

Changes in some soil chemical properties, growth, and yield of cucumber (*Cucumis sativus* L) are caused by *Trichoderma reesei* and *Trichoderma longibrachiatum* in different land-use systems

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Abstract

The study investigated the growth-promotion effects of indigenous *Trichoderma* species, specifically *Trichoderma reesei* and *Trichoderma longibrachiatum*, on cucumber (*Cucumis sativus* L) yield parameters and soil chemical properties across different land uses. The aim was to assess the growth-promoting abilities of these *Trichoderma* species, both individually and in combination, in various land use systems. The land uses considered in the study included cultivated land (CL), forest land (FL), and developed area (DA). Soil samples were collected at a depth of 0-30 cm and the results demonstrated a significant increase ($p < 0.05$) in yield parameters, such as leaf area and overall yield, alongside improved soil properties, including pH, total nitrogen, organic carbon, and essential minerals. The combined application of both *Trichoderma* species notably enhanced cucumber yields, and improved soil chemical properties compared to the control group. These findings suggest the potential for developing effective bio-stimulants and highlight the important roles of fungal characteristics and soil quality.

Keywords: yield parameters; *Trichoderma*; physiological characteristics; soil properties

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 [21]. 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 [4]. Additionally, [5] 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 [6]. *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 [7]. 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 [8].

In a study by [9], 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 [10]. *Trichoderma* fungi support the growth of plant roots and shoots by dissolving phosphates and micronutrients in the soil [11]. They have also been shown to enhance plant resilience to environmental stresses such as drought and high salinity [12].

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These characteristics position *Trichoderma* spp. as promising candidates for developing bio-stimulant products aimed at sustainable agricultural management [13].

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. [14] 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 [15] 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 [16]. 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* [17-18] 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.

2.0 MATERIALS AND METHODS

2.1 Study Site

Olusegun Agagu University of Science and Technology (OAUSTECH) lies in Okitipupa local government area of Ondo State. OAUSTECH lies between longitude 4.759 °E to 4.772 °E and latitude 6.45°N to 6.464°N within the tropical rainforest zone of Nigeria. OAUSTECH covers an area of 178.79 Hectares (ha). It is located on Okitipupa's tertiary sandy sediments geological formation. The mean annual temperature is 27°C and precipitation has a mean of 1900 mm with total annual rainfall often over 2000 mm.

2.1.1. Climate

The study area is typical of southern Nigeria, where tropical humid conditions dominate. This region experiences two distinct seasons: the rainy season and the dry season. The rainy season generally lasts from March to November, with

peaks occurring in July and September. In contrast, the dry season runs from December to February, characterized by reduced rainfall and higher temperatures. Average annual rainfall from 1,500 mm to 2,000 mm, which supports the dense forest cover and extensive farming activities observed in the region. Temperatures remain warm throughout the year, with average daily temperatures between 25°C and 30°C. Humidity levels are high, especially during the rainy season, which contributes to the lush vegetation seen in the forested areas of the study site. The climate significantly influences land use patterns in the region. The abundant rainfall and warm temperatures foster a diverse range of vegetation, making the area ideal for both forestry and agriculture.

2.1.2. Vegetation and Land-use

The vegetation of the study site is diverse and reflects the region's tropical climate. The forested areas shown on the map are likely dominated by tropical rainforest species, which are known for their dense canopies and high biodiversity. These forests serve as critical ecosystems, providing habitat for wildlife, and maintaining soil fertility. The farmland areas represent a significant portion of the study site, indicating the importance of agriculture in the local economy. The farmland is likely used for growing crops such as cassava, maize, yams and vegetables, which are staples in the diets of local communities, some areas may be used for animal husbandry, including cattle, goats and poultry.

2.1.3. Land use Mapping, soil samples collection and Laboratory Analysis

Preliminary traverses of each land use in the research region were done using cadastral maps, satellite imagery, and topographic sheets when available. The field borders and survey numbers depicted on the cadastral sheets were identified on-site by tracing permanent features, including roads, cart tracks, canals, streams, and tanks. All detected modifications were included into the cadastral map. Three distinct land uses were identified by visual assessment: cultivated land (CL), forest land (FL), and developed area (DA). Each land type contained three transects, each measuring 100 meters in length. The transects were subdivided into three sub-plots, each measuring 20 meters by 20 meters. Soil samples were obtained from a depth of 0-30 cm in each sub-plot. A total of nine plots were developed for each kind of terrain. A Dutch soil auger was employed to get soil samples. The samples were aggregated by merging those obtained from the identical plot and depth. The samples were air-dried at ambient temperature and passed through a 2 mm screen to prepare them for analysis, eliminating any coarse particles and roots. The composite soil samples were subsequently sent to the laboratory for further examination.

