach to ameliorate bulky soil. The perspective of crop sustainability lies in the utilisation of organic fertilisers' capacity to improve growth and yield, as well as their significant potential to replace chemical fertilisers (9, 10). Thus, this study has chosen coco peat, paddy husk and vermicompost with special emphasis on the role of AMF in improving soil physical properties and plant performance (11). By adopting such natural and sustainable approaches, it may be possible to enhance productivity while preserving long-term soil health. Thus, the present study aimed to ameliorate compacted clay soil through the application of organic amendments using chilli as the test crop.

Materials and Methods

The study area was conducted at SRM College of Agriculture Sciences (SRMCAS) farm in Baburayanpettai, at 12.3867° N latitude and 79.7344° E longitude (Google Maps).

Study period

The study was conducted from 28 July 2025 to 29 January 2026. During this period, the crop was exposed to various climatic conditions, including high temperatures and heavy rainfall.

Soil sampling

The topsoil was collected to a depth of 20 cm from an uncultivated area. The physical characteristics of the soil were analysed in the soil science laboratory of SRMCAS. The soil from the experimental site was initially analysed for porosity, pH and bulk density to assess its physical limitations in the Soil Science Laboratory at SRMCAS.

Soil sterilisation

The collected soil sample was sterilised by drying in sunlight for four weeks and tyndallisation was subsequently performed to eliminate harmful microorganisms and spores.

Mycorrhizae inoculum

Arbuscular mycorrhizal fungi were purchased from Agriya Agrotech, which containing 1200 infective propagules per gram.

Estimation of bulk density

The bulk density of the soil sample collected from the study area was estimated by the wax coating method. This method estimates the bulk density of soil clods by coating dried, irregular samples with paraffin wax and determining their volume by water displacement based on Archimedes' principle (12). The soil sample (ped) of known weight is coated with wax and immersed in a known volume of water and the volume of water displaced was used to determine the volume of the soil ped, from which the bulk density was calculated.

Organic amendments

The experiment was conducted in grow bags of 12 × 12.

Treatments

The research was conducted in a completely randomised design (CRD) with 7 treatments and 4 replications. In the T1, T2 and T3 treatments, a single organic amendment was mixed with the bulk soil at a 1 : 1 ratio. Similarly, a combination of two organic amendments in T4, T5 and T6 in a 1 : 1 : 1 ratio. The T7 treatment was a combination of three organic amendments mixed with bulky soil in a 1 : 1 : 1 : 1 ratio. Clay soil without mycorrhizal inoculation or organic amendments served as the control (Table 1).

Transplantation

Test crop chilli variety priyanka: Chilli seeds were planted in the pro-tray and on the 20th day, the seedlings were transplanted application of grams of mycorrhizal inoculum.

Data collection

Measurement of growth parameters: The test plant: *C. annum* height (in cm), flowers (numbers), fruits (numbers) and weight (g) were recorded at weekly intervals. Leaf length and breadth of the

plants were measured using a leaf area metre. The collected data were analysed using a standard procedure.

Assessment of root colonisation

Plants from each treatment and replication were carefully pulled out and the root portion was separated and washed. 1 cm of 10 rootlets from each treatment and control were analysed for the presence of mycorrhiza using a compound microscope at the microbiology laboratory.

Root colonisation assessment of vesicular-arbuscular mycorrhiza (VAM) was carried out by using the root-clearing method (13). The percentage of VAM colonisation was calculated by using the following formula.

$$\text{Colonisation percentage} = \frac{\text{No. of root segments colonised with VAM}}{\text{Total no. of root segments observed}} \times 100$$

Biomass analysis

The washed roots were oven-dried at 35 °C for 48 hr and weighed for their dry weight which was expressed in grams (g).

Biopore assessment

The plants in the 4th replication were used for biopore estimation. The data were analysed using Pearson correlation matrix.

Statistical analysis

For treatment comparison of each parameter, analysis of variance (ANOVA) appropriate for a CRD was performed. If the treatment effect was significant, the critical difference (CD) test was used for pairwise comparison. All assumptions were verified before analysis.

Result

The data collected revealed the plant growth characteristics, viz., height, leaf length, breadth, number of flowers, fruits and yield of the test crop, chilli, in treatments and control. The significance of variance was measured.

