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CHANGES IN SOME SOIL CHEMICAL PROPERTIES, GROWTH, AND YIELD OF CUCUMBER (CUCUMIS SATIVUS L) ARE CAUSED BY TRICHODERMA REESIE AND TRICHODERMA LONGIBRACHATUM IN DIFFERENT LAND-USE SYSTEMS

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Abstract: The study evaluated the growth-promotion effects of indigenous Trichoderma species—Trichoderma reesii and Trichoderma longibrachatum—on cucumber (Cucumis sativus L) yield parameters and soil chemical properties across different land uses: cultivated land (CL), forest land (FL), and developed area (DA). Soil samples were collected at depths of 0-30 cm and replicated three times. The Trichoderma strains produced key enzymes such as peroxidase and laccase. Results showed a significant increase ($p < 0.05$) in yield parameters like leaf area and overall yield, along with improvements in soil properties such as pH, total nitrogen, organic carbon, and essential minerals. The combined application of both Trichoderma species significantly enhanced cucumber yields, and improved soil chemical properties compared to the control. These findings suggest the potential for developing effective bio-stimulants, emphasizing the influence of both fungal characteristics and soil quality.
Keywords: Yield parameters; Trichoderma; Physiological characteristics; Soil properties

1 INTRODUCTION

The widespread use of synthetic pesticides and fertilizers in crop production has had negative effects on the environment, human health, and ecosystems [1]. Additionally, intensive farming practices, the extensive use of pesticides and fertilizers (especially those containing nitrogen), the prevalence of monocultures, and aggressive tilling all have harmful effects on soil microbiota and crop productivity [2].

Research has shown that Trichoderma spp. can effectively suppress soil-borne pathogens such as Fusarium and Pythium, which are detrimental to cucumber plants. [3] demonstrated that Trichoderma could inhibit the growth of Fusarium species, thereby fostering a more favorable growth environment for cucumbers through reduced disease pressure [3]. Additionally, [3] found that specific species, such as *T. ghanense* and *T. citrinoviride*, exhibit significant antagonistic effects against Pythium aphanidermatum, highlighting their role in biocontrol strategies for cucumber cultivation [4].

Trichoderma spp. had also been extensively researched and are currently sold as bio-pesticides and bio-fertilizers. They can protect plants, stimulate growth, and manage plant-damaging agents across various agricultural settings [5]. The success of products containing these fungal antagonists can be attributed to the large quantity of viable propagules that can be rapidly produced in numerous fermentation systems. These fungi have also been widely used as model microorganisms in studies aimed at analyzing and enhancing our understanding of their roles in important biological interactions, such as those with crop plants and plant-damaging agents [5].

In a study by [5], it was found that several Trichoderma species—namely Trichoderma asperellum, Trichoderma atroviride, Trichoderma harzianum, Trichoderma virens, and Trichoderma viride—are the most extensively researched regarding their mechanisms of action. These species also exhibit strong bio-stimulant effects on horticultural crops. The extracellular oxidoreductases produced by Trichoderma contribute to the breakdown of phenolic compounds from both natural and synthetic sources, making them suitable for soil bioremediation [6].

Additionally, Trichoderma fungi support the growth of plant roots and shoots by dissolving phosphates and micronutrients in the soil [7]. They have also been shown to enhance plant resilience to environmental stresses such as drought and high salinity [8]. These characteristics position Trichoderma spp. as promising candidates for developing bio-stimulant products aimed at sustainable agricultural management [9].

Soil is a complex and dynamic system; thus, fungi with specific physiological and biological characteristics play a crucial role in producing effective bio-products. The application of Trichoderma not only controls pathogens but also improves soil health. [10] reported that Trichoderma can enhance the soil microenvironment, leading to the proliferation of beneficial microorganisms that aid in nutrient availability, ultimately contributing to higher productivity and disease resistance in cucumbers. This finding is supported by [11], which indicated that co-culturing various Trichoderma strains results in better antagonistic activities and improved cucumber seedling growth compared to monocultures.

Various methods for applying Trichoderma-based products to seeds, seedlings, plants, or soil have been developed, with most products being used as biopesticides. However, there has been little focus on utilizing Trichoderma as a biofertilizer or plant growth enhancer [10].