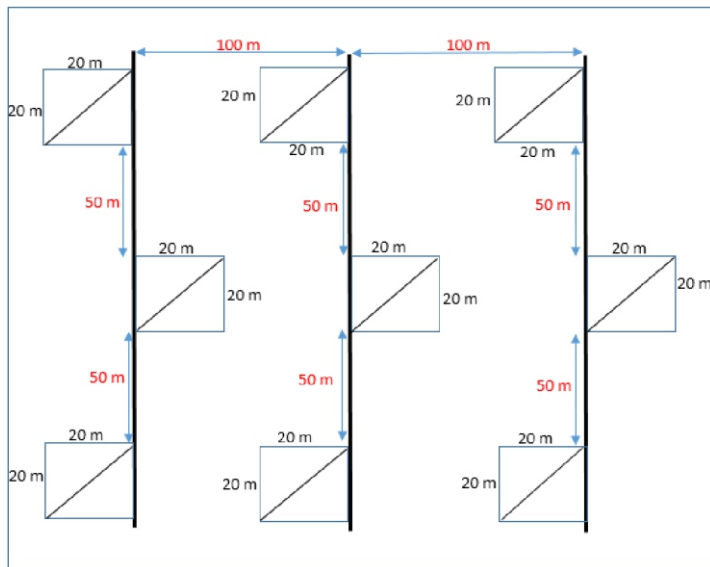


Fig. 1. Sampling methods for soil samples collection

2.1.4. Soil chemical properties determination

pH was evaluated using pH meter in a 1:2.5 soil: water (w/v) suspension (Anderson and Ingram, 1993). Soil Organic Carbon (SOC) was quantified using the Colorimetric technique (Schulte and Hoskins, 2009), whereas organic matter was computed using a conversion factor (1.724) from SOC. The Kjeldahl technique was used to estimate total Nitrogen [19-20], while the C/N ratio was computed as the ratio of SOC to N. K, Ca, Mg, and P were determined by plasma-atomic emission spectroscopy [21-22]. The available Phosphorus was extracted colorimetrically using the molybdenum blue technique. Cation exchange capacity was evaluated by the summation of NH_4OAc -extractable cations + 1.0N KCl extractable acidity.

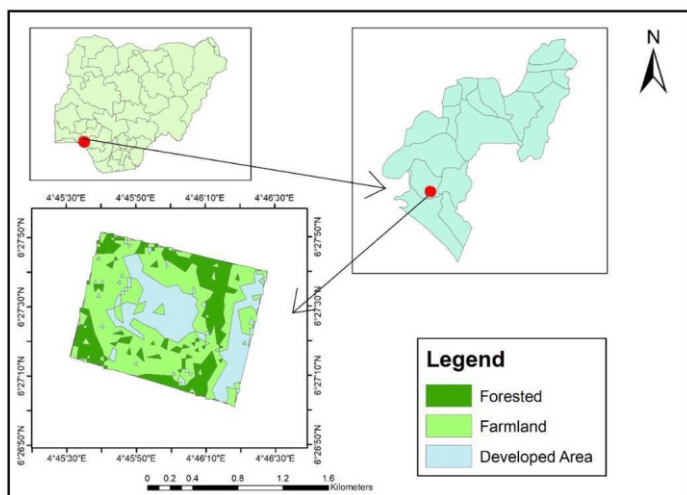


Fig. 2. Map of the study site

2.1.5. Screenhouse Experimental Design

The experiment entailed filling plant buckets with 4 kg of unsterilized soil from cultivated land, wooded land, and developed regions. The fungi were cultured on PDA at 26°C for 7 days to prepare the inoculum. Suspensions of *Trichoderma* spp. were made in 0.9% saline from mature cultures, and the concentration of the suspensions was estimated by measuring the optical density at 530 nm using an Evolution 60S and subsequently verified by plating on

PDA. The ultimate inoculum concentrations were 1×10^9 conidia ml^{-1} . Five milliliters of the inoculum were put to each bucket and mixed thoroughly with the soil at the initial inoculation. Afterward, the inoculum was applied to the soil surface at intervals of 10 days for 50 days until the cucumbers were harvested. Three experiment versions were established utilizing soil injected with *Trichoderma reesei* (I), *Trichoderma longibrachiatum* (II), and a combination of *Trichoderma reesei* + *Trichoderma longibrachiatum* (III). Non-inoculated soil served as a control (IV). Each treatment was reproduced in triplicate. The buckets were planted with Darina F1 var. of cucumber seeds. After germination, the seedlings were trimmed to two seedlings per bucket and allowed for 45 days, during which leaf area, leaf area index, and yield were measured and recorded. After the trial, soil samples from different treatments were carefully obtained and studied in the laboratory, and examined according to the methodology given in section 2.1.4.