Rainfall recorded during the study period

Rainfall received during the study period was estimated based on regional India Meteorological Department (IMD) climatology and data from nearby weather stations (Fig. 1). The rainfall pattern showed a gradual increase from July 2025, reaching a peak in November 2025, followed by a decline until January 2026. Peak rainfall in November (approximately 310 mm) resulted in surface runoff, low water infiltration and poor aeration, thereby adversely affecting crop growth. Excess rainfall during October and November 2025 also resulted in waterlogging-related stress. Soil swelling and shrinking occurred during the Northeast monsoon.

Table 1. Treatment and organic amendment combination and ratio

Treatment	Test plant: <i>Capsicum annum</i> variety Priyanka mycorrhiza 5 g (all treatments)	Soil + organic amendment ratio
	Soil and organic amendment	
T1	soil + cocopeat	1 : 1
T2	soil + paddy husk	1 : 1
T3	soil + vermicompost	1 : 1
T4	soil + cocopeat + paddy husk	1 : 1 : 1
T5	soil + paddy husk + vermicompost	1 : 1 : 1
T6	soil + cocopeat + vermicompost	1 : 1 : 1
T7	soil + cocopeat + vermicompost + paddy husk	1 : 1 : 1 : 1
T8 Control	soil + chilli	Bulk soil

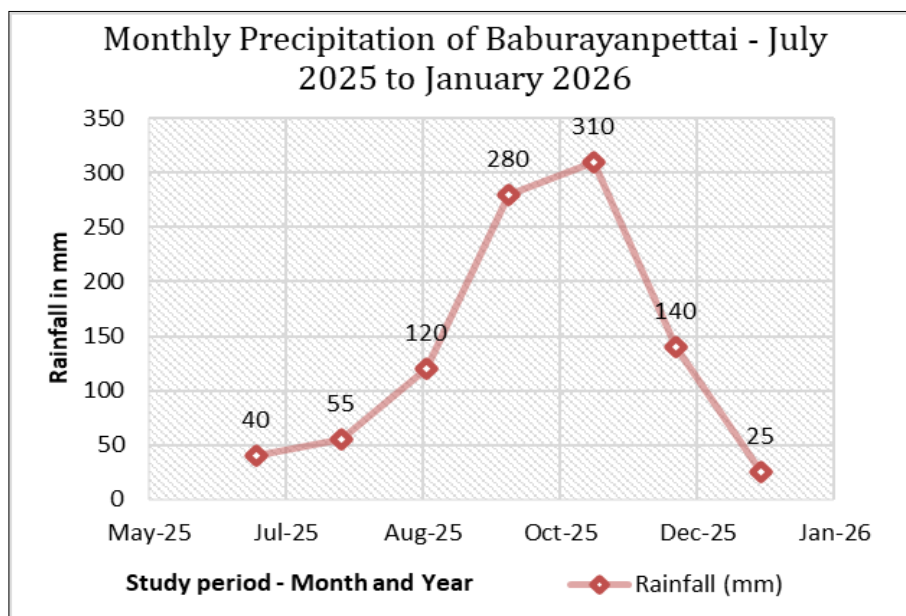


Fig. 1. Rainfall data of the study area.

Soil parameters

The soil test result indicated how the organic amendments, cocopeat, paddy husk and vermicompost amended or escalated the abiotic stress of the bulky soil used in this study. The initial pH noted in the control and in the treatment cocopeat and vermicompost was 6.6, i.e., near neutrality. The pH increased to 7.4 at the end of the experiment. The same trend was noted in other treatments viz., T1, T2, T3, T4, T5 and T6 (Fig. 2A).

Electrical conductivity was highest in T6, followed by T3 and decreased by the end of the experiment. Among the major nutrients, potassium (K) content was highest, followed by phosphorus (P) and nitrogen (N), towards the end of the experiment, which was attributed to the addition of organic amendments and mycorrhiza (Fig. 2B). The analysis of organic carbon showed a value of 2.4 % in the treatment containing all three amendments, namely cocopeat, paddy husk and vermicompost, mixed with bulky clay soil. The low organic carbon content recorded in the treatments at the end of the crop cycle indicated its utilisation by the plants for growth and yield (Fig. 2C). Leaf length was lowest in the cocopeat and compacted soil combination among all treatments, including the control. The plants in T2, which received paddy husk, recorded a leaf length of 16 cm (Fig. 2D). This was 37.5 % higher than that of the control plants and 11.8 % higher than the normal leaf length recorded in the other treatments (T2, T4, T5, T6 and T7). The greater leaf length may be attributed to the N supplied by the paddy husk amendment. Nutrient depletion was faster in T2 than in the other treatments, as indicated by leaf yellowing and reduced yield. Plants receiving the vermicompost-paddy husk combination with bulky soil showed normal growth. In contrast, plants receiving the cocopeat blend with bulky soil showed stunted growth, with a leaf length of 5.2 cm, which was lower than that of the control plants (Fig. 2E, F).

