DOI: 10.12731/2658-6649-2025-17-3-1444 **EDN: MVZWQP**
UDC 631.46:579

Original article

A COMBINATION OF BENTONITE, BIOLOGICAL SUBSTRATE, AND MICROBIAL PRODUCTS TO ENHANCE CORAL SAND AND INFLUENCE THE GROWTH PERFORMANCE OF HEAT-RESISTANT MUSTARD GREENS, BRASSICA JUNCEA

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Abstract

Background. Coral sand along the coast of Vietnam presents several challenges for plant growth, including inadequate nutrition, poor moisture retention, and high salinity, which complicate the cultivation of vegetables and trees.

Purpose. This study aims to address the challenge of enhancing coral sand by optimizing its physical and chemical properties, moisture retention, nutrient availability, and suitability for cultivation.

Materials and methods. The quality of mixed substrates is assessed using standard methods in accordance with Vietnamese Standards.

Collected data were analyzed using SPSS 22 statistical software (IBM, USA) and MS Excel 365 software (Windows, USA). Comparison of differences between experiments based on one-factor ANOVA analysis at 95% confidence level.

Results. Results indicate that with the improved soil formulation incorporating adhesive additives, organic substrates, salt-tolerant polysaccharide membrane-forming microorganisms, and salt-tolerant beneficial microorganisms at varying concentrations, porosity has increased to 54.90%, nearly matching that of alluvial soil at 56.14%. Consequently, the remediation formulas proved to be effective in enhancing soil characteristics. A growth index monitoring test conducted on the heat-resistant vegetable Brassica juncea after 35 days of cultivation demonstrated that the selected soil improvement formula yielded growth and productivity comparable to the control sample of alluvial soil, with the number of leaves reaching 7-8, an average leaf area of approximately 20 dm^2 per plant, a harvested vegetable yield of 20 g per plant, and a SPAD index of 23.87.

Conclusion. The effect of adding microbial preparations and bentonite to coral sand increases EC and post-harvest vegetable volume but is not significantly different from formulas without preparations and bentonite.

Keywords: Coral sand soil; improved soil; bentonite; microbial preparation

For citation. Nguyen, C.T., Vu, D.N., Bui, N.T., Dinh, T.T.T., Le, T.H., & Vu, M.T. (2025). A combination of bentonite, biological substrate, and microbial products to enhance coral sand and influence the growth performance of heat-resistant mustard greens, *Brassica juncea*. *Siberian Journal of Life Sciences and Agriculture*, *17*(3), 300-318. https://doi.org/10.12731/2658-6649-2025-17-3-1444

Introduction

Vietnam encompasses approximately 0.5 million hectares of sandy soil, approximately 339,000 hectares (68%) of which are located in the coastal areas of the Central Region. Notably, the climate and soil in these coastal and island regions exhibit a dry and saline environment. In areas characterized by coral sand, agricultural practices and tree cultivation face significant challenges. The sandy soil of the South Central Coast (SCC) is primarily composed of sand (> 90%), features low clay content, exhibits low cation exchange capacity (CEC), high acidity, minimal organic matter, and poor water retention capabilities. The application of scientific and technological advancements to transform chronically contaminated coral sand into arable land holds both scientific and economic significance. The characteristics, soil properties, and climatic conditions of the coastal and island regions in the South Central area of Vietnam are predominantly characterized by loose sandy soil, salinity, inadequate water retention, nutrient deficiency, a hot climate, water scarcity during the dry season, and flooding during the rainy season, compounded by the tendency for land to become saline due to the geographical features of the region. Consequently, this study aims to address the challenge of enhancing coral sand by optimizing its physical and chemical properties, moisture retention, nutrient availability, and suitability for cultivation. In addition to its poor moisture retention, coral sand is deficient in nutrients and exhibits salinity. Therefore, it is essential to incorporate humectants to improve the soil, alongside the addition of nutrients and microorganisms. Alluvial soil is regarded as a highly suitable type of soil for various crops, particularly vegetables. To convert coral sand into viable arable land for vegetables and crops, the criteria for this soil type must be established. Key indicators to consider include porosity, maximum moisture storage capacity, soil salinity, and nutritional components (organic matter, CEC, total nitrogen, total phosphorus, nitrate), all of which must meet appropriate levels to optimize vegetable growth, particularly soil acidity (pH). Most plants thrive in neutral to slightly acidic soil, with the optimal pH range for vegetable growth being between 5.5 and 7.0, as this pH level facilitates the optimal uptake of nutrients by the plants.

