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Effects of Vermicompost on Soil Physical Properties, Organic Carbon Content, and the Growth, and Yield of Carrot (*Daucus carota* L.) on Inceptisols

Raisha Amanda April Amertha[1], Heru Widiyono[1*], Kartika Utami[1], M. Faiz Barchia[1]

[1]*Department of Soil Science, Faculty of Agriculture, University of Bengkulu, Indonesia*

Corresponding Author : *widiyonoheru@gmail.com*

ABSTRACT

Carrot (Daucus carota L.) is a root vegetable cultivated year-round, particularly in subtropical and highland regions, serving as a vital source of vitamins and minerals. In Indonesia, favorable environmental conditions—such as temperature, rainfall, humidity, and soil type—support carrot cultivation. Among the dominant soil types, Inceptisols are widely distributed but often constrained by low organic carbon content and suboptimal physical properties. However, studies on the long-term effects of organic amendments, particularly vermicompost, on soil quality and crop performance in highland Inceptisols remain limited. This study evaluated the effects of long-term vermicompost application on selected soil physical properties, organic carbon content, and the growth and yield of carrot plants cultivated on Inceptisols. The experiment was conducted from November 2023 to February 2024 in Air Duku Village, Selupu Rejang Subdistrict, Rejang Lebong District, at an altitude of 1,054 meters above sea level. The site had received vermicompost applications for nine consecutive years. A randomized complete block design (RCBD) was employed, with five vermicompost doses (5, 10, 15, 20, and 25 tons ha⁻¹), each replicated three times, resulting in 15 experimental plots. Soil and plant analyses were performed at the Soil Science Laboratory, Faculty of Agriculture, University of Bengkulu. Application of 15 tons ha⁻¹ vermicompost significantly improved pF1 (37.89%), soil organic carbon content (4.15%), and root weight per plant (198.68 g). The 20 tons ha⁻¹ dose significantly increased soil permeability (6.17 cm h⁻¹) and total plant weight (36.17 kg plot⁻¹), while 25 tons ha⁻¹ enhanced water retention at pF2 (43.95%) and pF3 (39.63%). *These findings demonstrate the potential of vermicompost to improve soil quality and carrot productivity in highland Inceptisols and support its integration into sustainable vegetable farming systems*.

Keywords: *carrot, Inceptisols, soil properties, sustainable agriculture, vermicompost*

INTRODUCTION

Sustainable vegetable production requires maintaining soil fertility and optimizing soil physical properties, particularly in regions where soils are constrained by low organic matter content. Carrot (*Daucus carota* L.) is a biennial root vegetable widely cultivated for its edible taproot and nutritional value, serving as an important source of vitamins and minerals. Although originally adapted to subtropical and temperate regions, carrot cultivation has expanded into tropical highland areas, where cooler temperatures and favorable agroclimatic conditions—such as moderate rainfall, high humidity, and fertile sandy loam soils—support year-round production (Harjo, 2021). In Indonesia, these favorable environmental factors are complemented by agro-economic aspects such as land availability, market access, and consistent selling prices, making carrot farming a promising enterprise (Yadiansyah *et al*., 2020).

Indonesia's agricultural landscape is dominated by Inceptisols, which cover approximately 40–50% of the national land area, or about 70.52 million hectares (Husein *et al*., 2023). Inceptisols are young soils with moderate development and are often characterized by low organic matter content, poor structure, and limited nutrient-holding capacity (Muslim *et al*., 2020).

These limitations hinder optimal plant growth and reduce the efficiency of soil water and nutrient management. Addressing these challenges requires soil amendments that can improve both chemical and physical soil properties.

Organic fertilizers are widely recognized for their role in enhancing soil fertility and supporting sustainable agriculture (Sipayung & Girsang, 2020). Among them, vermicompost has gained considerable attention due to its high nutrient availability, microbial activity, and positive effects on soil structure. Produced through the decomposition of organic materials by earthworms, vermicompost is rich in readily available nutrients and contributes significantly to improving soil biological and physical properties. Compared to conventional compost, vermicompost provides superior benefits in terms of nutrient release and soil conditioning (Aziez & Budiyono, 2018).