The effectiveness of Trichoderma-based products can vary depending on soil quality. Inefficient use of fungal inoculants may result from soil properties that are unfavorable for the growth of Trichoderma [12]. [13] found that arable, grove, and forest soils have different impacts on the efficiency of two strains of Trichoderma harzianum in promoting the growth of Brassica rapa. However, there have not been enough studies investigating the effects of Trichoderma spp. on plant growth promotion across various land-use systems, particularly in agricultural settings. Further research on fungi in soils of different qualities is needed. This study aims to assess the growth promotion abilities of Indigenous Trichoderma reesei and Trichoderma longibrachiatum, as well as their combined applications, on soil properties, growth, and yield of cucumbers in various land-use systems.

2 MATERIALS AND METHODS

2.1 Study Site

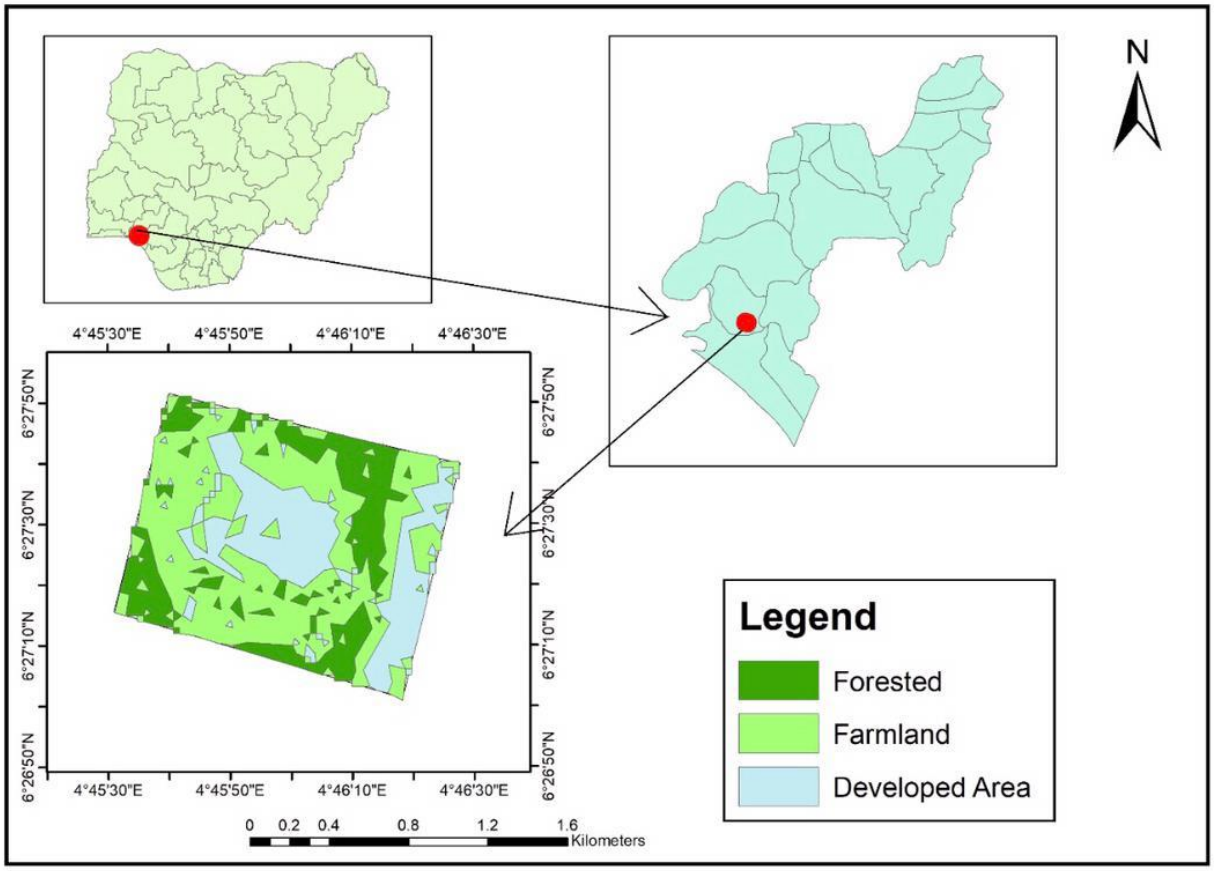

Figure 1 The Study Site [14]