Root biomass and yield of chilli

The highest root biomass was recorded in the treatment containing paddy husk and vermicompost combined with compacted clay soil at a ratio of 1 : 1 : 1. The cocopeat and vermicompost treatment combined with soil showed high moisture content but low root biomass (Fig. 3A). This treatment resulted in significantly greater plant growth and yield than those observed in the treatments with individual amendments (T1, T2 and T3) and the control. Root

number and root network development varied among the treatments, with the highest values recorded in T5. The presence of mycorrhiza was confirmed through microscopic observation of root samples. In terms of yield, T5 recorded the highest yield.

Vegetative growth

The number of flowers and fruits was higher in plants receiving the dual treatments containing vermicompost and paddy husk, as well as in the treatment combining vermicompost, paddy husk and cocopeat. Flower production was very low in the cocopeat-paddy husk and cocopeat-vermicompost treatments and the control (Fig. 3B). These results indicate that cocopeat may have negatively affected the growth and reproductive performance of chilli plants. Similar trends were observed for fruit production and fruit weight. No fruits were produced in the cocopeat-soil treatment. Likewise, fruit production was negligible in the cocopeat-paddy husk and cocopeat-vermicompost treatments and the control. Mycorrhizal inoculation also had no apparent effect on plant growth under the soil stress conditions. The highest yield (671.11 g) was recorded in the paddy husk-vermicompost treatment and this was further enhanced by mycorrhizal inoculation. The highest number of fruits was recorded in the vermicompost treatment with compacted soil. This difference was attributed to variations in the weight of the chilli fruits produced. Overall, cocopeat and its combinations did not appear to improve soil physical conditions or chilli productivity (Fig. 3C).

Root network and aggregate

The roots of plants inoculated with mycorrhiza in the vermicompost- and paddy husk-amended treatments showed a well-developed root network (Fig. 4A), with normal plant aggregates visible (Fig. 4B). Furthermore, the percentage of mycorrhiza-infected roots was higher in the treatment containing paddy husk and vermicompost added to bulky soil at a ratio of 1 : 1 : 1 (Fig. 4C). Microscopic observation of the roots confirmed the presence of mycorrhiza (Fig. 4D). The major reason for the reduction in bulk density from 1.5–0.7 g cm⁻³ (Fig. 4E) was the formation of biopores (Fig. 5A) by mycorrhiza-infected roots and soil macrofauna. Whiteflies (Fig. 5B) and pill bugs (Fig. 5C) were also observed in the treatments containing vermicompost.