Currently, numerous solutions exist globally to enhance soil quality, involving the application of soil-improving and moisturizing agents including natural minerals like bentonite, organic moisturizers, biochar, and CMC. These can be combined with organic nutrient sources, including microbial fertilizers, straw, and agricultural waste.

Bentonite serves as a soil improver and moisture retainer, having been extensively studied and effectively applied in numerous countries characterized by arid and semi-arid climates [6-8]. Due to its exceptional moisture retention and high adsorption capacity, bentonite is recognized as a natural material that enhances soil quality and increases fertility, particularly in sandy soils that necessitate substantial improvement for agricultural purposes. In its moist state, bentonite's swelling ability diminishes the capillary channels within the soil, thereby facilitating water retention and reducing permeability in sandy soils. As soil moisture levels rise, bentonite also enhances the thermal conductivity of the soil, thereby improving the heat resistance of sandy soils [9].

Bentonite is derived from volcanic ash, primarily composed of the mineral montmorillonite, which features a layered structure. This mineral clay exhibits swelling properties, high viscosity, and the capacity to adsorb various substances. Bentonite has found extensive application in soil enhancement. Beyond its moisturizing effects, it possesses the ability to retain nutrients and purify both soil and the environment. As a natural mineral, bentonite contains over 45 chemical elements of significant nutritional value, including CaO, MgO, SiO_2, and Al_2O_3. Consequently, it is utilized by numerous countries worldwide in the agricultural sector for the production of animal feed, fertilizers, and soil improvement.

In Vietnam, published studies on the application of Vietnamese bentonite for soil enhancement have been limited. Currently, only a handful of studies exist, notably by the authors Hoai Chau Nguyen [13], who investigated the effects of bentonite on the cation exchange capacity and moisture retention of sandy soil in Ninh Thuan province for asparagus cultivation. Transforming coral sand soil into a medium suitable for growing leafy vegetables, such as onions and mustard greens, presents a significantly greater challenge.

Growing media is widely utilized for plant cultivation due to its numerous advantages, including porosity, appropriate density, balanced nutrition, and efficient drainage. Various types of growing media exist, most of which are composed of natural materials that include rice husk, coconut fiber, sawdust, sand, and stone powder.

Beneficial microorganisms enhance soil nutrition through various mechanisms: nitrogen-fixing and phosphorus-decomposing microorganisms provide essential nitrogen and phosphorus nutrients; cellulose-decomposing microorganisms supply carbon sources and elevate organic carbon content in the soil; EPS-synthesizing microorganisms promote adhesion, enhance structure, and increase moisture retention capacity in cultivated soil. The introduction of beneficial microorganisms is crucial for the enhancement of numerous cultivated lands, particularly significant for the long-term transformation of coral sand soil into arable land.

Green mustard (*Brassica juncea L.*), a member of the cabbage family, is a plant capable of enduring drought and exhibiting moderate to good salinity tolerance (pH ≈ 8.6, EC ≈ 3.2-10 mS/cm, ESP ≈ 15) (Shirazi et al., 2011). It is cultivated extensively across various regions globally, particularly in Asian countries [14]. This vegetable is recognized for its high economic viability for farmers, attributed to its straightforward cultivation and rapid harvest cycle.

With their relatively low nutritional requirements compared to other crops, mustard greens can utilize organic fertilizers as basal nutrients, thereby producing safe organic products while also mitigating the drawbacks associated with inorganic fertilizers. Numerous studies have been conducted on mustard greens in recent years [15-20].

This study integrates bentonite with microorganisms and organic substrates to enhance coral sand, rendering it suitable for cultivation, while also examining the growth process of heat-resistant mustard greens, Brassica juncea.

Materials and methods

Materials and chemicals

Material: Bentonite and additives.

Substrate: utilized with the following specifications: Density 1.28 g/cm^3; Porosity ranging from 70-75%; EC: 0.705 mS/cm; pH 7-7.5; N, P, K index attains 3% ± 0.2% (commercially purchased).

Bioinoculants: Salt-tolerant polysaccharide biofilm-producing microbial formulation BTS (comprising *Bacillus velezensis TSD5* and *Meyerozyma guilliermondii DTA-Y5.8* strains); Salt-tolerant beneficial microbial formulation NPC (comprising nitrogen-fixing *Azotobacter chroococcum TSL B1.2*, phosphate-solubilizing *Pseudomonas sp. TSD-B5.7*, and cellulose-decomposing *Bacillus amyloliquefaciens DTA-B5.1* strains). The density of selected microorganisms is ≥ 10^8 CFU/g.