2.1 Fungi

The research used *Trichoderma reesie* and *T. longibrachatum* strains isolated from garden soil at Olusegun Agagu University of Science and Technology, Okitipupa, Nigeria during the rainy seasons of 2023 and 2024. To isolate Trichoderma, the soil serial dilution plate method was employed [15]. In summary, 10 g of soil sample was mixed with 90 mL of sterilized water and shaken on an orbital shaker at 200 rpm for 1 hour. Following shaking, a series of 10-fold dilutions of the suspension were made, and suitable dilutions were plated on malt extract agar with chloramphenicol (250 mg L−1). The plates were then incubated at 28°C for 5 days. Individual colonies of fungi were isolated, purified, and stored on potato dextrose agar (PDA; Oxoid, Basingstoke, Hampshire, UK) slants at 4°C.

2.2 Identification of Fungi

The fungi were identified based on their morphology, observed through microscopy of Trichoderma species. This was done using a Leica DM5000 microscope with a mounted Leica DFC450 camera. The morphology of Trichoderma spp. was examined from cultures grown on MEA at 28°C for 5 days.

2.3 Experimental Sampling and Soil Samples Collection

Experimental treatments were conducted on three different types of land (cultivated land CL, forest land FL, and developed area DA), as well as a control group. Each land type and the control group had three transects, each measuring 100m. These transects were further divided into three sub-plots measuring 20m x 20m. Soil samples were collected at a depth of 0-30 from each of these sub-plots. In total, nine plots were set up for each land type (refer to Figure 2).