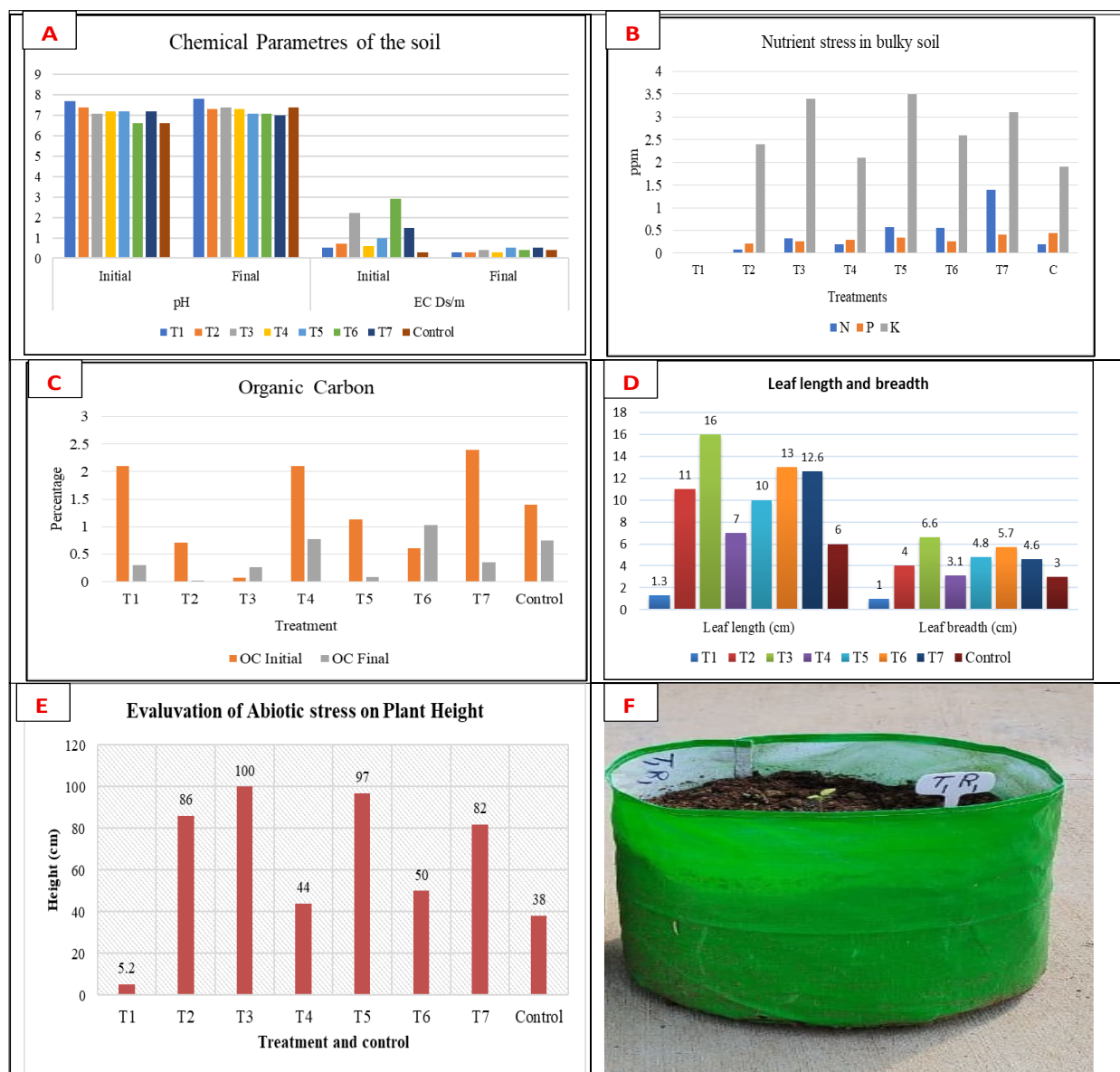


Fig. 2. Soil parameters. A: soil pH and electrical conductivity (EC); B: nitrogen, phosphorous and potassium (NPK); C: carbon in soil; D: leaf length and breadth; E: plant height; F: stunted plant.