Plant Varieties

Heat-resistant Hong Kong Mustard green F1 variety from Viet A Vegetable Company

General Characteristics of Coral Sand

Coral sand soil in the study exhibited a grain size primarily ranging from 0.2 to 5 mm, characterized by an unstable structure. The attributes of coral sand are as follows:

Table 1.

Physical and Chemical Properties of Coral Sand

pH (H_2O)	Salinity ‰	Particle Density (g/cm^3)	Burk density (g/cm^3)	WHC (%)	Total Nitrogen (%)	Total Phosphate (%)
8,0-9,0	4,5-12,7	1,33	2,44	23.17	0.06	0.02

Experimental setup

The experiment was carried out at the Vegetable Greenhouse, Faculty of Agronomy, Vietnam Academy of Agriculture, under the following conditions: Temperature ranged from 28 °C to 35 °C; Humidity varied from 50% to 70%; Light intensity exceeded 6000 lux. The study employed a randomized complete block design (RCBD), with each formula replicated three times, and each replicate consisting of three plants, utilizing the following experimental:

Table 2.

Experimental Formulations

	Coral sand	Bentonite	Substrate	BTS Polysaccharide film forming salt tolerant microorganisms	NPC salt tolerant beneficial micoorganisms
DC1	100%	-	-	-	-
DC2	97%	3%	-	-	-
DC3	90%	-	10%	-	-
DC4	89.5%	-	10%	0.25%	0.25%
DC5	87.3%	2.7%	10%	-	-
DC6	100% Alluvial soil				
CT1	86.82%	2.68%	10%	0.25%	0.25%
CT2	81.97%	2.53%	15%	0.25%	0.25%
CT3	77.12%	2.38%	20%	0.25%	0.25%
CT4	91.67%	2.83%	5%	0.25%	0.25%
CT5	89.24%	2.76%	7.5%	0.25%	0.25%

The experiments are maintained under a consistent regimen. Watering occurs twice daily through manual methods, ensuring an even distribution of water across all experiments.

Analytical Methods

Soil physical and chemical parameters

The quality of mixed substrates is assessed using standard methods in accordance with Vietnamese Standards:

Determination of particle density

Determine the density based on TCVN 11399:2016

The treated soil samples were determined for specific gravity using a pycnometer.

Determination of bulk density

Determine bulk density based on TCVN 11399:2016

After being completely dried, the soil samples will be weighed using an analytical balance with an error of 0.001 mg at the Biochemistry Department - Institute of Biotechnology - Vietnam - Joint Vietnam-Russia Tropical Science and Technology Research Center.

Determination of porosity

Soil porosity is determined according to ASTM D1557

Soil porosity: is the percentage of voids in the soil compared to the soil volume. Soil porosity P (%) is determined through the specific gravity and bulk density of the soil.

Formula for determining porosity:

$$P(\%) = (1 - \frac{d}{D}) \times 100.$$

In which: d is density (g/cm^3)

D is density (g/cm^3)

Determination of EC conductivity

The electrical conductivity (EC) of the substrate mixture was assessed using a handheld EC meter (Hana 901, Taiwan), with each formula measured three times, involving two plants per measurement. This assessment was conducted weekly. The EC of the substrate was determined in accordance with ISO 11265:1994

The soil EC is measured with a handheld EC measuring pen (Hana 901, Taiwan), measuring each formula 3 times, each time measuring 2 trees. Measure 1 time/week.

pH measurement

Soil pH_{H2O} is assessed in accordance with ISO 11277.

Total nitrogen and phosphorus content

Total nitrogen is determined according to ISO 14237; total phosphorus is determined according to ISO 11263.

Indicators for monitoring plant growth

Number of leaves

Measure the number of leaves on a weekly basis, observing leaf growth and the total number of leaves per plant prior to harvesting. Each formula is assessed three times, with two plants evaluated during each assessment.

SPAD Index

The SPAD index was assessed using a SPAD 502 meter (Japan), measuring each plant with two new leaves and calculating the average value. Each formula was evaluated three times, with two plants measured during each assessment.

Harvest yield

Harvest yield was determined by multiplying the individual yield by standard density per square meter. The sample harvest occurred two months post-sowing. Fresh stems and leaves were weighed to compute the harvest yield and subsequently stored at 70°C for 48 hours to ascertain the accumulated dry matter mass.

Data Processing

Collected data were analyzed using SPSS 22 statistical software (IBM, USA) and MS Excel 365 software (Windows, USA). Comparison of differences between experiments based on one-factor ANOVA analysis at 95% confidence level.