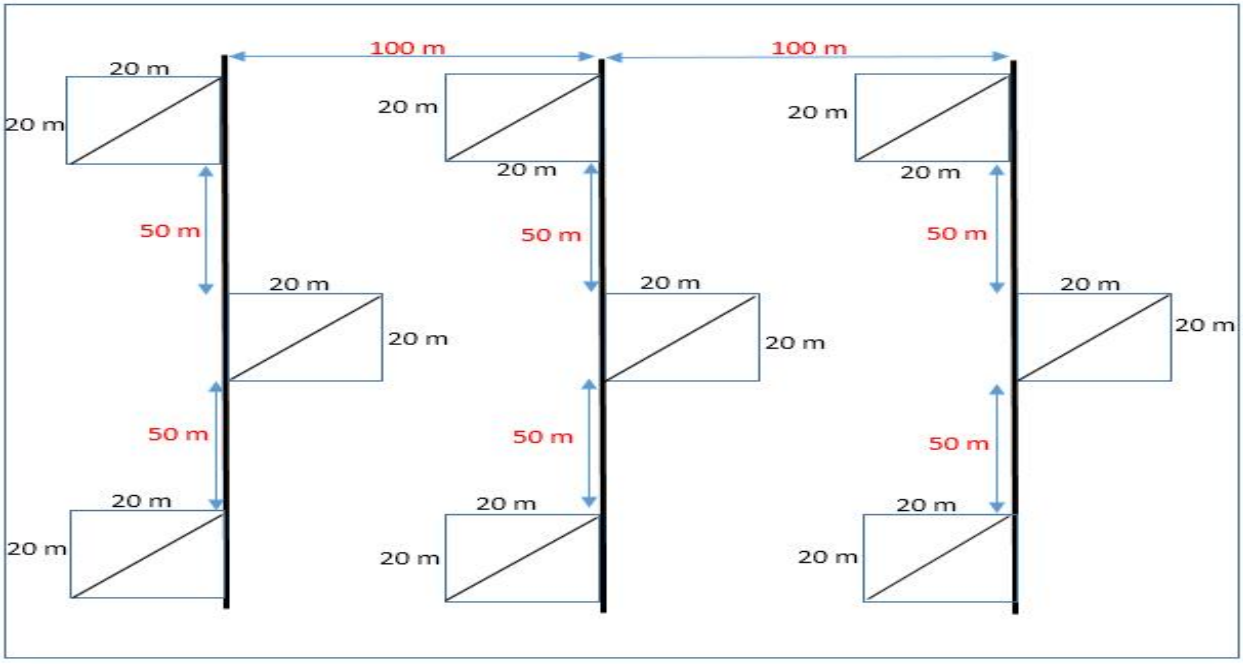

Figure 2 Plot Layout and Sampling Technique Adopted for Each Land Use System

2.4 Soil Sampling and Analysis

Soil samples were gathered from the top layer (0–30 cm) of soil in three different land-use systems: cultivated land (CL), forested land (FT), and developed area (DA). These land uses have been maintained over many years in the study area. The samples were collected using a Dutch soil auger after cultivation. Before the experiment, the original soil samples were examined for their chemical properties. The chemical analysis of the soil was carried out at the Chemical Research Laboratory of Olusegun Agagu University of Science and Technology in Okitipupa, Nigeria (see Table 1 for results).

2.5 Soil microbial Counting

The experiment aimed to determine the number of fungi in the original soil and soil after inoculation using the soil serial plate method [Germida and de Freitas, 2007]. Diluted samples were directly plated onto malt extract agar with chloramphenicol (250 mg L−1). The plates were then incubated at 26°C for 2 to 5 days, and the total colony-forming units (CFUs) of each repetition were counted. All experiments were repeated in triplicate.

2.6 Field Experimental Design

The experiment involved filling plant buckets with 4 kg of unsterilized soil from cultivated land, forest land, and developed areas. The fungi were cultivated on PDA at 26°C for 7 days to prepare the inoculum. Suspensions of Trichoderma spp. were prepared in 0.9% saline from mature cultures, and the concentration of the suspensions was determined by measuring the optical density at 530 nm using an Evolution 60S and then checked by plating on PDA. The final inoculum concentrations were 1 × 10^9 conidia ml−1. Five milliliters of the inoculum were added to each bucket and mixed well with the soil at the

first inoculation. Afterward, the inoculum was added to the soil surface at intervals of 10 days for 50 days until the cucumbers were harvested. Three experiment variants were designed using soil inoculated with *Trichoderma reesie*, *Trichoderma longibrachatum*, and a complex of *Trichoderma reesie* + *Trichoderma longibrachatum*. Non-inoculated soil served as a control. Each treatment was replicated in triplicate. The buckets were planted with Darina f1 var. of cucumber seeds. After germination, the seedlings were thinned to two seedlings per bucket and left for 45 days, during which leaf area, leaf area index, and yield were measured and recorded. After the experiment, soil samples from different treatments were carefully taken and analyzed in the laboratory.

2.7 Statistical Analysis

The measurements for root length, shoot length, and dry weight were analyzed using main effects ANOVA with treatment (control, I, II, and III). The different types of soil (control, cultivated land, forested land, and developed area) were used as categorical predictors. Afterward, significant factors were used for ANOVA analysis and Tukey's HSD for post-comparisons. The confidence level was set to $p < 0.05$. Statistical t-values were calculated using Microsoft Excel to determine the significance of the variables.

3 RESULTS

3.1 Identification of Trichoderma and Their Physiological Characteristics

Morphological features were used to classify the species of Trichoderma. The isolates had fast-growing hyaline, later becoming green due to conidium production, colonies, and repeatedly branched conidiophores bearing flask-shaped phialides. According to these morphologic characteristics, the isolates were assigned to the Trichoderma genus (Figure 3).

A B

Figure 3 Micromorphology of Trichoderma strains on PDA after 7 days: A - *Trichoderma longibrachatum,* B – *Trichoderma release*

3.2 The Chemical Properties of the Study Sites

The experiment selected soil from different land-use systems (farmland, developed area, and forested land) as shown in Table 1. The soil chemical analysis revealed that the forested land was more productive than both farmland and developed areas. It was nearly three times richer in organic matter, organic carbon, and nitrogen compared to the farmland and developed area. The pH of the forested land soil was 5.61, while the developed area had a pH of 5.42 and the farmland had a pH of 5.43, with no significant difference. The studied forested land was significantly richer in P2O5 and C/N ratio, while the developed area showed higher amounts of K, Ca, and Mg, which are influenced by human activity.