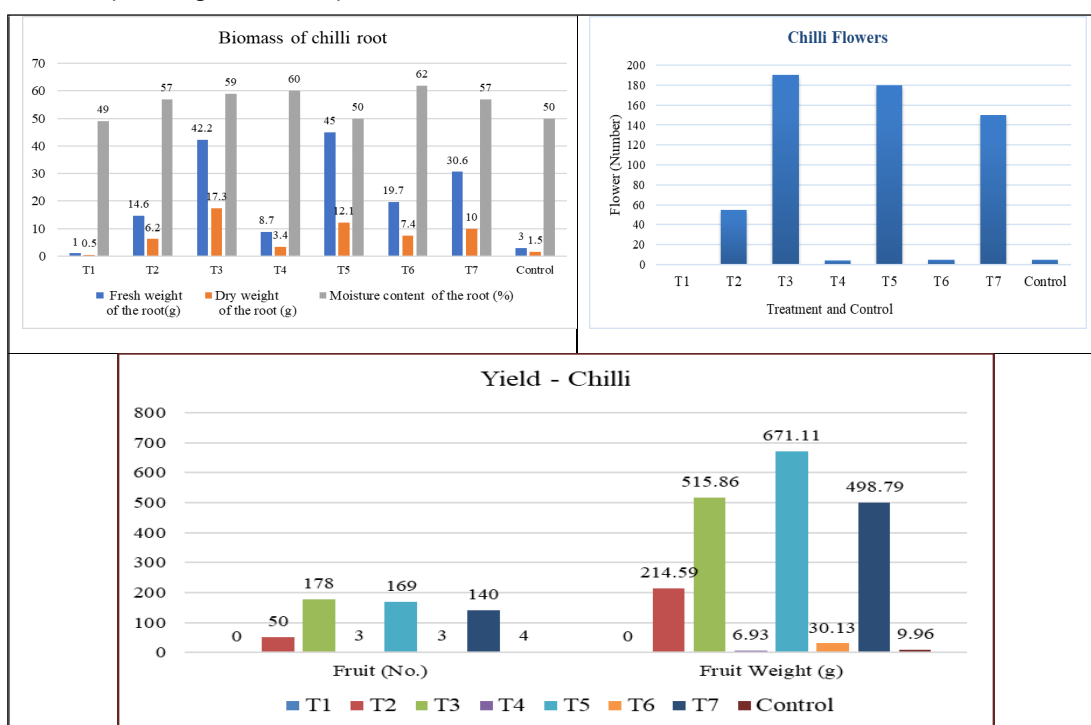


Fig. 3. Root biomass and yield of chilli. A: biomass of chilli root; B: flowers of chilli; C: fruit number and weight.

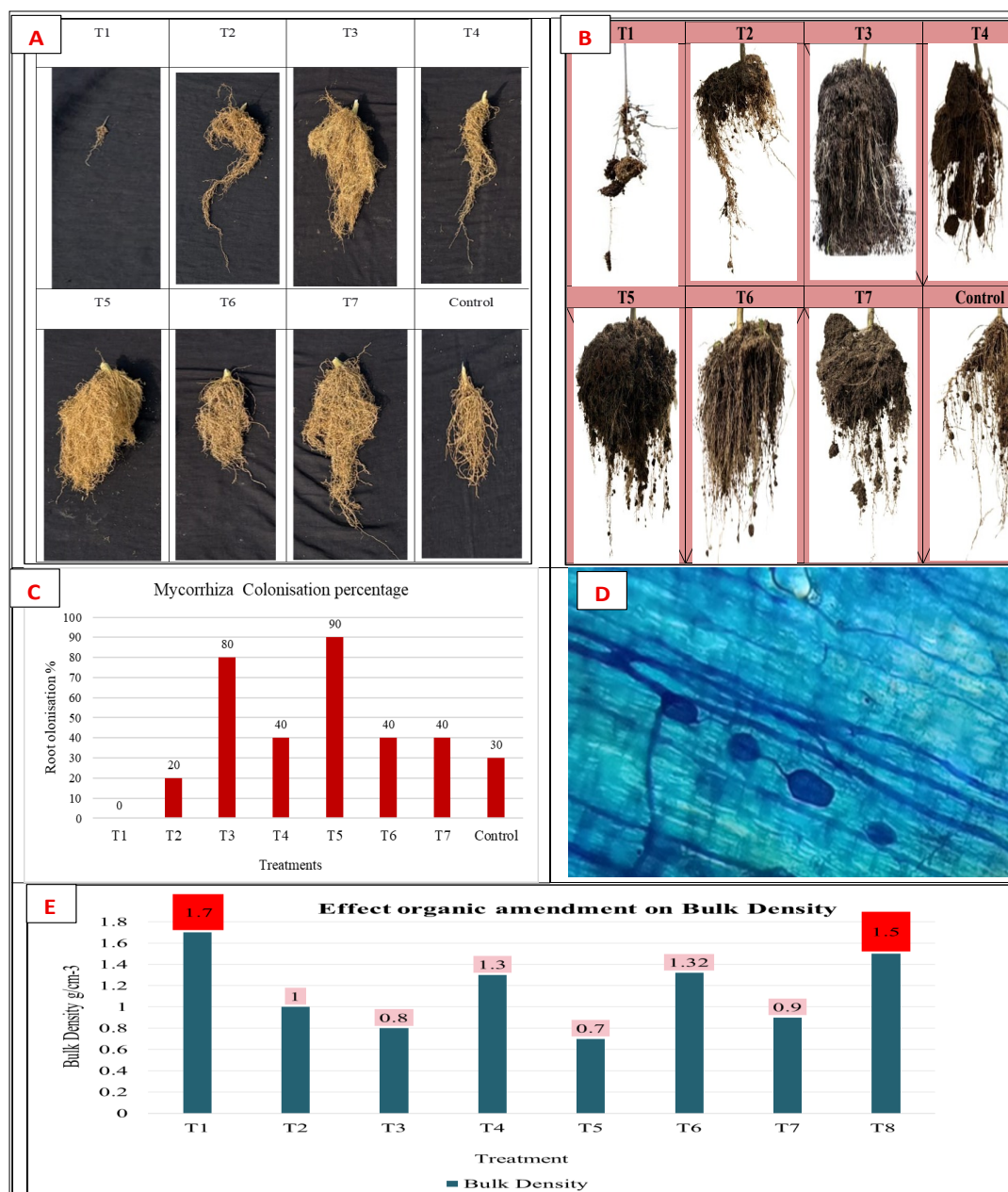


Fig. 4. Root network and aggregate. A: Root network; B: Soil aggregates; C: Root colonisation; D: Microscopic observation of mycorrhiza colonised root; E: Bulk density of the treated and untreated soil.