Several studies have demonstrated the beneficial effects of vermicompost on soil health and crop productivity. Daniati *et al*. (2021) reported that organic fertilizer application increased carrot root weight to 144.58 g plant^{-1} and up to 35.63 tons ha^{-1} in total yield. Nur *et al*. (2022) observed that vermicompost improved soil organic carbon content, particularly in Inceptisol soils. Hailu *et al*. (2024) found that vermicompost enhanced carrot yield to 45.5 tons ha^{-1}, outperforming conventional compost and inorganic fertilizer treatments due to its balanced nutrient profile. In addition, Adiprasetyo *et al*. (2022) emphasized the role of vermicompost in improving nitrogen (N), phosphorus (P), and potassium (K) distribution—nutrients essential for plant development. Moreover, Hindersah *et al*. (2019) showed that vermicompost helps maintain bulk density within the optimal range (1.0–1.3 g cm^{-3}), thereby supporting root growth and water uptake. Mulatu & Bayata (2024) further reported that vermicompost enhances soil water retention, increases permeability, and stabilizes soil aggregates.

Despite these promising findings, limited research has evaluated the specific effects of vermicompost on soil physical properties and carrot performance in highland Inceptisol soils under long-term application scenarios. Understanding these interactions is essential for developing sustainable soil fertility management strategies in marginal upland areas.

Therefore, this study aims to evaluate the effects of different vermicompost doses on selected soil physical properties (bulk density, permeability, water content, and water potential), soil organic carbon content, and the growth and yield of carrot (*Daucus carota* L.) cultivated on Inceptisol in a highland region.

MATERIALS AND METHODS

Study site and duration

This study was conducted from November 2023 to February 2024 in Air Duku Village, Selupu Rejang Subdistrict, Rejang Lebong Regency, at an elevation of 1,054 meters above sea level. The research site is geographically located at 3.45986° S and 102.61510° E. The area has received continuous vermicompost applications for nine consecutive years. Soil sample analyses were carried out at the Soil Science Laboratory, Faculty of Agriculture, University of Bengkulu.

Tools and materials

The tools used in this study included soil sampling rings, rulers, hoes, field knives, plastic bags, labels, permanent markers, and laboratory equipment for soil analysis. The materials consisted of disturbed and undisturbed soil samples collected from fifteen plots at a depth of 0–20 cm using purposive sampling. Carrot plant samples were also collected after harvest.

Experimental design

The experiment employed a Completely Randomized Block Design (CRBD) with five levels of vermicompost application: 5, 10, 15, 20, and 25 tons ha^{-1}, each replicated three times, resulting in 15 experimental plots.

Soil preparation

The experimental field was prepared using conventional tillage with a hoe. Raised beds measuring 5 m × 5 m (25 m^2) and 40 cm high were constructed on the prepared plots.

Fertilizer application

Vermicompost used in this study was sourced from local farmers and derived from cow manure composted with *Perionyx excavatus* earthworms over approximately three months. The vermicompost was applied uniformly on each plot according to the designated treatment (5, 10, 15, 20, and 25 tons ha^{-1}) and then evenly spread using a hand fork. The soil was left undisturbed for about seven days following application.

Carrot planting

Carrot seeds derived from previous crops were broadcast on each experimental plot. Thinning was performed at 40–45 days after sowing by removing excess plants to achieve an interplant spacing of 20 cm.

Carrot harvesting

Harvesting was conducted uniformly across all plots when the carrot plants were 90–95 days old. Maturity was indicated by partial yellowing of the leaves. Carrots were harvested manually by pulling the plants individually from the soil.

Observation of growth and yield variables

Three plants were randomly selected from each plot for observation of growth and yield parameters. Plant height and root length were measured using a ruler (in cm), while root weight per plant was measured using a digital scale (in g), and total plant weight per plot was measured using a collective balance (in kg).