Results and discussion

Changes in the physical properties of the soil

Table 3.

Physical parameters of soil in the improvement experiment

Experiment	Particle Density (g/cm³)	Burk density (g/cm³)	Porosity (%)
DC1	2,10	1,31	37,46
DC2	2,16	1,01	53,32
DC3	1,99	0,90	54,93
DC4	2,11	0,97	54,08
DC5	2,16	0,98	54,60
DC6	2,28	1,00	56,14
CT1	2,03	0,92	54,90
CT2	1,87	0,81	56,55
CT3	1,81	0,72	60,21
CT4	2,29	1,13	50,69
CT5	2,06	0,95	53,99

The indices of physical properties, including density, bulk density, and porosity of soil, are displayed in Table 3.

In comparison to control 1 (DC1) - Coral sand, the densities of the 15% (CT2) and 20% (CT3) mixing experiment are lower, whereas experiment DC5 and DC6 exhibit higher densities. The other experiments demonstrated equivalent densities when compared to coral sand.

However, the bulk density of all formulations containing mixed substrates was lower than control 1 (DC1). As the ratio of organic substrate increased, the bulk density of the mixture decreased. Concurrently, the porosity of the mixture rose progressively from 37.46% (DC1) to 60.21% (CT3 - mixed 20% organic substrate).

Changes in soil chemistry

The alteration in the chemical properties of coral sand soil following renovation is evidenced by indicators including soil pH, electrical conductivity (EC), total nitrogen, and total phosphate (Table 4).

Table 4.

Soil Chemical Indices in the Enhancement Experiment

Experiment	pH	EC (μS/cm)	Total Nitrogen	Total Phosphate
DC1	8,15c	212de	0,32e	0,01e
DC2	8,23ab	314de	0,19e	0,02e
DC3	7,69efg	1.377b	1,58c	0,32c
DC4	7,68fg	1.083c	1,58c	0,35ab
DC5	7,69g	1.056c	1,58c	0,35a
DC6	7,26d	174d	0,92d	0,20d
CT1	7,65ef	1.048c	1,76bc	0,32bc
CT2	7,61e	1.043c	2,11b	0,35abc
CT3	7,50fg	1.879a	2,88a	0,34abc
CT4	7,84a	354de	0,69d	0,20d
CT5	7,74b	432d	0,83d	0,22d

The assessment of the physical and chemical parameters of the enhanced soil formula mixture indicates that:

The pH of the formulations comprising 10 - 20% substrate in conjunction with bentonite and microbial preparations was approximately 7.6. A decrease in pH was observed as the organic matter content increased. In contrast, the formulations containing 5% and 7.5% substrate exhibited lower pH levels than coral sand (8.15), registering at 7.84 and 7.74, respectively. The incorporation of bentonite generally resulted in an elevation of the substrate's pH.

The electrical conductivity (EC) of coral sand was measured at 212 μS/cm, which was higher than DC6 (alluvial soil) but significantly lower than the experiment incorporating organic substrates. The EC exhibited a gradual increase with a rising ratio of organic substrates, with CT3 recording the highest EC at 1879 μS/cm. Formulations containing 10% to 15% organic substrates did not demonstrate a distinct change in EC following mixing. The addition of bentonite and microbial preparations also did not result in a significant increase in the EC of the mixture utilizing substrates prior to planting.

The incorporation of substrates markedly enhanced the total nitrogen (N) and phosphorus (P) levels in the experimental formulations when compared to the coral sand control (DC1) and the coral sand combined with bentonite (DC2). Elevating the substrate mixing ratio to 10% resulted in a fivefold increase in N content in formulations Control 3 (DC3), Control 4 (DC4), Control 5 (DC5), and CT1. Further increases in the substrate mixing ratio to 15% (CT2) and 20% (CT3) led to a rise in N content from seven to nine times relative to Control 1. In contrast, CT4 and CT5 exhibited only a two- to threefold increase in N content compared to Control 1 (DC1). Notably, increasing the substrate amount from 5% to 7.5% resulted in a twentyfold increase in P content, while raising the mixed substrate proportion from 10% to 20% elevated P content by as much as thirty-five times compared to Control 1 (DC1). Nevertheless, no statistically significant differences were observed among formulations CT1, CT2, or CT3 at substrate mixing levels of 10%, 15%, or 20% at the $p < 0.05$ significance level.