Table 1 Pre-Chemical Properties of Soil Samples from Different Land Use Areas

Pre-chemical properties of original soil samples				
Chemical Properties	Cultivated land	Developed area	Forest land	Method of Analysis
pH	5.43[ab]	5.42 [a]	5.61 [ab]	Determined by the potentiometric method in 1 M KCl (1:2.5, w/v) extract.
OC	1.03 [b]	0.51 [a]	2.57 [a]	Spectrophotometric measurement method at 590 nm using glucose as a standard after wet combustion [15].
OM	1.77 [a]	0.80 [a]	4.43 [a]	Calculated using conversion factor (1.724) from SOC.
N	0.11 [a]	0.09 [a]	0.21 [a]	Kjeldahl method uses a spectrophotometric measurement at 655 nm.
C/N	9.36	5.67	12.23	Calculation as the ratio of SOC to Nt.
P	3.74[a]	2,74 [a]	4.14 [a]	Mehlich-3, [16]
K	0.14 [ab]	0.28 [b]	0.18 [a]	Mehlich-3, Optical Emission spectrometry (ICP-OES), [17]
Ca	1.24 [a]	2.05 [b]	1.18 [a]	Mehlich-3, Optical Emission spectrometry (ICP-OES), [18]
Mg	0.50 [b]	1.23 [c]	0.58 [b]	Mehlich-3, [16]

*Mean with the same superscript along the rows is not significantly different at p>0.05

3.3 Physiological Characteristics of Trichoderma Species Used

In Table 2, the Trichoderma strains exhibited different physiological characteristics. Both Trichoderma strains grew in PDA in terms of length (cm) and weight (g). At 48 and 72 hours, Trichoderma longibrachiatum appeared to weigh significantly more than Trichoderma reesie. Conversely, *Trichoderma reesie* recorded a higher weight at a higher temperature than *Trichoderma longibrachiatum* (see Table 2).

The results of the study indicate that *Trichoderma longibrachiatum* exhibited significantly higher growth in terms of diameter elongation at 24 and 48 hours compared to *Trichoderma reesie*. However, at 72 hours, *Trichoderma reesie* showed significantly more growth. Additionally, regardless of the temperature (10, 15, 25, and 35 °C), *Trichoderma reesie* demonstrated significantly greater diameter rates than *Trichoderma longibrachiatum*.

Furthermore, the study revealed that the two strains differed in their ability to decompose organic matter. *Trichoderma longibrachiatum* was found to be significantly more effective in decomposing organic residues containing cellulose.

Table 2 Physiological Characteristics of Trichoderma reesie and Trichoderma Longibrachiatum

Physiological Characteristics	*Trichoderma reesie*	*Trichoderma longibrachiatum*
Growth (Weight) on PDA (g) in Hours 24	0.51	0.42
48	32.0 *	37.0 *
72	31.9*	37.5*
Growth (Weight) on PDA at 10^0C	3.0	4.0
15^0C	27.0 *	39.0*
25^0C	46.6*	35.6*
35^0C	56.2*	46.6*
Growth (diameter, cm) on PDA Hrs 24	1.0	1.9
48	3.40*	5.6 *
72	7.5*	6.1*

Growth (diameter, cm) on PDA 10^0C	1.3	1.0
15^0C	4.0*	3.5*
25^0C	6.6*	4.2*
35^0C	5.2*	3.2*
Decomposition of cellulose, %	23.7*	32.6*
Decomposition of lignin, %	12.0 *	14.2*

*Mean with the same superscript along the rows is not significantly different at p>0.05