2.1.6. Fungi

The research employed *Trichoderma reesei* and *T. longibrachiatum* strains recovered 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 technique was applied [23-24]. A 10 g soil sample was mixed with 90 mL of sterilized water and agitated on an orbital shaker at 200 rpm for 1 hour. Following the shaking, tenfold dilutions of the suspension were made, and suitable dilutions were plated on malt extract agar containing chloramphenicol (250 mg/L). The plates were then incubated at 28°C for 5 days. Individual fungal colonies were isolated, purified, and preserved on potato dextrose agar (PDA; Oxoid, Basingstoke, Hampshire, UK) slants at 4°C.

2.1.7. Identification of Fungi

The fungus was identified based on their morphology, detected by microscopy of *Trichoderma* species. This was done using a Leica DM 5000 microscope with a mounted Leica DFC450 camera. The morphology of *Trichoderma* spp. was investigated from cultures grown on MEA at 28°C for 5 days.

2.1.8. Enumeration of Fungi from Soil Samples

The experiment attempted to measure the quantity of fungus in the original soil and soil after inoculation using the soil serial plate method [25]. Diluted samples were immediately 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 repeat were counted. All tests were done in triplicate.

2.1.9. Statistical Analysis

The data for root length, shoot length, and dry weight were evaluated using main effects ANOVA with treatment (control, I, II, and III). The three types of soil (control, cultivated land, wooded land, and developed area) were employed as categorical predictors.

Afterward, significant variables were employed for ANOVA analysis and Tukey's HSD for post-comparisons. The confidence level was set to $p < 0.05$. Statistical t-values were generated using Microsoft Excel to determine the significance of the variables.

3.0 Results

3.1. The Physiological Features of *Trichoderma* and Their Identification

The species of *Trichoderma* were categorized using morphological characteristics. *T. reesei* has sparsely branch, irregular, short and flask-shaped phialides, with small, oval, loose cluster conidia, it also exhibits slow growth and light green of colony appearance while *T. longibrachiatum* highly branched, elongated conidiophores, long, tapering and whorled phialides, it has larger, elongated and densely cluster conidia with rapid growth and dark green colony appearance, based on these features, the isolates were classified within the *Trichoderma* genus. (Figure 2).



Fig. 2. Micromorphology of *Trichoderma* strains on PDA after 7 days: A - *Trichoderma longibrachiatum*, B - *Trichoderma reesei*

3.2. The Chemical Properties of the Study Area

As indicated in Table 1, the experiment chose soil from several land-use systems based on fig. 2 (farmland, developed area, and wooded land). 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 P_2O_5 and C/N ratio, while the developed area showed higher amounts of K, Ca, and Mg, which are influenced by human activity.

Table 1: Chemical properties of the Land use area prior to the experiment
Soil Chemical Properties of the study area

Chemical Properties	Cultivated land	Developed area	Forest land
pH	5.43 ^{ab}	5.42 ^a	5.61 ^{ab}
OC	1.03 ^b	0.51 ^a	2.57 ^a
OM	1.77 ^a	0.80 ^a	4.43 ^a
N	0.11 ^a	0.09 ^a	0.21 ^a
C/N	9.36 ^b	5.67 ^c	12.23 ^a
P	3.74 ^a	2.74 ^a	4.14 ^a
K	0.14 ^{ab}	0.28 ^b	0.18 ^a
Ca	1.24 ^a	2.05 ^b	1.18 ^a
Mg	0.50 ^b	1.23 ^c	0.58 ^b

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

3.3. Physiological Characteristics of *Trichoderma* species used

The *Trichoderma* strains in Table 2 displayed various physiological traits. Table 2 displays the weight (g) and length (cm) of both *Trichoderma* strains as measured in PDA. At 48 and 72 hours, *T. longibrachiatum* appeared to weigh significantly more than *Trichoderma reesei*. Conversely, *T. reesei* recorded a higher weight at a higher temperature than *T. longibrachiatum* (see Table 2).