Effects of improvement experiments on plants

EC changes during vegetable growing

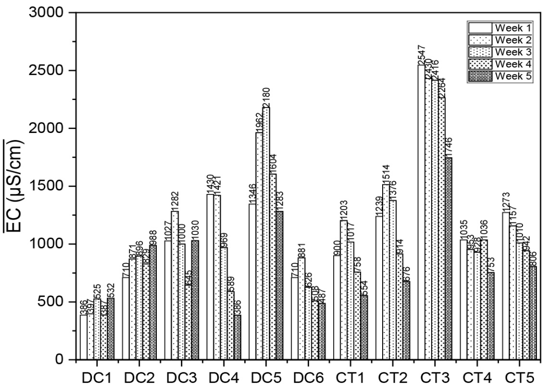

Fig. 1. EC in experimental

EC in experimental is illustrated in Figure 1. Generally, the EC measured directly in soil pots exceeds that obtained in laboratory settings. However, under actual growing conditions, where the water content in the substrate mixture is significantly lower than the dilution ratio used in the laboratory (1:5), the concentration of exchangeable cations in experimental pots is elevated. Consequently, the EC measured directly in experimental pots is greater than the laboratory results.

In the formulation utilizing organic substrate CT3 (20%), the recorded electrical conductivity (EC) was the highest at 2500 μS/cm, gradually diminishing as the substrate ratio decreased, reaching its lowest point in coral sand (< 500 μS/cm). Throughout the monitoring weeks, the EC value of the mixture also exhibited a significant decline in the mixed formulations, whereas the control formulations DC1 and DC2 displayed an upward trend.

Impact of enhancement experiments on the leaf growth rate of vegetable plants

For vegetable plants, the quantity of leaves and leaf area serve as crucial indicators for assessing growth and yield potential at harvest.

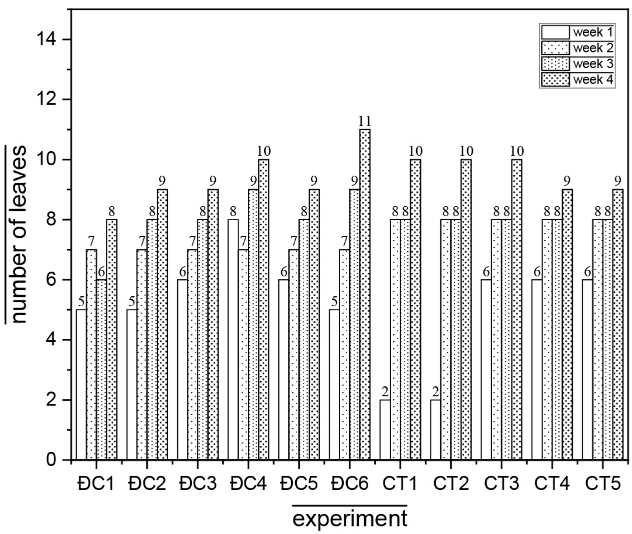

Fig. 2. Leaf growth rate in experimental formulations

Monitoring of leaf growth indicated a gradual increase in the number of leaves over the monitoring period, with the most pronounced growth observed in experiment CT1 and CT2, which contained 10% and 15% organic substrate, respectively. In contrast, experiment DC1-coral sand and DC2-coral sand + bentonite exhibited a significantly lower rate of leaf growth compared to those mixed with organic substrate. Additionally, the application of microbial preparations (DC5, CT1 - CT5) resulted in an increased leaf count; however, no significant difference was noted when compared to experiments that did not incorporate microbial preparations (DC3).

Through monitoring, the final leaf count in formula DC1 was the lowest, averaging only 5 leaves across both plantings (Figure 3). Formula DC2 exhibited a leaf count ranging from 5 to 7 leaves. These two experiments were significantly lower than the substrate mixing experiment ($P < 0.05$). The remaining experiment had an average final leaf count of 7 to 8 leaves in both plantings, demonstrating a clear difference at the 95% statistical significance level.