3.3 Chemical Properties of the Soils after Inoculation

Inoculation with Trichoderma spp. had a significant stimulating effect on soil chemical activity. The most significant effect on this activity was observed in the soil of forested land when *Trichoderma longibrachatum* and a combination of *Trichoderma ressie* with *Trichoderma longibrachatum* were applied (refer to Tables 3, 4, and 5).
In cultivated land, Trichoderma spp had a significant impact on soil chemical properties. The treatment with the combination of *T. ressie* + *T. longibrachatum* resulted in a significantly higher pH (6.13) compared to other treatments. Additionally, organic carbon and organic matter had significantly higher values compared to other treatments, except for *T. longibrachatum,* which showed no significant difference. A similar trend related to soil pH was observed for P2O5 and total Nitrogen. All inoculated treatments had higher values than the control. For K, Ca, and Mg, we observed numerically higher values from the combination of *T. ressie* + *T. longibrachatum* treated pots, but the differences were not statistically significant. Nonetheless, they all showed significantly higher values over control.
In the forested land (FL), we observed higher values for almost all measured parameters, following a similar trend as observed in the cultivated land (CL).

Table 3 The chemical properties of Cultivated land (CL) after 55 days of inoculation

	Variants			
Chemical Properties of Soil	*Trichoderma ressie*	*Trichoderma longibrachatum*	*Trichoderma ressie* + *Trichoderma longibrachatum*	Control
Cultivated land				
pH	5.53^{c}	6.03^{b}	6.13^{a}	5.03^{d}
OC	1.65^{b}	2.04^{a}	2.01^{a}	0.9^{c}
OM	2.84^{b}	3.52^{a}	3.47^{a}	2.53^{c}
N	0.16^{b}	0.19^{b}	2.0^{a}	0.11^{c}
C/N	10.31	10.73	1.00	8.18
P	3.74^{c}	4.74^{b}	5.74^{a}	2.75^{d}
K	0.13^{ab}	0.14^{ab}	0.16^{ab}	0.10^{ab}
Ca	1.48^{a}	1.38^{a}	1.59^{a}	1.20^{a}
Mg	0.80^{ab}	0.70^{b}	0.90^{a}	0.50^{c}

*Mean with the same superscript along the columns are not significantly different at p>0.05

Table 4 The Chemical Properties of Forested Land (FL) after 50 days of Inoculation

	Variants			
Chemical Properties of Soil	*Trichoderma ressie*	*Trichoderma longibrachatum*	*Trichoderma ressie* + *Trichoderma. longibrachatum*	Control
Forested land				
pH	5.91^{ab}	6.11^{b}	6.21 ^{a}	5.01^{c}
OC	2.97^{b}	2.77^{ab}	3.37^{a}	1.77^{c}
OM	5.12^{b}	4.78^{ab}	5.81^{a}	3.05^{c}
N	0.28^{b}	0.32^{b}	0.38^{b}	0.21^{b}
C/N	10.60	8.66	8.86	8.43
P	5.34^{ab}	5.44^{b}	5.94^{a}	5.19^{c}
K	0.28^{ab}	0.34 ^{a}	0.38^{a}	0.19^{c}
Ca	1.28^{a}	1.38^{a}	1.48^{a}	1.14^{b}
Mg	0.59^{ab}	0.65^{b}	0.75^{a}	0.59^{c}

*Mean with the same superscript along the columns is not significantly different at p>0.05

The results from the developed area (DA) showed that the soil pH was highest in the pot with the combination of *Trichoderma ressie* + *Trichoderma longibrachatum*. However, this was not statistically different from the other readings, but it was statistically higher than the control pot. The values for organic carbon, organic matter, and total nitrogen were lower than those obtained from other land uses (CL and FL). Although the pot treated with the combination of *Trichoderma ressie* + *Trichoderma longibrachatum* recorded numerically higher values, these were not statistically different from the other readings, except for the control, which remained statistically lower.