Soil sampling

Soil samples were collected at a depth of 0–20 cm. Undisturbed soil samples were collected using sampling rings for analysis of bulk density (BD), per-meability, and water retention (pF), while disturbed composite samples were collected using a peat auger for analysis of moisture content and organic carbon (C-organic). All samples were stored in labeled plastic bags.

Soil sample preparation

Disturbed soil samples were spread on clean trays and placed on drying racks at ambient room temperature (25 °C) for 1–2 weeks. After air-drying, the samples were crushed using a mortar and pestle and sieved through a 0.5 mm mesh for further analysis.

Soil sample analysis

Soil analysis was performed at the Soil Science Laboratory, Faculty of Agriculture, University of Bengkulu. The undisturbed soil samples were analyzed for bulk density using the ring method, water retention (pF) using a pressure plate apparatus at 0.1, 0.5, and 1 atm and oven-dried at 105 °C for 24 hours, and soil permeability using the hydraulic conductivity method. The air-dried disturbed samples were analyzed for organic carbon content using the Walkley and Black method, and for moisture content using the gravimetric method.

Observed variables

The variables observed in this study are presented in Table 1.

Table 1. Observed variables of soil physical properties and carrot plant growth and yield

Sample	Characteristic	Observed variable	Method
Soil	Physical	Bulk density (BD)	Ring method
		Permeability	Hydraulic conductivity method
		Soil moisture content	Gravimetric method
		Water retention (pF 2, 2.7, 3, 4)	Pressure plate (0.1, 0.5, 1 atm; oven-dried at 105 °C for 24 h)
	Chemical	Organic Carbon (C-organic)	Walkley & Black Method
Plant	Growth	Plant height (cm)	Ruler
		Root length (cm)	Ruler
	Yield	Root weight per plant (g)	Digital Scale
		Total weight per plot (kg)	Collective Scale

Data analysis

The collected data were analyzed using Analysis of Variance (ANOVA), and treatment means were compared using Duncan's Multiple Range Test (DMRT) at the 5% significance level.

RESULTS AND DISCUSSION

General overview

This study was conducted in Air Duku Village, Selupu Rejang District, Rejang Lebong Regency, Bengkulu Province, located at coordinates 3.45986° S and 102.61510° E. The total research area covered 1 hectare, comprising 25 plots, each formed into raised beds measuring 40 cm in width and 5 m in length, with a planting distance of 20 cm. The dominant soil type in the area is Inceptisols, and the majority of the local population is engaged in the agricultural sector.

The study began with the preparation of vermicompost using dairy cattle manure processed with the earthworm *Perionyx excavatus*. The vermicompost was applied to both soil and carrot (*Daucus carota L.*) crops to assess its effects on physical soil properties, organic carbon content, plant growth, and yield.

Summary of analysis of variance results

Statistical analysis was performed using analysis of variance (ANOVA) with F-tests for all observed variables, as presented in Table 2.

The application of vermicompost had a significant effect on soil permeability, water retention at various pF levels, organic carbon content, and carrot yield. However, it did not significantly affect bulk density, gravimetric water content, or vegetative growth variables, as determined by F-tests at the 5% significance level (Table 2).

Table 2. Summary of analysis of variance results

Observed variables	F-value	CV (%)	Significance
Physical properties			
Bulk density	1.58	0,57	ns
Permeability	4.43	0,90	*
Gravimetric water content	1.59	0,66	ns
Water content at pF 2	7.17	0,43	*
Water content at pF 2.7	7.54	0,50	*
Water content at pF 3	4.12	0,82	*
Water content at pF 4.2	3.20	0,89	ns
Organic carbon (C-organic)	4.21	0,73	*
Growth and yield variables			
Plant height	2.17	0,27	ns
Root length	1.13	0,42	ns
Root weight per plant	4.69	0,72	*
Total yield per plot	5.63	0,42	*

Note: * = statistically significant at 5% level ($F_{0.05}$ = 3.84); ns = not significant; CV = Coefficient of Variation

Soil bulk density

The analysis of soil bulk density revealed no statistically significant differences among the treatments (Table 3). The relatively low bulk density values can be attributed to the high organic matter content in the soil. This finding is consistent with the statement by Delsiyanti *et al*. (2016), which indicates that organic matter concentrated in the topsoil can improve soil quality by increasing organic carbon content and enhancing soil biota activity, ultimately reducing soil bulk density.