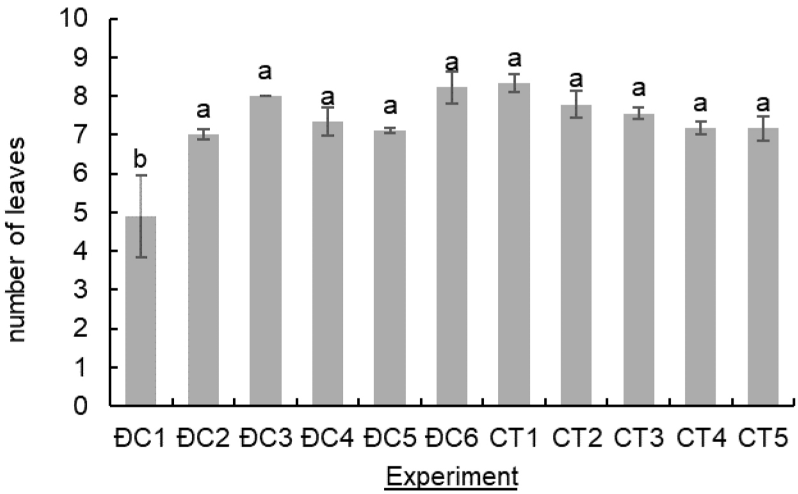

Fig. 3. Final count of leaves in experimental experiment (Characters in experiment denote the difference at a 95% confidence level between experimental experiment at the same monitoring time; error bars represent the standard error of the sample SE)

The evaluation of the leaf area index at harvest indicated that the leaf area in experiment DC3 - DC5 and CT1 - CT3, which incorporated 10 - 20% organic substrate combined with microbial products and bentonite at equivalent levels, exhibited no significant difference (Figure 4). In contrast, the leaf area in experiment DC1 and DC2 was significantly lower than that of the other experiment ($p < 0.05$). Formula DC6, utilizing alluvial soil, demonstrated the highest leaf area, significantly surpassing the other experiments ($p < 0.05$). Experiment CT4 and CT5 exhibited a significantly greater leaf area than DC1 and DC2 ($p < 0.05$), yet remained lower than the other experiment at the statistical significance level.

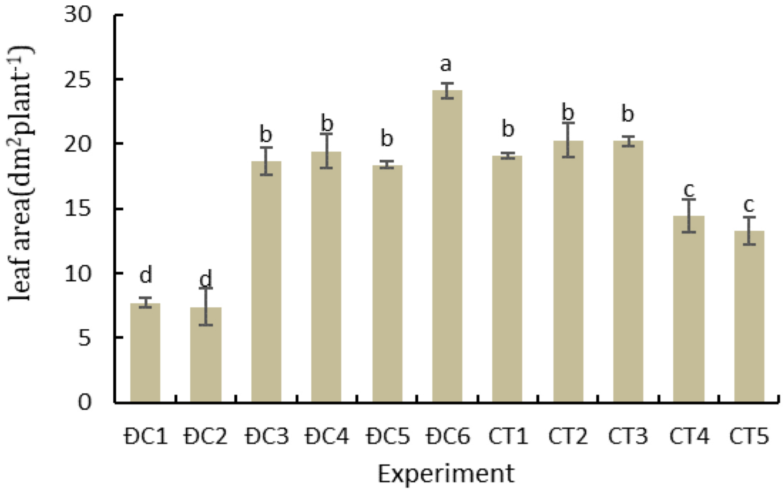

Fig. 4. Leaf area at harvest in experimental experiments (Characters in experiments denote the differences at a 95% confidence level between experimental experiments at the same monitoring time; error bars represent the standard error of the sample, SE.)

Impact of soil formulations on plant SPAD index

The SPAD index quantifies the chlorophyll content in crops, which is closely linked to their capacity to utilize nitrogen nutrients [1]. In the case of leafy vegetables, this factor significantly influences both the quality and yield at various fertilizer levels during harvest [2].

Through monitoring and evaluation, the SPAD index in experiments DC1 and DC2 was markedly lower than in the other experiments during both planting periods (Figure 5). This indicates that the efficiency of nitrogen utilization by plants in coral sand is inferior to that of the experiments incorporating organic substrates for soil enhancement. No significant difference was observed between the experiments when comparing those that utilized organic substrates and microbial preparations for soil improvement. Furthermore, the SPAD index in the improvement experiments did not fall below that of the control on alluvial soil. This suggests that the effectiveness of using substrates to enhance sand is considerable. However, the effect of the organic substrate ratio in the mixture of 5 - 20% on the SPAD index was negligible.

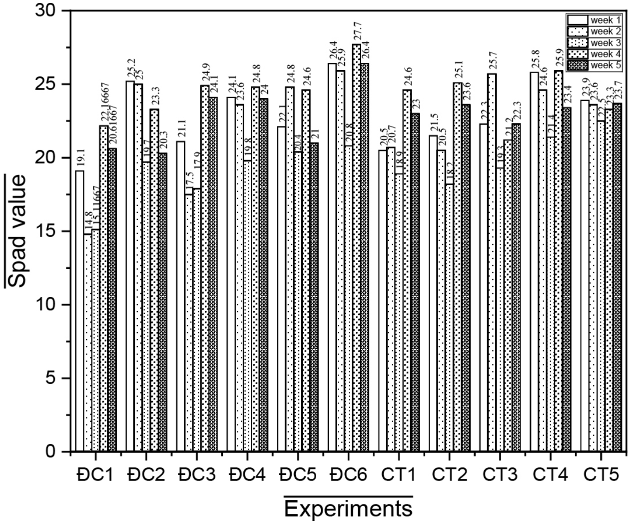

Fig. 5. Variation of the SPAD index of vegetables in experimental formulations throughout the growing weeks