The levels of P2O5, total nitrogen, K, Ca, and Mg were higher in the pot treated with *Trichoderma ressie* + *Trichoderma longibrachatum* compared to previous land uses, but the differences were not significant. On the other hand, the control showed significantly lower values

Table 5 The Chemical Properties of Developed Area (DA) after 55 Days of Inoculation

	Variants			
Chemical Properties of Soil	*Trichoderma ressie*	*Trichoderma longibrachatum*	*Trichoderma ressie* + *Trichoderma longibrachatum*	Control
Developed Area				

pH	5.45 [ab]	5.52[b]	5.82[a]	5.12[c]
OC	0.71[ab]	0.81[b]	1.21[a]	0.61 [c]
OM	1.22[ab]	1.40[b]	2.10[a]	1.05[c]
N	0.15[ab]	0.17[b]	0.24[a]	0.11[c]
C/N	4.73	4.76	5.04	5.54
P	6,74[ab]	6,94[a]	7,24[a]	5,24[c]
K	1.23[ab]	1.73[b]	2.63[a]	0.23 [c]
Ca	2.75 [ab]	2.85 [b]	3.35 [a]	2.05[b]
Mg	1.83[ab]	2.03[b]	2.73 [a]	1.23[c]

*Mean with the same superscript along the columns is not significantly different at p>0.05

3.4 Impact of Trichoderma spp on some yield parameters of Cucumber

The combination of *Trichoderma ressie* and *Trichoderma longibrachatum* in forest land resulted in a significantly higher yield of 2.19 tons/ha compared to all other treated pots. In addition, all inoculated pots yielded significantly more than the control. The leaf area and leaf area index were also significantly higher in the pots inoculated with the *Trichoderma ressie* + *Trichoderma longibrachatum* combination compared to the control as well as other treatments. Similar trends were observed in farmland and developed areas, albeit with lower values.

Table 6 Showing the leaf Area, Leaf index, and Yield after inoculation for 50 days in Forestland

Treatment	Leaf area (cm^2)	Leaf Area Index	Yield. (ton/ha)
Trichoderma ressie + Trichoderma longibrachatum	145.01[a]	5.37[a.]	2.19[a]
Trichoderma longibrachatum	110.62[b]	4.11[b]	0.83[b]
Trichoderma ressie	77.01[c]	2.56[c.]	0.75[c]
Control	42.96[d]	1.62[d.]	0.54[d]

*Mean with the same superscript along the columns is not significantly different at p>0.05

Table 7 Showing the leaf Area, Leaf index, and Yield after inoculation for 50 days in Cultivated Land

Treatment	Leaf area (cm^2)	Leaf Area Index	Yield. (ton/ha)
T. ressie + T. longibrachatum	125.01[a]	5.17[a.]	1.91[a]
T. longibrachatum	100.02[b]	3.81[b]	0.723[b]
T. ressie	72.01[c]	2.16[c.]	0.65[c]
Control	40.36[d]	1.22[d.]	0.50[d]

*Mean with the same superscript along the columns is not significantly different at p>0.05

Table 8 Showing the leaf Area, Leaf index, and Yield after inoculation for 50 days in a Developed Area

Treatment	Leaf area (cm^2)	Leaf Area Index	Yield. (ton/ha)
T. ressie + *T. longibrachatum*	121.01^{a}	$4.35^{a.}$	1.4^{a}
T. longibrachatum	96.62^{b}	3.01^{b}	0.613^{b}
T. ressie	74.01^{c}	$2.06^{c.}$	0.55^{c}
Control	32.96^{d}	$1.12^{d.}$	0.44^{d}

*Mean with the same superscript along the columns is not significantly different at p>0.05

4 DISCUSSION

The study on inoculating soil and plants with different Trichoderma spp showed that the physiological characteristics of fungi and the quality of the soil both play important roles in promoting plant growth [19]. The successful and efficient use of bioproducts for plant growth promotion depends on the active development of fungi in the substrates. Both abiotic and biotic factors could either promote or suppress the action of fungi in the soil. Therefore, the physiological characteristics of fungi and their ability to survive and adapt to various environmental conditions are of great interest. [17] observed the importance of pH values and found a negative correlation between Trichoderma koningii abundance and soil pH.

Furthermore, [13] highlighted the significance of soil quality in the impact of various Trichoderma strains on the growth of Brassica rapa. The study revealed that fungi thrived under different optimal conditions. It was noted that *Trichoderma reesei* exhibited superior development at lower temperatures compared to *Trichoderma longibrachatum,* while the latter showed optimal growth across a wider pH range. Additionally, *Trichoderma longibrachatum* demonstrated better abilities in decomposing cellulose and lignin. It is anticipated that *Trichoderma longibrachatum* would be more adaptable in various soil types and more efficient in organic matter mineralization.