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

Table 2: Physiological Characteristics of *Trichoderma reesei* and *Trichoderma longibrachiatum*

Physiological Characteristics	<i>Trichoderma reesei</i>	<i>Trichoderma longibrachiatum</i>
Growth (Weight) on PDA (g)		
24 Hrs	0.51	0.42
48	32.0 *	37.0 *
72	31.9*	37.5*
Growth (Weight) on PDA at difference temperature		
10°C	3.0	4.0
15°C	27.0 *	39.0*
25°C	46.6*	35.6*
35°C	56.2*	46.6*
Growth (diameter, cm) on PDA		
24 Hrs	1.0	1.9
48	3.40*	5.6 *
72	7.5*	6.1*
Growth (diameter, cm)		
10°C	1.3	1.0
15°C	4..0*	3.5*
25°C	6.6*	4.2*
35°C	5.2*	3.2*

*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. exhibited a substantial stimulating effect on soil chemical activity. The most substantial effect on this activity was detected in the soil of wooded area when *T. longibrachiatum* and a combination of *T. reesei* with *T. longibrachiatum* were treated (refer to Tables 3, 4, and 5).

In cultivated land (CL), *Trichoderma* spp had a significant impact on soil chemical properties. The treatment with the combination of *T. reesei* + *T. longibrachiatum* 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. longibrachiatum*, and *T. reesei* + *T. longibrachiatum* which showed no significant difference. A similar trend related to soil pH was observed for P_2O_5 and total Nitrogen. All inoculated treatments had higher values than the control. For K, Ca, and Mg, *Trichoderma* combination had the highest value, but the differences were not statistically significant among all treatments for K and Ca, while only for Mg the values of *Trichoderma* treatments were significant

compared to 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) except for N which showed significant difference in all the treated pots, for K, the values showed significant over the control but showed no significance among the treated pots. Ca values were significantly higher in all treated pots over that of control but showed no significance among the treated pots.

Table 3: The chemical properties of Cultivated land (CL) after 50 days of inoculation

	Variants			
Chemical Properties of Soil	<i>Trichoderma reessie</i>	<i>Trichoderma longibrachatum</i>	<i>Trichoderma reessie</i> + <i>Trichoderma longibrachatum</i>	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 ^a	10.73 ^a	10.00 ^{ab}	8.18 ^c
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	<i>Trichoderma reessie</i>	<i>Trichoderma longibrachatum</i>	<i>Trichoderma reessie</i> - <i>Trichoderma. Longibrachatum</i>	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 *T. reesei* + *T. longibrachiatum* and all treated pots were 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 *T. reesei* + *T. longibrachiatum* recorded numerically higher values, these were not statistically different from the other readings, except for the control, which remained statistically lower.

The levels of P_2O_5 , total nitrogen, K, Ca, and Mg were higher in the pot treated with *T. reesei* + *T. longibrachiatum* compared to other treated pots and control, 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 50 days of inoculation

	Variants			
Chemical Properties of Soil	<i>Trichoderma reessie</i>	<i>Trichoderma longibrachatum</i>	<i>Trichoderma reessie</i> + <i>Trichoderma longibrachatum</i>	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 reessie* 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 produced significantly higher yields than the control. The leaf area and leaf area index were also significantly higher in the pots inoculated with the *T. reessie* + *T. 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)
<i>Trichoderma reessie</i> + <i>Trichoderma longibrachatum</i>	145.01 ^a	5.37 ^a	2.19 ^a
<i>Trichoderma longibrachatum</i>	110.62 ^b	4.11 ^b	0.83 ^b
<i>Trichoderma reessie</i>	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)
<i>T. reessie</i> + <i>T. longibrachatum</i>	125.01 ^a	5.17 ^a	1.91 ^a
<i>T. longibrachatum</i>	100.02 ^b	3.81 ^b	0.723 ^b
<i>T. reessie</i>	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)
<i>T. reessie</i> + <i>T. longibrachatum</i>	121.01 ^a	4.35 ^a	1.4 ^a
<i>T. longibrachatum</i>	96.62 ^b	3.01 ^b	0.613 ^b
<i>T. reessie</i>	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* species indicated that the physiological properties of fungus and the quality of the soil both play major roles in encouraging plant growth [26]. The effective and efficient utilization of bioproducts for plant growth promotion depends on the active development of fungi in the substrates. Both abiotic and biotic variables might either encourage or hinder the activities of fungus in the soil. Therefore, the physiological properties of fungi and their capacity to survive and adapt to varied environmental situations are of significant interest. [27-28] recognized the relevance of pH values and identified a negative link between *Trichoderma koningii* abundance and soil pH. Furthermore, [29] underlined the relevance of soil quality in the influence of several *Trichoderma* strains on the