The SPAD index at harvest, which ranged from 22 to 26 in the coral sand enhancement experiments utilizing microbial products and substrates containing bentonite, exhibited minimal variation (Figure 6).

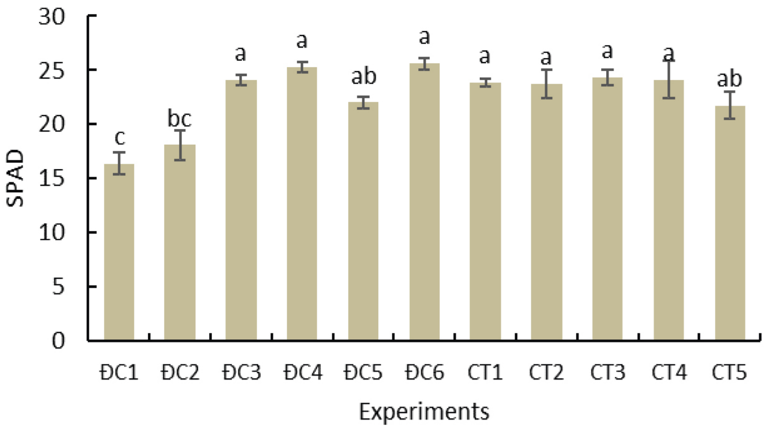

Fig. 6. SPAD index of vegetables in experimental formulations at harvest time (Characters in formulations indicate a 95% confidence difference between experimental formulations at the same time of follow-up; error bars represent SE sample errors)

Impact of enhancement experiments on the yield of vegetable crops

The harvested vegetable mass is illustrated in Figure 7. The mass is significantly greater in experiment DC6 utilizing alluvial soil (27 g/plant) compared to the other experiments. The superiority in harvested biomass is evident, as the initial growth rate of the other experiment is inferior to that of plants grown in alluvial soil. This may be attributed to the elevated pH and electrical conductivity of the mixed substrate experiments, which adversely affect plant growth, particularly during the initial planting phase [3]. This is further demonstrated by the slower growth rate in the number of leaves for the experiments employing coral sand and mixed substrate in comparison to DC6 during the first three weeks.

Utilizing coral sand can result in a harvest; however, the plant weight remains quite low, averaging around 5 g per plant. In contrast, the formulation incorporating bentonite - DC2 shows some enhancement, though its efficiency relative to DC1 remains ambiguous. While both formulations exhibit low pH and electrical conductivity comparable to alluvial soil, their capacity to enhance productivity is limited when relying solely on inorganic fertilizers.

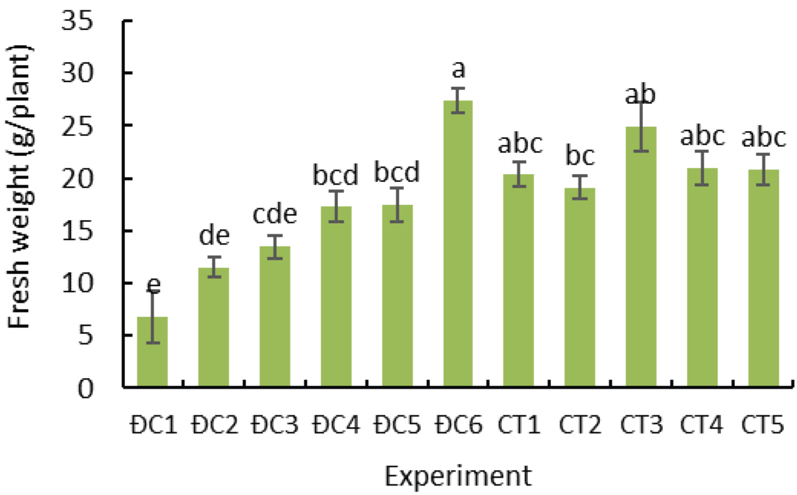

Fig. 7. Harvested vegetable mass across various experiments in batches (Characters in experiments denote the differences at a 95% confidence level between experimental experiments at the same monitoring time; error bars indicate sample error SE)

The harvested vegetable mass of the experiments utilizing mixed substrates in conjunction with microbial preparations and bentonite (DC4, DC5, CT1 to CT5) demonstrated a significant superiority over DC1 ($p < 0.05$). In comparison to DC3, which employed only 10% organic substrates, the harvested vegetable mass of experiments DC4, DC5, and CT1 (utilizing substrates at the same level combined with microbial preparations and bentonite) was greater, although not statistically significant ($p < 0.05$).