The recent experiment compared soils with different chemical properties. The chemical analysis showed that the arable soil in developed areas (DA) had less organic carbon compared to cultivated land (CL) and forest land (FL). This could be because forest soil is less disturbed and retains more organic carbon. Similarly, the lower organic carbon levels in farmland may be due to farming activity, which potentially contributes to the increase in soil organic carbon. Additionally, total nitrogen and P_2O_5 levels were higher in farmland and forest land compared to developed areas, likely due to farming activities in the farmland and more stable conditions in the forest land. The increased values of K, Ca, and Mg in developed areas as opposed to other land uses might be due to human activities such as the deposition of house waste and the absence of farming activities in such areas which might have led to the long accumulation of these mineral elements in such areas.

The most significant increase in this activity was detected in forest soil, followed by farmland, and the least in developed areas compared with the control when *Trichoderma longibrachatum* and the combination of *Trichoderma ressie* + *Trichoderma longibrachatum* were applied. The plausible explanation for this might be a lower number of microorganisms and weaker competition with native microorganisms. Forestland and farmland soil microbiomes are richer in a few species of microorganisms. Studies have shown that Trichoderma produces active cellulolytic enzymes, leading to the mineralization of organic matter and enhancing nutrient uptake as well as root hair development. The promoting effect of fungi such as Trichoderma on plant growth is well known and described by different researchers [19-22]. An increase in minerals such as organic carbon, total nitrogen, P_2O_5, and soil pH was observed in the pots that were inoculated compared to the control group. Applying Trichoderma inoculum early in the crop growth stage maximizes the benefits in terms of root development and nutrient uptake [5]. These findings are particularly important when using Trichoderma as a soil plant growth promoter. In this experiment, we evaluated the impact of soil on the growth-promoting abilities of different Trichoderma strains and their complexes using measurements of leaf area, leaf area index, and yield. The study's results indicated that the influence of Trichoderma inoculation varied across farmland, forested land, and developed areas, and was dependent on the species of fungi used. Significant positive effects on the leaf area, leaf area index, and total yield of Cucumber were observed in all land uses with the highest values recorded in the combination of T. ressie + T. longibrachatum. The measurements of leaf area and leaf area index demonstrated the growth-promoting effects of indigenous Trichoderma strains. Statistically significant differences were observed in the leaf area, leaf area index, and yield across forest land, farmland, and developed areas with the inoculation of Trichoderma spp ($p = 0.005$) compared to the control. The interaction between plants and Trichoderma spp is believed to have effectively improved root architecture and increased the length of lateral and primary roots, resulting in enhanced nutrient uptake, larger leaf area, and yield [21]. Similarly, [23] found a positive correlation between total leaf area, leaf area index, chlorophyll content, and maize grain yield. The fungus Trichoderma spp. Releases auxins, small peptides, volatiles, and other active metabolites into the

rhizosphere. These compounds promote root branching and nutrient uptake, leading to increased plant growth and yield [5]. In sterile soil, the growth-promoting effect of Trichoderma spp. was even more significant. For instance, *T. longibrachiatum* increased tomato root volume by 96% [24], which aligns with some aspects of our study findings. Since the effectiveness of Trichoderma spp. Inoculum in promoting growth may vary depending on the soil type, selecting the right fungal strain is crucial. The complexity of Trichoderma's growth-promoting effects necessitates comprehensive research.

5 CONCLUSIONS

In our study, we tested different indigenous Trichoderma species with various physiological characteristics as bio-stimulants to see their impact on soil chemical properties and yield parameters of Cucumber plants. We found that not only do the physiological characteristics of fungi play a significant role, but also the quality of the soil has an impact on promoting plant growth. The inoculation of *T. longibrachiatum, T. reesie*, and their combination enhanced Cucumber leaf area, leaf area index, and yield. Additionally, Rye seedling root growth was also improved by these species when applied to different land use types ($p = 0.005$). Moreover, the application of these species to the land use types enhanced some soil chemical properties. These results can potentially be useful for developing new and efficient bio-stimulants and practical strategies for sustainable soil fertility management.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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