development of *Brassica rapa*. The study indicated that fungus grew under varied ideal circumstances. It was found that *T. reesei* demonstrated improved development at lower temperatures compared to *T. longibrachatum*, but the latter showed optimal growth throughout a larger pH range. Additionally, *T. longibrachatum* displayed improved ability in digesting cellulose and lignin. It is hoped that *T. longibrachatum* would be more adaptive in diverse soil types and more efficient in organic matter mineralization. The current investigation tested soils with varied chemical characteristics. The chemical study indicated that the arable soil in developed regions (DA) contained less organic carbon compared to cultivated land (CL) and forest land (FL). This might be because forest soil is less disturbed and holds more organic carbon. Similarly, the lower organic carbon levels in farms may be attributed to farming activities, which perhaps adds to the rise in soil organic carbon. The total nitrogen and P₂O₅ levels were greater in farmland and forest land compared to developed regions, possibly due to farming operations in the farmland and more stable circumstances in the forest land. The elevated levels of K, Ca, and Mg in developed regions as opposed to other land uses could be owing to human activities such as the deposition of house waste and the absence of farming operations in such places which would have contributed to the lengthy accumulation of these mineral elements in such locations.

The greatest substantial increase in this activity was identified in forest soil, followed by farmland, and the least in developed regions compared with the control when *T. longibrachatum* and the combination of *T. reesei* + *T. longibrachatum* were treated. The logical explanation for this would be a lesser number of microorganisms and weaker competition with local bacteria. Forestland and farming soil microbiomes are richer in a few kinds of microorganisms [14] studies have demonstrated that *Trichoderma* generates active cellulolytic enzymes, resulting to the mineralization of organic materials and improving nutrient intake as well as root hair formation. The stimulating impact of fungi such as *Trichoderma* on plant development is widely documented and reported by many studies[30]. An increase in minerals such as organic carbon, total nitrogen, P₂O₅, and soil pH was detected in the pots that were inoculated compared to the control group. Applying *Trichoderma inoculum* early in the crop growth stage enhances the advantages in terms of root development and nutrient absorption [19]. These findings are particularly crucial when utilizing *Trichoderma* as a soil plant growth stimulant. In this experiment, we examined the influence of soil on the growth-promoting capacities of several *Trichoderma* strains and their complexes using measures of leaf area, leaf area index, and yield. The study's results suggested that the impact of *Trichoderma* inoculation differed across agricultural, wooded land, and developed regions, and was depending on the variety of fungi utilized. Significant favorable impacts on the leaf area, leaf area index, and total yield of Cucumber were detected in all land uses with the greatest values reported in the combination of

T. reesei + *T. longibrachiatum*. The measures of leaf area and leaf area index indicated the growth-promoting effects of indigenous Trichoderma strains. Statistically significant variations were seen in the leaf area, leaf area index, and yield across forest land, agricultural, and developed regions with the inoculation of Trichoderma species ($p = 0.005$) compared to the control. The interaction between plants and Trichoderma species is considered to have successfully improved root architecture and extended the length of lateral and main roots, resulting in greater nutrient absorption, bigger leaf area, and yield [13]. Similarly [10] observed a favorable association between total leaf area, leaf area index, chlorophyll content, and maize grain production. The fungus Trichoderma spp. Releases auxins, tiny peptides, volatiles, and other active compounds into the rhizosphere. These chemicals boost root branching and nutrient absorption, resulting to higher plant growth and yield [19]. In barren soil, the growth-promoting impact of Trichoderma species was considerably more strong [28]. For instance, *T. longibrachiatum* enhanced tomato root volume by 96% [28], which agrees with several elements of our study findings. Since the efficiency of Trichoderma species. inoculum in encouraging growth may vary depending on the soil type, selecting the proper fungal strain is vital. The intricacy of Trichoderma's growth-promoting actions needs detailed investigation.

5. Conclusions

In this study, we evaluated several indigenous Trichoderma species with distinct physiological features as bio-stimulants to examine their influence on soil chemical qualities and yield metrics of Cucumber plants. We observed that not only do the physiological properties of fungi play a vital influence, but also the quality of the soil has an impact on stimulating plant development. The inoculation of *T. longibrachiatum*, *T. reesei*, and their combination boosted Cucumber leaf area, leaf area index, and yield, cucumber seedling root development was similarly boosted by these species when administered to diverse land use types ($p = 0.005$). Moreover, the application of these species to the land use categories boosted various soil chemical qualities. These results might possibly be beneficial for generating innovative and efficient bio-stimulants and practical ways for sustainable soil fertility management.

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