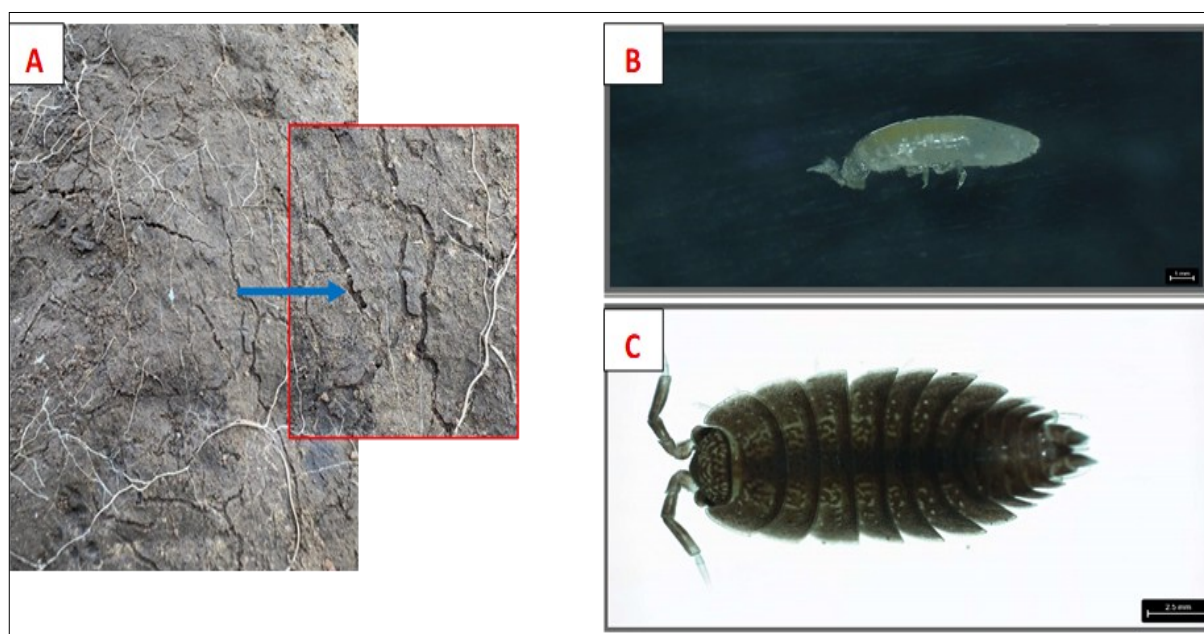


Fig. 5. Soil biopores and soil-dwelling organisms. A: biopore-root network; B: white fly; C: pill bug.

Biopore measurement

Soil slice analysis revealed the presence of biopores formed by mycorrhiza-infected root networks and the movement of earthworms, whiteflies and pill or grey bugs. Biopore formation was positively associated with plant root length, earthworm castings and the percentage of roots colonised by mycorrhiza. Bulk density was negatively correlated with organic carbon content, bacterial colonies and mycorrhiza-infected roots. Particle density and pore space showed no significant correlation with bulk density (Fig. 6).

Discussion

Modern agriculture has long relied on inorganic fertilisers to enhance crop yield and productivity (14, 15). However, excessive and prolonged use of chemical fertilisers has resulted in several adverse effects, including degradation of soil microbial diversity, decline in long-term soil fertility and alterations in soil organic carbon. Therefore, the use of organic amendments is a key strategy for promoting life on land (SDG 15).

Cocopeat

Cocopeat, a by-product of the coconut industry, has gained considerable attention as an alternative to growing medium because of its favourable physical and chemical properties. It is characterised by high water-holding capacity, good porosity and appreciable cation-exchange capacity, which collectively support plant growth and development. Cocopeat improves moisture retention and aeration, making it suitable for use in horticultural systems (16, 17). In the present study, the cocopeat amendment increased soil bulk density from 1.5–1.7 g cm⁻³, creating an unfavourable environment for root penetration by the test crop, chilli. In contrast, early researches reported that the use of cocopeat enhanced crop growth and yield (10).