Table 3. Soil bulk density (BD) analysis

Vermicompost dose (ton ha^{-1})	Bulk density (g cm^{-3})	Category*
5	1.01	Moderate
10	0.86	Moderate
15	0.80	Moderate
20	0.84	Moderate
25	0.81	Moderate

*Source: LPT (1979) as cited in Imelda (2023)

Soil permeability

Permeability refers to the property of porous materials that allows fluids, such as water, to flow through pore spaces. Soil pores are interconnected, enabling water to move from areas of high energy to lower energy. Soil permeability is strongly influenced by its physical characteristics. The results of the post hoc analysis of soil permeability are presented in Table 4.

Table 4. Post hoc analysis of soil permeability

Vermicompost dose (ton ha^{-1})	Permeability (cm h^{-1})	Class*
5	3.28 b	Moderate
10	4.64 ab	Moderate
15	5.15 ab	Moderate
20	6.17 ab	Moderate
25	6.61 a	Moderately Fast

*Source: LPT (1979) in Imelda, 2023

Note: Values followed by the same letters are not significantly different at the 5% level (DMRT).

Permeability reflects a soil's ability to transmit water. Soils with relatively high permeability rates enhance infiltration and reduce surface runoff (Penhen *et al*., 2022). Significant differences in permeability were observed, with the greatest contrast between 5 ton ha^{-1} (3.28 cm h^{-1}) and 25 ton ha^{-1} (6.61 cm h^{-1}), a difference of 3.33 cm h^{-1}. The 20 ton ha^{-1} dose yielded similar results to the 25 ton ha^{-1} dose, suggesting that the lower dose may provide comparable permeability benefits. Soils classified as having moderate to moderately fast permeability are ideal for many crops, maintaining a balance between drainage and moisture retention. Widyantika & Prijono (2019) stated that soils are considered permeable when permeability falls within the moderate range of 2.00–6.25 cm h^{-1}.

Soil texture also influences permeability. Texture analysis indicated that the experimental soil was classified as sandy loam. Rizal *et al*. (2022) noted that high clay content reduces infiltration rates. Organic amendments such as vermicompost improve permeability by enhancing microbial activity and promoting earthworm tunneling, which increases macroporosity. Permeability is also a key determinant of soil erosion sensitivity—higher permeability generally results in lower erosion risk (Azhari *et al*., 2022).

Soil moisture content

Soil water plays a vital role in dissolving and binding soil particles and transporting dissolved substances critical to soil formation and degradation processes. The results of the gravimetric soil moisture analysis are shown in Table 5.

Table 5. Gravimetric soil moisture content

Vermicompost dose (ton ha^{-1})	Moisture content (%)	Class*
5	34.81	Moderate
10	38.58	Moderate
15	34.81	Moderate
20	44.69	Moderate
25	45.62	Moderate

*Source: Physical Properties of Soil and Their Analytical Methods, 2022

There were no significant differences in gravimetric moisture content across treatments. All values fell within the moderate range, indicating good tillage conditions. High moisture content may cause soil compaction, while low moisture levels can hinder tillage and plant growth. Organic matter contributes significantly to moisture retention, with higher organic content generally leading to increased soil water availability.

Soil water potential (pF)

Soil water potential (pF) quantifies the energy with which soil particles hold water. It was measured using standard instruments such as the pressure membrane and pressure plate apparatus. Available water is defined as the difference in water content between field capacity and the permanent wilting point, typically between pF 2.54 and pF 4.2. In this study, measurements were taken at pressures of 0.1 atm (pF 2), 0.5 atm (pF 2.7), and 1 atm (pF 3).