The negligible difference in the volume of vegetables produced using both organic substrates, bentonite and microbial preparations (CT1 to CT5), indicates that the incorporation of organic matter ranging from 5% to 10% in conjunction with these preparations can sustain vegetable yield while decreasing enhancement costs by 15% or 20% relative to the substrate quantity. Nonetheless, assessing the factors that enhance the chemical and physical properties of the soil remains essential.

Fig. 8. Photos of vegetable plants in pre-harvest recipes

Discussion

Research indicates that the combined application of bentonite, biological substrates, and microbial preparations enhances the physical and chemical properties of coral sand, thereby benefiting cultivation and plant growth. The quality of the soil post-improvement is contingent upon the quantity of substrate added, particularly its porosity. Soil porosity is a critical factor, as higher porosity facilitates aeration and promotes robust root development. Initially, the coral sand exhibited a loose structural composition with a porosity of only 37.46%. Analysis of soil samples from experimental formulations post-improvement reveals an increase in porosity compared to the original coral sand sample. With a substrate mass of 10%, porosity reached 54.90%, nearly matching that of alluvial soil at 56.14%, indicating that the improved soil is nearly equivalent to alluvial soil in terms of porosity, making it suitable for vegetable cultivation.

Physical and chemical parameters of the soil, such as pH, reached 7.65, and electrical conductivity (EC) measured 1048 μS/cm. In contrast, the initial coral sand sample had a higher pH of 8.15 and a lower EC of 212 μS/cm. The incorporation of organic substrate significantly elevated the levels of nitrogen and phosphorus in the mixture post-renovation, enhancing nutrient availability for improved plant growth compared to the coral sand control. With a bentonite component ratio of 3% (w/w), an organic substrate of 10%, and each of the polysaccharide mucilaginous microbial preparations and salt-tolerant beneficial microbial preparations at 0.25%, the growth metrics for mustard greens included an average leaf count of 7-8, an average leaf area of approximately 20 dm^2/plant, a harvested vegetable weight of 20 g/plant, and a SPAD index of 23.87. In comparison, the coral sand control sample yielded an average leaf count of only 5, a leaf area of 7.73 dm^2/plant, a SPAD index of 16.37, and a harvested vegetable weight of merely 6.77 g/plant. Furthermore, these metrics were not inferior to those of the alluvial soil control sample. Consequently, the indices at the 10% organic substrate addition ratio are more favorable for mustard greens than those of the other formulations. Although the 5% and 7.5% supplementation experiments yielded similar results, they did not lower soil pH. Therefore, the optimal formulation for enhancing coral sand is the inclusion of 10% organic substrate. The addition of microbial preparations and bentonite to coral sand resulted in increased EC and vegetable weight post-harvest, although no significant difference was observed compared to the formulations lacking these preparations and bentonite.

Conclusion

Through the evaluation of the growth and development of vegetable plants in coral sand remediation recipes, it was found that:

The improvement of coral sand is necessary, the coral sand remediation formulas all give good results. The addition of organic substrate increases porosity, reduces capacity, and enhances the nutrient content in the soil, thereby increasing the growth and harvest yield of vegetables compared to coral sand control. The formula adds 10% organic substrate to the growth indicators and the volume of harvested vegetables is not lower than the addition of 15% or 20% organic substrate, and the chemical indices (pH, EC) of the soil are at a level more suitable for vegetables than the rest of the formulas. The additional 5% and 7.5% formulations, although with the same yield as the above formulations, do not reduce soil pH. Therefore, the right formula for coral sand remediation is to use 10% organic substrate.

The effect of adding microbial preparations and bentonite to coral sand increases EC and post-harvest vegetable volume but is not significantly different from formulas without preparations and bentonite.

Acknowledgments. This project is supported and implemented by the Laboratory of Biochemistry - Department of Biotechnology/ Joint Vietnam - Russia Tropical Science and Technology Research Center.

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Поступила 26.12.2024
После рецензирования 01.02.2025
Принята 14.02.2025

Received 26.12.2024
Revised 01.02.2025
Accepted 14.02.2025