In treatment T3, which included vermicompost and mycorrhizal inoculation, the chilli cultivar Priyanka showed a significant increase in vegetative growth compared with the control. It also exhibited significantly greater plant height, leaf area and fruit yield compared with T1 and T2. This improvement was likely due to increased nutrient availability, improved soil aeration and enhanced root development associated with the addition of paddy husk and mycorrhiza. This finding is consistent with the findings reported that the use of cocopeat enhanced the growth and yield of chilli (18). Cocopeat acts as a sponge and improves soil physical properties, indicating its potential as a soil conditioner.

Paddy husk

Paddy husk compost facilitated a suitable soil pH and reduced soil swelling (19). In contrast, the present study used whole paddy husk to improve aeration, promote biopore formation and enhance soil structure under conditions of high moisture resulting from heavy rainfall. The plants recorded the greatest leaf length, possibly due to the availability of N from vermicompost.

Vermicompost

Vermicompost plays a significant role in mitigating soil compaction and improving structural stability (20) and its continuous application improves pore-size distribution (21). In addition, the present results were consistent with those of earlier studies (22). The study also demonstrated improved crop yield, reduced bulk density and enhanced microbial activity. Among the dual-amendment treatments, T5 produced significantly greater growth and yield parameters than T4 and T6. This may be attributed to the improved nutrient availability provided by paddy husk, which facilitated better nutrient uptake and mycorrhizal activity.

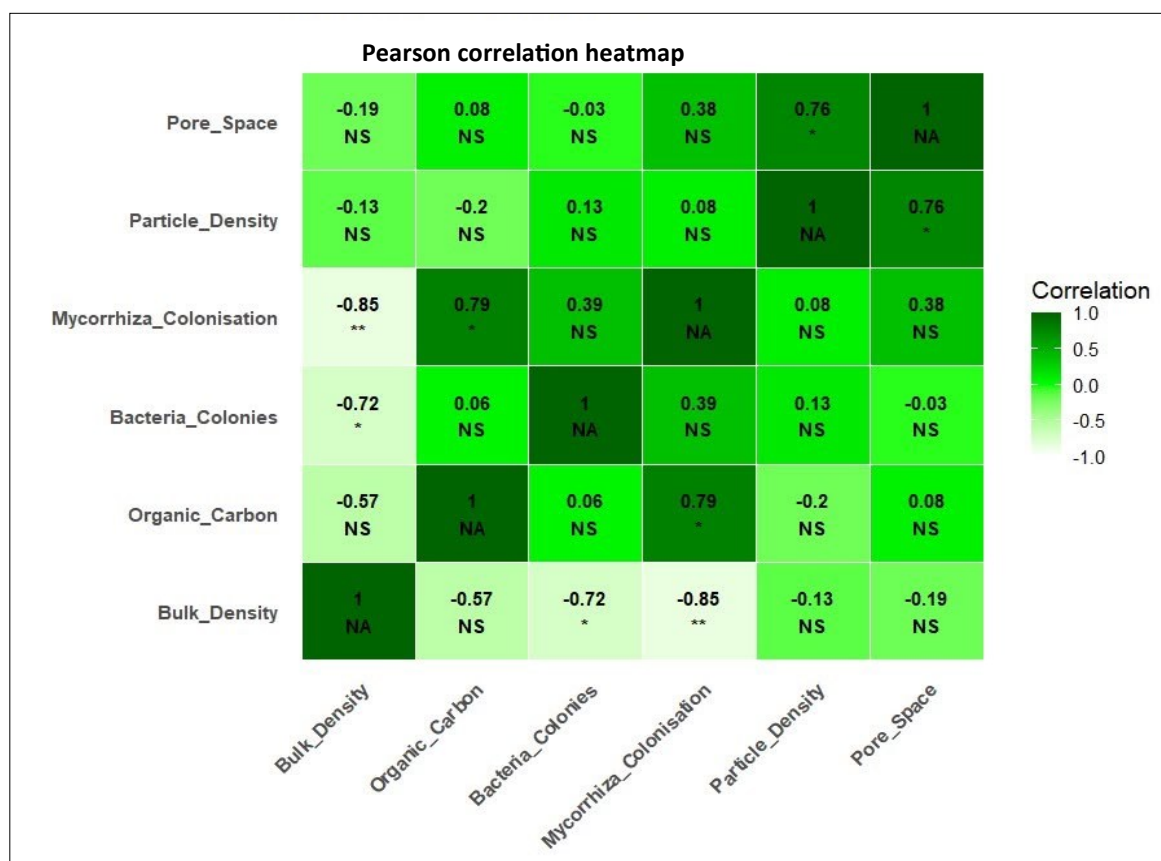


Fig. 6. Pearson correlation between bulk density and poracity.