Table 6. Post hoc analysis of soil water potential

Vermicompost dose (ton ha^{-1})	Water potential (%)
	pF 2
5	35.09 bc
10	32.22 c
15	37.89 ab
20	42.91 b
25	46.74 a

Note: Values followed by the same letter within each column are not significantly different at the 5% DMRT level.

The results showed significant differences in pF values, especially between the 10 ton ha^{-1} and 25 ton ha^{-1} treatments. The largest increases were observed at pF 2 (14.52%), pF 2.7 (16.84%), and pF 3 (18.11%). Similarities in results among the 15, 20, and 25 ton ha^{-1} doses suggest that moderate applications (15 ton ha^{-1}) can achieve comparable water retention to higher doses.

pF 2 represents saturation, where soils hold the maximum water volume. pF 2.7 corresponds to field capacity—optimal for plant uptake—while pF 3 indicates that water is still available but more tightly bound to soil particles, reducing plant absorption efficiency. These results indicate that vermicompost application significantly improves soil water retention across a range of moisture conditions.

Organic carbon (C-organic)

Organic carbon (C-organic) refers to organic matter found both on the soil surface and within the soil profile, originating from naturally occurring carbon compounds. It encompasses a variety of organic components including plant litter, light organic matter fractions, microbial biomass, water-soluble organic compounds, and stable organic substances such as humus.

Table 7. Post hoc analysis of soil organic carbon

Vermicompost dose (ton ha^{-1})	C-organic (%)	Classification*
5	3.29 c	High
10	3.52 bc	High
15	4.15 ab	High
20	4.89 ab	High
25	5.32 a	Very high

*Source: LPT (1979) in Imelda *et al., 2023*

Note: Values followed by the same letters in each column are not significantly different at the 5% DMRT level.

The results demonstrated that the application of vermicompost had a significant effect on soil organic carbon (C-organic) content (Table 7). The lowest C-organic value was recorded at the 5 ton ha^{-1} treatment (3.29%), whereas the highest value was observed at the 25 ton ha^{-1} treatment (5.32%), representing a 61.7% increase. A substantial difference was also observed between the 5 ton ha^{-1} and 20 ton ha^{-1} treatments, with a 48.63% increase in C-organic content. Although no statistically significant differences were detected among the 15, 20, and 25 ton ha^{-1} treatments, these findings suggest that lower application rates, such as 15 ton ha^{-1}, may be sufficient to achieve comparable improvements.

The overall trend indicates a dose-dependent increase in soil organic carbon, likely attributable to the higher input of organic matter from vermicompost. According to Fitra *et al*. (2020), soil fertility is strongly influenced by its organic carbon content. C-organic is essential for maintaining soil fertility and productivity, as it enhances soil structure through the formation of stable aggregates and promotes granulation. Vermicompost serves as a rich source of organic material, which stimulates microbial activity and organic matter decomposition. The positive correlation between increasing vermicompost application rates and C-organic content reinforces the conclusion that greater organic inputs contribute to improved soil quality and functionality.

Plant growth components

Plant growth is defined as an irreversible increase in size or biomass, primarily resulting from water uptake and the accumulation of assimilates within plant cells. This process is closely associated with cell division and cell enlargement, particularly in meristematic tissues, and is strongly influenced by environmental factors. The observed data on carrot plant growth are presented in Table 8.

Table 8. Carrot plant growth variables

Vermicompost dose (ton ha^{-1})	Plant height (cm)	Root length (cm)
5	59.10	15.99
10	64.73	19.02
15	60.70	17.99
20	64.04	17.98
25	67.54	17.63

Statistical analysis (Table 8) indicated that vermicompost application had no significant effect on plant height or root length. This result may be attributed to the complex interplay of multiple factors, including internal (genetic) traits and external environmental conditions such as climate, soil characteristics, and biotic stresses. According to Harjo (2021), environmental variables—particularly light intensity, temperature, and atmospheric CO_2 concentration—play a crucial role in regulating plant development.