Combined effect of cocopeat, paddy husk and vermicompost

The combination of three organic amendments resulted in higher values for all recorded parameters after T5 and it was significantly superior to all other treatments in terms of plant height, root length, number of fruits and weight of the fruit. The N availability was high due to the addition of paddy husk compost (19). The synergistic effect of improved physical properties, enhanced nutrient availability and increased biological activity created an optimal rhizosphere environment under pot culture conditions. This suggests that the roots of chilli plants colonised by mycorrhizal fungi formed an extensive network that contributed to soil loosening.

Mycorrhiza bio-fertiliser

Many researchers emphasised the significant potential of integrating AMF and other organic amendments into sustainable crop management systems. Their synergistic effects not only improve nutrient cycling and soil health but also enhance the productivity and nutritional quality of crops, such as chilli. This study demonstrated that the most effective treatment involved the integration of paddy husk and vermicompost with mycorrhizal inoculation. This combination significantly improved chilli growth and yield under pot culture, confirming that the combined use of nutrient-rich vermicompost with structural amendments is essential for improving crop performance in confined growing media.

Mycorrhiza and chilli crop in bulky clay soil

In addition, the results suggest that physical improvement alone does not provide sufficient nutrient supply in pot culture. The mycorrhizal network facilitates the uptake of essential nutrients, P, N, K and zinc (Zn) and supports plant growth in nutrient-poor soils (23), such as compacted clay soil. Arbuscular mycorrhizal fungi form symbiotic associations with the roots of more than 80 % terrestrial plants (24). Thus, these symbiotic associations improve drought tolerance, soil aggregation and carbon stabilisation (25–28). The AMF application increased chilli growth and yield by mobilising nutrients in compacted clay soil. It also enhanced root development and P availability, potentially through enzymatic solubilisation of soil P. Mycorrhiza improved the growth of aerobic rice in sandy soil (29, 30) and chilli and peanut (31).

Plant-microbe interactions in the rhizosphere

The growth and yield of crops belonging to the Solanaceae family, viz., tomato, brinjal and chilli, were enhanced by mycorrhiza under low P levels in the soil or soil solution. Above the threshold level of 50 kg ha⁻¹ P₂O₅, VAM is less active or inactive in these Solanaceae crops (32). Besides promoting growth, VAM may also provide protection against root rot caused by *Rhizoctonia solani* in Solanaceae crops (33). This study recorded 1.008 kg ha⁻¹ of P in the compacted clay soil of the study area (Fig. 2B).

Biopore

Plant roots colonised by AM fungal hyphae can contribute to the entanglement and enmeshment of soil particles, promoting the formation of macroaggregates, which are fundamental components of soil structure. Biopore formation was higher in the paddy husk-vermicompost combination, in which the root system of the test plant was more extensive, with numerous rootlets, compared with the other treatments. This is consistent with the previous results (34). Biopore formation was positively correlated with plant biological properties, viz., the mycorrhizal network (35).

Research outcome

Chemical pesticides and fertilisers were not used in this study. This research found that the application of paddy husk and vermicompost with mycorrhiza can effectively reduce abiotic stress in bulky clay soil. As an additional note, the author suggests that the crop stubble should be retained to stabilise the biopore and organic matter stability in the problematic, bulky clay soils.

Conclusion

The integrated application of vermicompost, paddy husk, cocopeat and arbuscular mycorrhizal fungi (AMF) significantly reduced soil bulk density while improving soil porosity, moisture retention, root colonisation and plant growth. The findings demonstrate that integrating organic amendments with AMF is an effective and sustainable strategy for alleviating soil compaction, enhancing soil health and improving crop performance in compacted soils.

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Authors' contributions

KB was involved in conducting the research and made significant intellectual contributions to the study. RAS assisted in data acquisition, analysis and interpretation of the results. KS was involved in correcting the draft manuscript and critically revising it for important intellectual content. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflicts of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Grammarly to check grammatical errors. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication

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