Adverse weather conditions, such as excessive heat, can lead to dehydration and thermal stress, thereby impairing root function and nutrient absorption, potentially resulting in seedling mortality. Conversely, prolonged periods of rainfall may cause waterlogging, which contributes to soil compaction, nutrient leaching, and an elevated risk of root rot induced by fungal and bacterial pathogens. In addition, limited nutrient availability resulting from the slow decomposition of organic amendments can constrain plant growth. As noted by Yusworo (2023), soil microbial communities require time to decompose organic materials into forms that are accessible to plants.

Yield components

Yield components are quantifiable indicators used to evaluate crop productivity and quality, offering valuable insight into the effectiveness of treatments and the potential for agronomic success. The post hoc analysis results for carrot yield are presented in Table 9.

Table 9. Post hoc analysis of carrot yield

Vermicompost dose (ton ha^{-1})	Root weight (g)	Total weight (kg plot^{-1})
5	111.67 b	29.17 c
10	166.52 ab	30.08 bc
15	198.68 a	30.83 bc
20	185.44 a	36.17 ab
25	203.78 a	39.17 a

Note: Values followed by the same letters in each column are not significantly different at the 5% DMRT level.

The application of vermicompost had a significant impact on carrot yield. The lowest average root weight was recorded at the 5 tons ha^{-1} treatment (111.67 g), whereas the highest was observed at 25 tons ha^{-1} (203.78 g). However, the treatments at 15, 20, and 25 tons ha^{-1} did not differ significantly, indicating that an application rate of 15 tons ha^{-1} may be sufficient to achieve optimal yield. Similarly, total yield per plot increased with higher vermicompost doses, with the maximum yield (39.17 kg plot^{-1}) obtained at 25 tons ha^{-1}, while the lowest yield (29.17 kg plot^{-1}) was observed at 5 tons ha^{-1}. A comparable yield was also recorded at 20 tons ha^{-1}, suggesting a plateau in response at higher application levels.

Vermicompost enhances root development and overall yield through multiple mechanisms, including improved nutrient availability, stimulation of microbial activity, and enhanced soil moisture retention. It contributes to improved soil fertility and structure while supplying essential nutrients and beneficial microorganisms. Additionally, vermicompost contains plant growth regulators (phytohormones) such as auxins, cytokinins, and gibberellins, which are synthesized by microbial populations and contribute to plant growth promotion (Hindersah *et al*., 2019). Nurdianti *et al*. (2022) further reported that vermicompost application can elevate auxin concentrations, thereby enhancing root and shoot development.

Despite the yield improvements observed, the results did not reach the crop's theoretical potential. The

Takis/WO 101 carrot variety has a reported potential yield ranging from 26.94 to 32.68 tons ha^{-1}, whereas the highest recorded yield in this study reached only 15.668 tons ha^{-1}—equivalent to 58.7% of the genetic potential. One potential limiting factor was the use of farmer-saved seed from previous plantings, which may have undergone genetic deterioration due to repeated hybridization, thus reducing seed vigor and performance.

Nevertheless, the observed yield improvements underscore the agronomic benefits of vermicompost application. As noted by Dawuda *et al*. (2011), enhancements in crop yield and quality due to fertilizer inputs significantly influence economic returns. Therefore, optimizing vermicompost application rates is essential to approach the genetic yield potential of the crop and ensure sustainable productivity.

CONCLUSION

This study successfully evaluated the effects of vermicompost on soil physical properties, organic carbon content, and the growth and yield of carrot (*Daucus carota* L.) cultivated on Inceptisol soils. A vermicompost dose of 15 tons ha^{1} is recommended as the optimal treatment, as it significantly improved key soil physical parameters—particularly water retention—and increased soil organic carbon content. These enhancements led to better nutrient availability and higher quality of the planting medium, resulting in improved carrot performance. The implementation of these findings suggests that vermicompost can be integrated as a sustainable soil amendment in carrot production systems, especially in highland areas with sandy loam Inceptisols. This practice enhances crop productivity and promotes long-term soil fertility and health. Adoption by farmers could reduce reliance on chemical fertilizers and support more resilient, eco-friendly agricultural practices. Further research is recommended to assess the long-term impacts of vermicompost use across various soil types and cropping systems.

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